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REVIEW

Antidiabetic Effects of Physical Activity: How It Helps to Control Type 2 Diabetes

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Abstract: Despite the improvements in clinical care of the patients, research updates, and public health interventions, there is still an increase in the prevalence, incidence, and mortality because of diabetes mellitus (DM). DM is a public health problem in both developed and developing countries. It has increased alarmingly, putting this disease in the dimension of an epidemic. Diabetes is associated with several complications which increase the risk of many serious health problems on the other side. Therefore, this review was aimed to discuss the antidiabetic effects of physical activity (PA) on type 2 DM (T2DM) by summarizing the significant studies on this topic. This review found that several studies have recommended the utilization of PA for the effective management of T2DM. PA is a non-pharmacologic therapy which is a significant strategy for the management of T2DM and is an appropriate lifestyle modification approach to be practiced by these patients. The studies showed that PA has antidiabetic effects which are evidenced by its substantial role in improving the blood glucose (BG) levels of the individuals with T2DM where it helps them to control their levels of glucose in the blood. It plays a significant role in glycemic control of this disease by lowering the BG levels through possible mechanisms such as decreasing insulin resistance, increasing production of glucose transporter type 4 (GLUT-4), lowering visceral adipose tissue (VAT), increasing pancreatic β-cell functions, using glucose for energy, and so on. In turn, the controlled glycemia helps to prevent the complications associated with uncontrolled T2DM and this would further improve the overall health of the patients and the burden on the health professionals as well. Finally, this review concludes that PA is the cornerstone in the management of T2DM. It also suggests that more attention is needed to its significance in the prevention, glycemic control, and its role in the management of the morbidity and mortality associated with T2DM. Practical PA recommendations and suggestions for the future direction of research in this area are also provided.

Keywords: diabetes mellitus, physical activity, exercise, glycemic control, type 2 diabetes

Background

Diabetes is defined as a group of chronic diseases characterized by hyperglycemia.[1] It is a chronic, progressive, partly understood metabolic condition mainly characterized by hyperglycemia.[2] DM is a serious, chronic disease that happens either when the pancreas does not produce enough insulin or when the body cannot effectively use its produced insulin.[3] Diabetes can be classified as type 1 DM (T1DM) (due to autoimmune b-cell destruction), T2DM (due to a progressive loss of β-cell insulin secretion frequently on the background of insulin resistance), gestational DM (GDM) (diabetes diagnosed in the second or third trimester of pregnancy), or specific types of diabetes because of other causes (monogenic

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diabetes syndromes, diseases of the exocrine pancreas, and drug- or chemical-induced diabetes).[4]

The socioeconomic status is a significant factor contributing to a rise of non-communicable diseases (NCD). This is because low socioeconomic groups consumeless fruit, vegetables, fish, and fibre than those of high socioeconomic status, whereas a high socioeconomic groups were found to be less physically active and consume more fats, salt, and processed food than individuals of a low socioeconomic status.[5] T2DM has developed as a major chronic NCD in several countries.[6] T2DM is a serious and common chronic disease resulting from a complex interaction of inheritance and environment besides other risk factors like obesity and sedentary lifestyle.[7] It is the most frequent metabolic disorders, but thecauses remain mostly uncertain. Insulin resistance, the common underlying abnormality, is the outcome of an imbalance between energy intake and expenditure favoring nutrient-storage pathways, which evolved to maximize energy use and preserve an acceptable substrate supply to the brain.[8] But the commonest reasons contributing to the pathophysiology of T2DM are impaired insulin secretion, resistance to tissue actions of insulin, or a combination of both.[2] The adipokines, resistin may be raised in the plasma of the subjects with T2DM while this is expected to contribute to the impaired glucose tolerance and insulin resistance seen in T2DM.[9] Besides, mitochondria dysfunction and reduced expression of GLUT-4 were recognized as the major factors of insulin resistance in this disease.[10] And also, mitochondrial dysfunction is a consistent phenotype related with insulin resistance in multiple tissues.[11]

Diabetes has several associated complications, broadly divided into macrovascular complications and microvascular complications. The macrovascular complications include stroke, coronary artery disease, and peripheral arterial disease. Whereas the microvascular complications comprise retinopathy, diabetic nephropathy, and neuropathy.[1] The DM leads to around a 2-fold higher risk of vascular diseases, independently from other conventional risk factors which are non-linearly linked for nondiabetic individuals.[12] T2DM individuals also suffer from problems like dysregulation of an excess cardiovascular and metabolic functions, comprising dysglycemia, dyslipidemia, arterial hypertension, obesity, and a decreased cardiorespiratory fitness.[13]

Diabetes is growing to an alarming epidemic level.[14] It is a pandemic of main public health significance that is unclear.[15] Diabetes is a vital public health problem, which is one of the four prioritized NCD targeted for action by world leaders. Both the number of cases and the prevalence of diabetes have been progressively rising over the past few decades.[3] The prevalence of diabetes has augmented in recent decades.[16] Globally, in 2014, it was found that about 422 million adults were living with DM, compared to 108 million in 1980. The global prevalence of diabetes has almost doubled since 1980, where it was increased from 4.7% to 8.5% in the adult population.[3] And also, the estimated prevalence of diabetes in adults was 4.0% in 1995, and this is expected to increase to 5.4% by the year 2025. The figure of adults with diabetes in the world will rise from 135 million in 1995 to 300 million in the year 2025 globally.[17] The evidence showed that the global prevalence of diabetes for all age groups was predicted to be 2.8% in 2000, and 4.4% in 2030. While the projected figure of patients with diabetes is to increase from 171 million in 2000 to 366 million in 2030.[18]

Further, in 2015, the proportion of diabetes in adults aged 20–79 years was predicted to be 8.8%, and this was predicted to rise to 10.4% in 2040.[19] And also, diabetes is on the rise globally, with a global proportion in adults being 8.8% of the world population in 2017, with the expectation of a further rise to 9.9% by 2045. This reflects that, in 2017, there were a population of 424.9 million patients with diabetes globally, with a predicted 48% rise to 628.6 million patients by 2045.[20] T2DM is a major contributor to a very huge increase in the rate of NCD affecting developed as well as developing countries.[2] The burden of diabetes-related complications and comorbidities are significant in Sub-Saharan Africans showing the urgent need for innovative public health approaches that prioritize the promotion of healthy lifestyles for prevention and early detection of T2DM.[21]

Overall, a significant rise in the prevalence of diabetes is proved in almost all regions of the world in recent decades. The rise in the figure of individuals with diabetes or with a longer duration of diabetes is probable to change the disease profile in several populations around the world, mainly because of a greater incidence of diabetes-related complications like kidney failure and peripheral arterial disease.[22] Amongst the diseases, diabetes is one of the leading and increasing causes of hospital admission and disability.[23] Elder patients with diabetes have been found to have a greater all-cause mortality rate than the general population.[24] Disability from T2DM is increased globally and across the levels of development. In 2017, diabetes emerged as the fourth leading cause of disability

worldwide.[25] The prevalence of individuals with T2DM is rising in developed and developing countries, but developing countries in particular.[26] T2DM and its related complications create a major global public health problem, affecting almost all populations in both economically developed and economically developing countries with high rates of diabetes-related morbidity and mortality.[7] However, recent evidence has shown that the present understanding of the international burden and variation in diabetes associated complications is poor globally.[22] Moreover, the high proportion of diabetes in adults also has significant social, financial, and development implications. There is a progressively urgent need for governments to implement policies to reduce the risk factors for T2DM and GDM and confirm a suitable access to management for all individuals living with diabetes.[19] Diabetes is a chronic illness that needs ongoing pharmacological care and patient self-management to avoid acute and chronic complications. Diabetes care is complex, and needs several issues to be addressed, it is beyond just glycemic control.[27]

Despite the significant funds in research, clinical care, and public health interventions, there seems to be no sign of a decrease in the incidence, prevalence, and mortality because of T2DM.[28] Physical inactivity has a major health consequence globally. Reducing or eliminating this unhealthy behavior could improve health significantly.[29] To accomplish a good metabolic control in diabetes, keeping a long-term integration of lifestyle modifications and pharmacological management is essential.[1,30] Several components of self-management involvements lead to clinically related progressin the behavior and clinical parameters.[31] Those people on self-management involvement can be considered as willing volunteers in the majority of cases where they have either required an intervention or decided to take part.[32] Self-management training is found to be effective in T2DM, especially in the short-term period,[33] and the significance of exercise in the prevention and management of T2DM is more evident.[6] Therefore, an exercise should be encouraged from diagnosis, as the individuals may be more agreeable to lifestyle modification. In order to improve an individual's confidence in managing their diabetes with exercise, standard advice on exercise, and diabetes needs to be made available to health professionals and patients with diabetes.[34]

Physical Activity

"PA" has been used interchangeably with the term "exercise".[35] However, the term "PA" should not be mistaken with "exercise" because an exercise is a subcategory of PA.[36] It is recommended that PA and exercise should not be used interchangeably.[37] Regarding the definition, PA is any bodily movement formed by the skeletal muscles that results in energy expenditure above resting levels. The term is broadly including exercise, sport, and PA done as part of daily living, occupation, leisure, and active transport. Whereas, an exercise is defined as a planned, structured PA typically performed with the intent of improving the health and/or fitness.[36,38]

Exercise can be classified as mechanical and metabolic properties. Mechanical includes dynamic exercise, which causes movement of the limb and static exercise which results in no movement of the limb. However, the metabolic classification includes aerobic and anaerobic processes.[39] Exercise could also be classified as aerobic and resistance exercise.[40] The aerobic exercise comprises repeated and continuous movement of huge muscle groups,[41] and it includes activities such as walking, cycling, jogging, and swimming, while resistance exercise includes activities like free weights, weight machines, body weight, or elastic resistance bands.[40]

Generally, PA is safe for almost everyone,[41] and its key role in the prevention and management of NCD has had widespread recognition.[42] It is broadly recognized as an effective strategy for the prevention and management of many chronic diseases.[43] Moderate exercise following Roux-en-Y gastric bypass surgery was found to provide additional improvements in insulin sensitivity, glucose effectiveness, and cardiorespiratory fitness for obese individuals.[44] The effects of exercise and leisure time PA have been extended from prevention to management of several components of metabolic syndrome and also for the mood and quality-of-life.[45] Exercise training is found to improve body composition, cardiovascular, and metabolic outcomes in people with metabolic syndrome.[46] As far as an exercise offers several health benefits,[47] the adoption and maintenance of PA are essential for management of BG and total health in people with diabetes and prediabetes.[48] Both aerobic and resistance exercise have beneficial effects for T2DM patients.[49] Overall, evidence shows that all types of exercise are helpful for individuals with T1DM and T2DM.[50] And also, people of all ages can benefit from

doing PA where it may reduce all-causes of morbidities, and raise their lifespan through improving their quality-of-life.[51,52]

The Role of Physical Activity in the Management of T2DM

The primary prevention of T2DM could be accomplished through a non-pharmacologic intervention like PA which can be applied in a primary healthcare setting.[53] The exercise improves BG levels in both diabetic and nondiabetic subjects.[54] The use of PA breaks during sitting moderately reduces post-prandial glucose, insulin, and triacylglycerol, with a better glycaemic reduction in individuals with a high body mass index (BMI).[55] The integration of dietary and PA is significant in diabetes improvement which may encourage to prevent or delay diabetes complications.[56,57] And also, the combined intervention of supervised structured exercise training and caloric restriction are effective in improving metabolic health and decreasing an excess weight in obese patients with T2DM.[58] The PA could result in an improved health status of T2DM patients and also decrease a burden of health professionals.[59] Besides, rising a PA may also decrease the risk of progression from GDM to T2DM.[60] Participating in PA prior to and during early pregnancy could prevent the development of GDM.[61–63] This is because exercise helps to improve the glycemic levels of women with GDM,[64–66] which could have the potential to protect the progression into T2DM. The PA may be used as a therapeutic tool in a variety of individuals who are with, or at risk for diabetes for its protecting effect against diabetes independently.[67–69]

PA plays a major role in the prevention and control of insulin resistance, prediabetes, GDM, T2DM, and diabetes related health complications.[70] Exercise is used for the prevention,[71] and treatment of T2DM[72–78] by improving glycemic control.[43,79–86] It is a comprehensive element of diabetes management.[87,88] A randomized trial has reported that exercise performed for 30 minutes after meal eating may provide better improvements in glycemic control for people with T2DM.[86] In these patients, 12 weeks of exercise training significantly improved oxygen uptake dynamics.[89] And also, PA improves metabolic parameters in patients with pre-diabetes or T2DM while a low PA is related to an increased risk of incident T2DM.[90] Even a single session of exercise can promote beneficial effects in T2DM individuals concerning blood pressure (BP) control, glycemia, carbohydrate oxidation during exercise, and fat oxidation after exercise.[91] Generally, the varying types, intensities, and durations of exercise decreased BG levels in most people, while an exercise of longer duration is possibly most effective.[92] Below is the summary of the effects of specific types of exercise such as the aerobic, resistance, and combined (aerobic plus resistant) exercise where each provides several health benefits for individuals with T2DM as they are proved by several studies.

Regarding aerobic exercise, the study found that aerobic exercise improves glycemic control,[93–104] insulin sensitivity,[105–107] insulin action,[70] body composition,[99] quality-of-life,[108] physical capacity,[99] nerve function,[109] functional capacity,[110] and cardiorespiratory fitness,[101,111] reduces insulin resistance,[97,112,113] insulin levels,[96] lipid profile,[97] BP,[97,100] cardiovascular risk,[106] hemoglobin A1c (HbA1c) levels,[95,111] and waist circumstances,[100] and modulates inflammatory cytokine levels[113] and adipocytokines[113] in T2DM patients.

The study also showed that resistance exercise improves glycemic control,[97,104,114–130] insulin sensitivity,[105,106,114,115,117,129] insulin responsiveness,[116] insulin action,[70] physical functions,[131] and cardiopulmonary fitness,[132] decreases insulin resistance,[97] abdominal fat,[114] BMI,[132] insulin levels,[118,132,133] triacylglycerol levels,[118] lipid profile,[97,105] body fat,[132] HbA1c levels,[119,132,133] BP,[97] and cardiovascular risk,[106] and increases GLUT-4 translocation in skeletal muscle,[117] and strength[119,120,128,131] in T2DM patients. Further, during resistance training, raised energy expenditure and excess post-exercise oxygen consumption in response to resistance training are also considered as other beneficial effects[117] in these patients.

Concerning combined exercise, the study found that combined exercise also improves glycemic control,[6,97,134–139] insulin sensitivity,[139,140] body composition,[137] functional capacity,[137,138] strength,[138] and vascular function,[141] and reduces blood lipids,[97,134,137] HbA1c levels,[136,142,143] BP,[97] and insulin resistance[97,144] in T2DM patients. In fact, a systematic review and meta-analysis showed that combined exercise might be the most efficacious exercise modality to improve glycemic control and blood lipids in T2DM patients.[134] A randomized trial also found that either the aerobic or resistance training alone improves glycemic control in T2DM, but the improvements are highest if they are combined.[135] Similarly, the aerobic and resistant modality seems to have the ability to improve HbA1c values in T2DM patients, but the combined exercise form appears superior.[142]

AminiLari et al[144] found that 12 weeks of combined exercise was more efficient in improving homeostasis model assessment of insulin resistance (HOMA-IR) and increasing serum omentin-1 among women with T2DM compared to aerobic and resistance exercises.

There are several trials evaluating the effect of PA/exercise in the management of T2DM. According to those findings, PA/exercise has a significant role in improvements of BG control, insulin sensitivity, and insulin resistance, reduction of BMI, HbA1c levels, and total cholesterol, etc.[72,100,111,132,133,145–152] This section summarizes (Table 1) the evidence about the role of PA/exercise on the control of T2DM.

The Physiological Effects of Physical Activity in T2DM

The mechanism of exercise in the improvement of T2DM is very complex and not completely known.[75] During an exercise, there is a complex biological response because almost all organs and systems are involved in the interactions that lead to adaptations at the levels of genetic, metabolic, and neuromuscular.[106] There are a few ways that PA could decrease BG levels.[153] The beneath are a brief summary of PA which shows the proposed mechanisms through which it can help to lowers the BG levels. For instance, by decreasing insulin resistance, increasing production of GLUT-4, lowering VAT, increasing pancreatic β-cell functions, using glucose for energy, and so on (Figure 1).

As explained above, evidence has shown that PA improves insulin sensitivity in T2DM patients.[9,13,75,79,84,105–107,114,115,117,129,139,140,153–161] The increased insulin sensitivity makes the muscle cells better able to use any available insulin to take up glucose during, and after exercise. In fact, whenever muscles cells contract during exercise, the muscle cells are able to take up glucose and use it for energy, whether insulin is available or not.[153] During PA, the production of GLUT-4 will be increased and this enhances the improvements of insulin sensitivity. The improved insulin sensitivity in turn increases glucose uptake and finally improves glycemic control.[159] This improvement in insulin sensitivity contributes to improving glycemic control into the normal range.[115,156] Bird and Hawley[161] found that regular PA decreases the risk of insulin resistance and also improves the insulin sensitivity when people adhere to an exercise accordingly. However, the study showed that there is a dose–response relationship between exercise dose and the improvements in insulin sensitivity.[157] A relatively modest single session of exercise in obese adults was even found to improve insulin sensitivity.[158] In addition to this, even a single bout of brisk walking for 1 hour improves muscle insulin sensitivity.[160]

Further, evidence has shown that PA leads to an improvement in insulin action.[70,85,162–164] This improvement in insulin action involves an enhanced sensitivity, and responsiveness of peripheral glucose uptake probably by muscle to insulin and also an increased inhibition of hepatic glucose production by insulin.[163] Besides, the improved insulin action involves glucose transport, glycogen synthesis, and glycogen synthase activation as well as amino acid transport.[164] An exercise also rises the rate of glucose uptake into the contracting skeletal muscles where this effect of exercise is identical to the action of insulin on glucose uptake. The mechanism through which both stimuli increase the skeletal muscle glucose uptake involves the translocation of GLUT-4 to the plasma membrane and transverse tubules.[165] A major proposed mechanism involved in raising insulin stimulation of glucose uptake after exercise appears to be due to the exercise-related reduction in muscle glycogen content.[164] Also, the improvement in mitochondrial muscle performance, and rises in muscle mass during resistance training may positively affect insulin responsiveness and glucose control.[116]

Furthermore, the studies showed that PA improves insulin resistance.[10,72,73,97,112,113,144,166–169] The evidence presented that an accumulation of lipid in skeletal muscle is assumed to be associated to the development of insulin resistance and T2DM. Exercise was found to decrease accumulation of lipids in muscle which in turn reduces the resistance.[105] The insulin resistance in individuals with T2DM can also be reduced via increasing the plasma levels of orexin-A and reducing in plasma levels of glucose and insulin by exercise.[112] The finding showed that exercise training improves insulin resistance and decreases diacylglycerol and ceramides.[167] A short-term aerobic exercise leads to reduced arterial stiffness in both common carotid and femoral arteries, while this decrease of stiffness was related with improvements of insulin resistance in T2DM patients.[168] In a randomized trial, PA was found to reduce weight and insulin resistance in men.[169] Also, regular exercise modulates several intracellular pathways improving insulin resistance and glucose uptake in the skeletal muscle of T2DM individuals.[10]

Table 1 The Summary of Main Systematic Reviews with Meta-Analysis Covering the Role of Physical Activity/Exercise on T2DM Control

References	Year	Major Features	Findings/Conclusions
Bgeginski et al[145]	2017	11 RCT	A reduction in the absolute FBG concentrations (WMD: −3.88 mg/dL, 95% CI: −7.33 to −0.42).
Grace et al[111]	2017	27 RCT	An improvement in HbA1C% (MD: −0.71%, 95% CI: −1.11 to −0.31; *P*=0.0005), improved peak VO_2, improved (HOMA-IR) (MD: −1.02, 95% CI: −1.77 to −0.28; *P*=0.007) as was fasting serum glucose (MD: −12.53 mmol/L, 95% CI: −18.94 to −6.23; *P*<0.0001) and serum (MD: −10.39 IU, 95% CI: −17.25 to −3.53; *P*=0.003).
Liu et al[132]	2019	13 RCT	A great improvement in body weight (MD: −1.22 kg, 95% CI: − 2.23 to − 0.18, *P*=0.02), BMI (MD: −0.40 kg/m^2, 95% CI: −0.78 to −0.02, *P*=0.04), HbA1c (MD: −0.37, 95% CI: −0.55 to −0.19, *P*<0.0001), relative VO_2peak (MD: 3.37 mL/kg/min, 95% CI: 1.88 to 4.87, *P*<0.0001) and absolute VO_2peak (MD: 0.37 L/min, 95% CI: 0.28 to 0.45, *P*<0.00001).
Fedewa et al[72]	2014	24 RCT	Improves fasting insulin and insulin resistance in youth (Hedges' d effect size=0.48, 95% CI: 0.22 to 0.74, *P*=0.001; and 0.31, 95% CI: 0.06 to 0.56, *P*=0.05, respectively).
Pan et al[146]	2018	37 RCT	0.30% reduction in HbA1c, FBG (9.38 mg/dL lower), total cholesterol (20.24 mg/dL lower), triacylglycerol (19.34 mg/dL lower), and LDL (11.88 mg/dL lower) in supervised aerobic exercises and a reduction in HbA1c (0.30% lower) and total cholesterol (22.08 mg/dL lower) in supervised resistance exercise.
Liu et al[133]	2019	24 Trials	A significant reduction in HbA1c (*P*=0.006) and insulin (*P*=0.015) while the reduction for HbA1c was greater with high intensity (−0.61; 95% CI: −0.90 to −0.33) than low-to-moderate intensity (−0.23; 95% CI: −0.41 to −0.05). But insulin levels were significantly reduced only with high intensity (−4.60; 95% CI: −7.53 to −1.67), not with low-to-moderate intensity (0.07; 95% C: −3.28 to 3.42). Notably, values between the subgroups were statistically significant for both HbA1c (*P*=0.03) and insulin (*P*=0.04), indicative of profound benefits of high-intensity RE.
Sampath Kumar et al[147]	2019	11 Trials (7 RCT + 4 Non-RCT)	The MD for fasting insulin level was −1.64 (95% CI: −3.38 to 0.10), Homa-Ir 0.14 (95% CI: −1.48 to 1.76]), FBS −5.12 (95% CI: −7.78 to −2.45), HbA1c 0.63 (95% CI: −0.82 to 2.08) and BMI −0.36 (95% CI: −1.51 to 0.79).
Thomas et al[148]	2006	14 RCT	Decrease in HbA1c levels by −0.6% (95% CI:−0.9 to −0.3, *P*<0.05), a reduction in VAT (−45.5 cm^2, 95% CI: −63.8 to −27.3), an increased insulin response (131 AUC, 95% CI: 20 to 242) (one trial), and decreased plasma triglycerides (−0.25 mmol/L, 95% CI: -0.48 to −0.02).
Umpierre[149]	2011	47 RCTs	A structured exercise training was associated with a decrease in HbA1c level by −0.67% (95% CI: −0.84% to −0.49%; I2, 91.3%), structured aerobic exercise is associated with a reduction in HbA1c level by −0.73% (95% CI: −1.06% to −0.40%; I2, 92.8%), structured resistance training is associated with a reduction in HbA1c level by −0.57% (95% CI:[1.14% to −0.01%; I2, 92.5%), and both combined (structured aerobic exercise and structured resistance training) were associated with a decrease in HbA1c level by −0.51% (95% CI: −0.79% to −0.23%; I2, 67.5%).
Yuing et al[150]	2019	15 Trials	Physical training is associated with an increase in the peak or maximal oxygen uptake, exercise tolerance time, and muscle strength, and a reduction in HbA1c levels.
De Sá et al[100]	2016	5 (RCT + CCS)	The chronic effect of aerobic exercise was significant in decreasing the WC, BG, and DBP.
Boulé et al[151]	2001	14 (11 RCT + 3 Non-RCT)	Decreases HbA1c level by 7.65% with the WMD of 0.66% (*P*<0.001) compared to control groups.
Way et al[152]	2016	14 RCT	Significant improvement in insulin sensitivity between 48 and 72 hours after exercise (95% CI: –1.392 to –0.012, *P*=0.046).

Abbreviations: RCT, randomized control trial; Non-RCT, non-randomized control trial; FBG, fasting blood glucose; WMD, weighted mean differences; MD, mean differences; peak VO_2, peak oxygen consumption; HOMA-IR, homeostatic model assessment of insulin resistance; CI, confidence interval; HbA1c, hemoglobin A1c; RE, resistance exercise; LDL, low-density lipoprotein; BMI, body mass index; VAT, visceral adipose tissue; WC, waist circumference; BG, blood glucose; DBP, diastolic blood pressure.

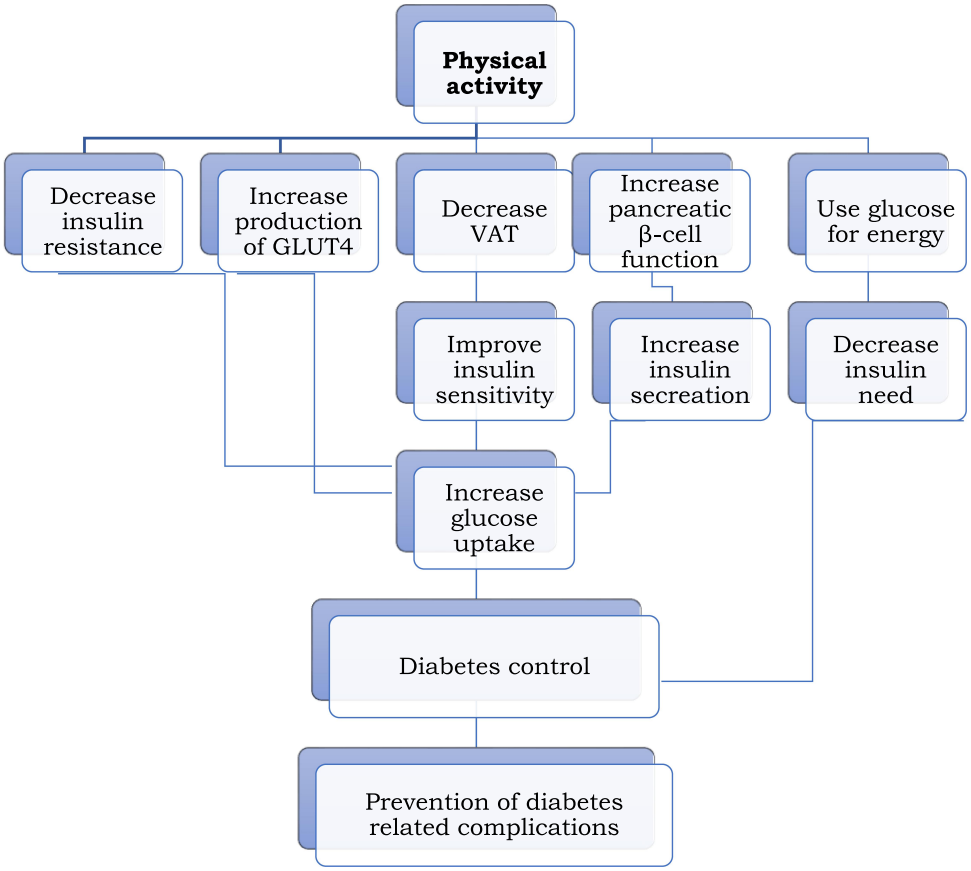

Figure 1 A short summary of the physiological effects of physical activity on type 2 diabetes.

Moreover, several studies have shown that PA reduces VAT.[35,140,154,158,170–176] Physical training reduces the VAT, which then leads to improvements in insulin sensitivity.[170] Exercise also leads to a loss of abdominal subcutaneous and VAT and increased muscle density, while insulin sensitivity is improved related to these changes.[140] Campos et al[171] found that the magnitude of reduction in visceral fat is an independent predictor for insulin resistance. There were positive correlations between the visceral fat decrease and glucose metabolism. The systematic review and meta-analysis showed that a regular aerobic exercise decreases VAT and may also decrease the liver fat in adults with overweight/obesity and T2DM.[173] The randomized trial showed that resistance training and aerobic training are equally effective in decreasing hepatic fat content among these patients.[174] A systematic review and meta-analysis showed that aerobic training of moderate or high intensity has the greatest potential to decrease VAT in overweight males and females.[172] Besides the evidence found that exercise decreases obesity and high-density lipoprotein concentration in the plasma by encouraging a loss of weight.[35] Also, a reduction in systemic fatty acid uptake was associated with performing an exercise.[158]

Likewise, PA also improves pancreatic β-cell function in T2DM individuals.[175–177] Two weeks of high-intensity interval or moderate intensity continuous training improved β-cell function in people with prediabetes or T2DM.[175] Similarly, functional high intensity training was found to improve pancreatic β-cell function in adults with T2DM.[177] The randomized trial demonstrated that 2 weeks of exercise training improves β-cell function.[176] The baseline and training-induced changes in β-cell function may be a key determinant of training-induced improvements in glycemic control. An exercise is explained primarily by improving insulin secretion.[178] Since the ectopic fat accumulation in the pancreas is a risk factor for T2DM, the study suggested that exercise training may help to decrease this ectopic fat, and in turn is used as an effective strategy to lower the risk of developing T2DM.[175]

Generally, an exercise improves the whole-body metabolic health in patients with T2DM. The adaptations to the

skeletal muscles are crucial for this improvement, while an acute bout of exercise rises skeletal muscle glucose uptake.[78] A resistance exercise reduces the requirements for insulin in overweight women with GDM.[179] There is improvement in microvascular vasodilator, insulin signaling, and attenuates capillary rarefaction in skeletal muscle among T2DM patients performing an exercise. This exercise-induced modification then improves glucose and insulin delivery and also the uptake of glucose.[180] The meta-analysis has reported that there were improvements in endothelial function in patients with T2DM performing aerobic or combined exercise.[181] During exercise, the consumption of oxygen may rise by as much as 20-fold, and even higher rises may happen in the working muscles. To meet its energy needs during this condition, the skeletal muscle uses its own stores of glycogen and triglycerides, and also free fatty acids derived from the breakdown of adipose tissue triglycerides and glucose released from the liver at a higher increased rate.[156]

Several studies have shown that PA also lowers the HbA1c levels.[79,95,111,119,132,133,136,142,143,146–151,182–184] This means that the effect of an exercise on the decrement of BG levels could be evidenced by the reduction of the biomarkers of glycemic control which is HbA1c levels. The term HbA1c refers to a glycated hemoglobin or glycosylated hemoglobin. It develops when hemoglobin, a protein within red blood cells that carries oxygen throughout the body, is combined with glucose in the blood. By measuring HbA1c, the health professionals are able to get an overall picture of what the average BG levels of the diabetic patients have been over a period of weeks/months. It is a measure of glucose control that is a result of glucose molecules attaching to hemoglobin for the life of the red blood cells which is 120 days. The amount of glucose that combines with this protein is directly proportional to the total amount of glucose that is in the system at that time. If the BG levels have been high in recent weeks, the HbA1c will also be higher. Umpierre et al,[184] however, found that the decrement of HbA1c in T2DM patients during exercise is determined by the volume of an exercise.

Finally, several studies have recommended the utilization of PA for T2DM patients.[13,57,68,85,122,154,155,185–190] The requirement for integrating regular exercise as a component of a patient's lifestyle, including into daily activities, should be underlined.[185] Exercise is frequently recommended in the management of diabetes because it can support and improve glycemic control.[154] Regular exercise is recommended for patients with T2DM for effective control of BG levels.[13] It is recommended for its valuable effects on glucose control and also for its abilities to delay the progression of other comorbidities which are common in individuals with diabetes.[57] And also, regular exercise/PA is featured as a key component in management of T2DM patients in a current guideline established by the American College of Sports Medicine and American Diabetes Association. They prescribe a moderate-intensity aerobic exercise for 150 minutes each week.[68] An exercise is also recommended for individuals who are at risk of developing or already have T2DM.[186]

It is commonly one of the primary management approaches recommended for people newly diagnosed with T2DM. Exercise is also a crucial component of obesity prevention if combined with other lifestyle modification.[187] The evidence shows that exercise snacking is an effective approach to improve glycemic control in these patients. On the other hand, doing intensive interval exercise bouts immediately before breakfast, lunch and dinner had a better impact on postprandial and consecutive 24 hour glucose concentrations than did a single bout of moderate, continuous exercise undertaken before an evening meal.[191] In obese T2DM patients, walking can be recommended as an adjunct therapy to diet management not only for body weight decrease but also for improvements of insulin sensitivity.[155]

Moreover, aerobic exercise and resistance exercise are recommended for diabetic people and must be adjusted to the physiological and metabolic limitations of each patient individually.[85] Resistance training could be recommended in the early stage of T2DM, particularly for people with relatively poor glycemic control, because it is effective to control the glycemia.[188] The study showed that a combined exercise is also recommended in the management of T2DM patients. Besides, 2–3 times per week, moderate-to-high intensity of the combined exercise is appropriate to be conducted for these patients.[189] However, the recommendations and precautions of PA are varied depending on patients' features and health status.[48] Also, an exercise can be present with a significant challenge to glycemic control in diabetes because excessive glucose lowering can occur under certain circumstances which can enhance the threat of hypoglycemia; in other situations, hyperglycemia can be accentuated.[57] Thus, those individuals who develop hyperglycemia after intensive exercise may require an injection of ultra-rapidly acting insulin at a time decided empirically.[192]

Conclusion

The burden of T2DM is significantly increasing worldwide. Because of this, a number of guidelines recommend the utilization of regular PA while it is the comprehensive component of diabetic management. It has been a long time since PA has been known to have beneficial effects for patients diagnosed with diabetes. It is found that exercise helps to improve the health status and decrease a burden on health professionals. The PA has antidiabetic effects due to its significant role in improving the BG levels of the individual with T2DM. It plays a substantial role in glycemic control of this disease by lowering the BG levels through the different possible mechanisms. Overall, PA plays an important role in the management approaches of T2DM patients because it offers several health benefits such as improving glycemic control, insulin sensitivity, body composition, quality-of-life, physical capacity, and cardiorespiratory fitness, reducing the obesity, insulin resistance, insulin level, lipid profile, VAT, BP, and cardiovascular risk, etc. However, PA is the most underutilized management of T2DM.

To achieve better benefits in the glycemic control of T2DM, the health professional should prescribe a structured frequency, volume, and intensity of training for patients diagnosed with T2DM. Also, the interaction of physician with patient is a major strategy in establishing a successful exercise programme for all patients with diabetes. Particularly, the multi-disciplinary team approach that comprise coordination among exercise physiologists, diabetes educators, the physician, the nurses, nutritionists, and the patient is usually the most effective way to create an individualized exercise regimen that provides benefits to the patient while avoiding potential harm. Further, PA is a tool, just like taking a medication or changing your diet in order to control the diabetes and it is so, so powerful. For most people with diabetes, it is a safe and highly recommended way to control diabetes and to reduce the risk of its complications. Therefore, the health professional should promote this message at every available opportunity in a clinical setting and public level. The patients should communicate their healthcare providers for special considerations needed to be known when they are working out and, primarily, it will be better if they test their BG levels before, after, and sometimes during exercise to observe how much their body responds to the exercise.

Finally, I will suggest that future study should be conducted on the duration, intensity, types of PA, and metabolic limitations that should be known to be prescribed considering all the characteristics of the patient. This is because I have seen that there is a limitation of literature on this information which could clearly identify it according to the patient characteristics. So, the findings of this study would be expected to encourage the utilization of exercise in an adjusted way to the physiological state of the T2DM patients.

Author Contributions

The author made a significant contribution to conception and design, acquisition of data, or analysis and interpretation of data; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; and agrees to be accountable for all aspects of the work.

Disclosure

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