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Research Article

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The Impact on Exercise Preventing Type 2 Diabetes Mellitus

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Abstract

This review will overview trends over time for the causes of type 2 diabetes as it continues to influence millions with its interrelated pathophysiology. A better understanding of how this chronic condition manifests with hallmark studies can aid in prevention. The main pillars of type 2 diabetes include excess body weight, insulin resistance, and systemic inflammation. These factors all play a role in the development of this disease and will be exemplified with numerous studies. In conjunction, the mechanism of aerobic exercise is introduced to mitigate the progression of diabetes. While many therapeutics exist to aid in reducing overall blood sugar, this review will emphasize on lifestyle habits to prevent the onset of diabetes before pharmacologic management is needed. A clear contrast of risk factors and exercise modalities should simplify the pathophysiology of diabetes to prevent the onset. With many of these risk factors interrelated, the supplementation of these studies can further explain diabetes and how exercise can impact all these risks.

1. Introduction

In the United States, 38.4 million people had diabetes in 2021, about 12% of the population [1]. Whereas 97.6 million had prediabetes in 2021, more than 1 out of every 3 in the United States [1]. The large amount of the population impacted by diabetes deserves attention, particularly the prediabetics to reduce their progression. Before being classified as a diabetic, many are in the prediabetic range, where a reversal to normal levels can occur. At this point, a fasting blood sugar from 100 mg/dL to 125 mg/dL, puts one in the prediabetic range [2]. To officially diagnose one with diabetes, multiple measurements of their fasting blood sugar need to be over 126 mg/dL [2]. Another measurement of blood glucose is the hemoglobin A1c test (HbA1c), with prediabetics ranging from 5.7-6.5% and diabetic being over 6.5% [2]. This detailed test averages blood glucose levels over the span of 3 months. Lastly, an oral glucose tolerance test measures ones blood glucose 2 hours after consuming sugar. Prediabetic range from 140-200 mg/dL and diabetics are over 200 mg/dL [2]. It is imperative to know ones glucose level to achieve their goal of staying in normal range, before a diabetic diagnose ensues.

The mainstay management option consists of metformin for drug therapy, which acts to sensitize insulin and reduce glucose production [3, 4]. If metformin fails and other co-morbidities exist, insulin injections or second-line options may be considered. It is worth noting, newer options such as glucagon-like-peptide-1 (GLP-1) agonists and gastric inhibitory polypeptide (GIP) agonists are becoming popular for increasing satiety, controlling insulin release, and ultimately weight loss [4, 5]. The principles behind these medications which are most enticing are weight loss capabilities with a weekly injection. While many diabetics achieve weight loss with the GLP-1 and GIP agonists, it is unclear if prediabetics reap the same benefits. Since these medications are expensive or only covered by insurance at a certain BMI or HbA1c level, the utilization of these by this population may not be realistic. Fortunately, weight loss can be achieved through exercise which is enough at the prediabetic stages, without the need for diabetic treatment.

Before anyone engages in exercise, it is important to overview the guidelines established by U.S. Department of Health and Human Services for all age groups. To measure exercise intensity, metabolic equivalent of task (METs) are used to categorize activities based on overall expenditure. For example, sitting down is roughly 1 METs whereas slow walking is 3 METs and running is 8 METs [6]. Depending on one's age and gender, each MET is equivalent to light, moderate, or vigorous intensity and these can vary slightly. To simplify these parameters, light exercise ranges from a METs of 1.0-3.0 and includes activities like house chores or light walking [7]. A moderate activity includes brisk walking, swimming or yard work and would have a METs of 3.0-6.0 [7]. Whereas a vigorous METs of at least 6.0 includes jogging, running, or weight training [7]. Now that the intensity is established, the frequency and dura-

tion needs to be highlighted as well. In adults, moderate intensity of aerobic exercises should be at least 150 minutes per week and up to the 300 minute mark [8]. In addition, 75 to 150 minutes of vigorous exercise can be implemented in this plan [8]. These exercise routines should be slowly added into ones routine and exercise-induced hypoglycemia should be monitored.

2. Methods

The following on-line databases such as the PubMed, JAMA Internal Medicine, and Medicine & Science in Sport and Exercise were used to find appropriate articles. Various keyword combinations were used including: exercise, T2DM, insulin resistance, physical activity, obesity, inflammation to narrow this search. About 3000 articles were found in these databases, on the initial search. The search was then filtered for articles the related to risk factors for diabetes like obesity, insulin resistance, or inflammation. Additional articles were selected relating to one specific prevention method, such as weight loss, increasing insulin sensitivity, or reducing inflammation. After choosing specific studies that fit the scope of this review, 31 articles were selected.

3. Discussion

3.1 Weight and T2DM

Of course, many therapeutics exist to lower blood sugar, but excess glucose is not the only issue. The effect of increased glucose is reduced insulin secretion. With insulin resistance being a marker for a diabetic state, one cannot ignore lifestyle habits like physical inactivity playing a role [9]. In addition to physical inactivity, high BMI poses an even greater risk to develop type 2 diabetes mellitus [10]. With many diabetics or those at risk for diabetes being overweight or obese, the implementation of exercise is important to reduce the progression. Ideal weight range is important for the prevention of metabolic diseases such as diabetes. Of course, not every overweight or obese person has diabetes, but the odds increase with this major risk factor, high BMI. A well-known study called the Nurses' Health Study in 1976 evaluated the incidence for chronic disease development and weight gain in a group of 113,861 female nurses [11]. In 1984, follow-up questions were sent out to see if any women gained weight or developed a chronic disease, using attributable risk, the results were interesting. Women weighing more than 70 kg had a 24-fold risk increase compared to those weighing less than 55 kg, for developing diabetes [11]. Regarding BMI as a risk factor, a normal weight can increase odds for development of diabetes, with higher BMI increasing these odds [11]. This hallmark study shows the relationship between BMI and type 2 diabetes development.

Although the data was collected some time ago, the statistics currently show the continuing epidemic of diabetes. Specifically, a change in BMI from 30 kg/m^2 to 35 kg/m^2 have a wide range of increased odds of diabetes from 28 to almost 100 times [12]. The ongoing association between excess weight and diabetes is clear, but the exact mechanism of this relation is still being studied. One theory connects the obese state to excess free fatty acids, impairing insulin sensitivity, due to excess fat storage [13]. Moreover, the elevated free fatty acids can cause lipotoxic effects on beta cells in the pancreas, leading to dysfunction [13]. Insulin resistance is a main consequence from beta cell destruction, thus leading to the development of type 2 diabetes.

3.2 Exercise for Weight Loss and T2DM

It is evident that excess weight and diabetes are interrelated, therefore the role of physical activity must be addressed. This paper will not delve into the depths on the pathogenesis of obesity, but it is clear there are not enough calories expended in obese individuals. Of course, it is not simple as walking on the treadmill to lose weight, as there are economic, social, and physical determinants of obesity. However, if one can engage in consistent exercise, weight loss is possible, with lower odds for chronic diseases like diabetes. Moreover, knowing that excess weight is a primary risk factor for diabetes, it is logical that reducing BMI can only benefit those at risk.

In a study of about 1,000 participants with an average BMI of 33.9 kg/m^2, lifestyle factors like exercise and diet were monitored annually [14]. After weekly 150 minutes of moderate physical activity and reduction of dietary fats to less than 25% of their total calories, for 3 years, the risk for diabetes development was assessed [14]. By decreasing fat intake and burning more calories, both in a realistic manner, promising goals could be achieved. Results from this study shows an average of 5-kg weight loss accounts for nearly 55% reduction in risk of diabetes in the 3-year [14]. Moreover, those who lost more than the average weight and stayed consistent with exercise and diet could decrease risks by more than 90% [14]. Thus, only a few pounds lost per year can have a massive impact on the development of diabetes.

Another long-term study compared lifestyle modifications like weight loss, to metformin, in diabetes prevention. High risk adults for diabetes were either in a lifestyle group, which entailed 150 minutes per week of moderate intensity physical activity or the drug group with metformin, 850 mg twice a day [15]. This study allowed for the comparison of lifestyle modifications like exercise to pharmacological agents, both with a goal to prevent onset of diabetes. With the lifestyle group though, the goal was to lose a certain amount of weight, to lower the odds of developing diabetes. In comparison to a drug that simply reduces blood sugar, this was a long-term study to see which mode of prevention is optimal. In the 2.8-year trial, the reduction of onset of diabetes was 58% in the lifestyle group and 31% in the metformin group [15]. With promising results, this long-term study wanted to be continued for years after, to see if these trends were maintainable. In the 10-year follow-up, diabetes incidence rates were reduced by 34% in the lifestyle group and 18% in the metformin group [15]. This reliable and continuing study exemplifies the benefits of weight loss instead of drugs to prevent diabetes. While both groups saw a

reduction in diabetes incidence, better outcomes were seen in the exercise group.

3.3 Insulin Sensitivity and T2DM

Insulin resistance or low insulin sensitivity is when the body cannot uptake glucose properly to tissues like muscle, fat, or the liver. The effects of insulin resistance are excess blood sugar, improper glycemic control, and potential destruction of beta cells [16]. Of course, these effects are all the signs of diabetes, so it's important to keep insulin sensitivity high. To monitor insulin sensitivity, an oral glucose tolerance test (OGTT) can determine glycemic levels. The ranges for prediabetes are from >7.8 mmol/L (140 mg/dL) to <11.0 mmol/L (200 mg/dL), while diabetes is characterized by glucose levels > 11.0 mmol/L [16]. While these values are from an OGGT test, it still explains the prediabetic versus diabetic range and insulin uptake. If blood sugar is too high, then glucose infusion rate is low and insulin sensitivity is lost, whereas a low blood sugar indicates high glucose infusion rate and enhanced insulin sensitivity. Keeping a regular monitoring of these numbers is vital as half of those with prediabetes have a chance of progressing to diabetes in the next decade or less [17]. Thus, lifestyle modifications like exercise can improve insulin resistance before it leads to diabetes.

3.4 Insulin Sensitivity and Exercise

Improving glucose levels in the blood to optimal range is an important step to prevent diabetes. Exercise can assist with insulin sensitivity, but not all exercise is the same. In a study done by Dubé and colleagues in 2012, training variables for 55 older men and women who were mostly overweight, were assessed for 16 weeks of moderate intensity exercise. Insulin sensitivity was monitored as participants engaged in 3-5 weekly sessions of aerobic exercise and no diet [18]. The training variables such as exercise volume and intensity were positively related to insulin sensitivity, while frequency had no impact [18]. Therefore, while it is more beneficial to walk everyday compared to being sedentary, the value of intensity during physical activity predominates. To measure the insulin sensitivity changes, glucose infusion rate, GIR, was used as it indicates skeletal muscle glucose uptake. Before the program, GIR was 367 mg/min and after the exercise program it was 449 mg/min [1]. The exercise intensity measured by peak heart rate in this group showed the improvement in insulin sensitivity.

Furthermore, the mechanism behind glucose uptake in skeletal muscle is interesting, as it is important for the entire body and insulin resistance. When exercising, skeletal muscle demands greater supply of oxygen and energy, therefore it needs to breakdown its glycogen storage to contract [19]. While the biochemistry behind muscle energy sources is beyond the scope of this review, the notion is there has to be glycogen for muscles to function and control insulin resistance. Continuing with this logic, higher exercise intensity can increase insulin sensitivity, as more muscle fibers are recruited which depletes glycogen quickly [20]. The insulin sensitivity increase is due to more GLUT 4 receptors on the cell surface, as more glucose is uptaken and more glycogen is resynthesized after this high intensity bout of exercise [20]. This fascinating theory exemplifies the impact of training variables like intensity, which can be measured through VO2max or peak HR%, to the actual improvements of diabetes prevention.

While exercise intensity can certainly play a role in insulin sensitivity, the type of exercise, aerobic or resistance is important as well. A study done by Lee and colleagues in 2013 compared the effects of aerobic versus resistance training to improve insulin sensitivity in obese adolescent females [21]. The results showed only aerobic exercise enhanced peripheral insulin sensitivity [21]. In another study done by Lee and colleagues in 2012, found that only the adolescent obese males had improvements in peripheral insulin resistance when performing resistance training, not aerobic exercise [22]. While both groups found some exercise modality to decrease insulin resistance, it highlights how different exercises can play a role in diabetes prevention.

3.5 Inflammation and T2DM

Another relative factor involved in the pathogenesis of type 2 diabetes is chronic inflammation. Certain pro-inflammatory markers such as Interleukin 6 (IL-6) and C-Reactive Protein (CRP) are associated with insulin resistance, the key determinant of type 2 diabetes mellitus [9]. Macrophages produce Tumor Necrosis alpha (TNF-α) and Interleukin 1 Beta (IL- 1β), more pro-inflammatory signals which can destroy beta cells, impairing glucose-stimulated insulin secretion [23]. While the scope of this paper focuses on some pro-inflammatory markers driving pancreatic beta cell dysfunction, the complexity and interrelation of the inflammatory response to many more metabolic diseases should not be ignored. As stated earlier, obesity is closely related to diabetes, in which insulin resistance results, creating low-grade inflammation [23]. With most diabetics being obese, it is difficult to determine that inflammation is due to excess adipose tissue or insulin resistance. As a matter of fact, inflammation can cause both, but where inflammation occurs is significant to the pathogenesis of type 2 diabetes.

In a study analyzing type 2 diabetic pancreas islet cells, increased numbers of macrophages, detected via a CD68 marker, were detected compared to nondiabetics [24]. Specifically, this marker is a part of the M1 macrophage class, indicating these cells were proinflammatory [25]. A study performed in animal models connects the development of insulin resistance and elevated free fatty acids promoting inflammation. Specifically, excess saturated fatty acids such as palmitate, is correlated with beta cell dysfunction as more macrophages are within the islet [26]. In summation, free fatty acids accumulate in diabetics who are obese, triggering an inflammatory cascade that impairs beta cells. Furthermore, it is evident that beta cell dysfunction and insulin resistance were associated with higher pre-diabetes and diabetes risk [27]. The on-going complication between inflammation and diabetes is being studied as exact mechanisms are not fully understood. It is still unknown if inflammation precedes these disorders or if these metabolic con-

ditions cause inflammation. Regardless, with diabetes associated with obesity, inflammation plays a role in both with many cells and pathways involved.

3.6 Exercise Reducing Inflammation and T2DM

Although the role of inflammation in diabetes is multifaceted, the ability to measure inflammatory markers can assist with diagnosing and preventing diabetes. With the knowledge of the relationship between inflammation and metabolic disorders, modalities like exercise can be implemented to reduce inflammation before the onset of these diseases. In a study done by Abramson and Vaccarino in 2002, a group of healthy men and women reported their habits of physical activity and markers like CRP, were measured to indicate inflammation [28]. The use of CRP in many disorders like chronic heart disease, obesity, and type 2 diabetes all signal to chronic inflammation [29]. With an understanding of the effect of CRP, the study found that those who had more physical activity throughout the month, were less likely to have higher CRP levels 28. This study introduces the connection between physical activity to reduce inflammation before the onset of metabolic diseases.

Cytokines, which are immunoregulators, respond to inflammation and typically TNF-α and IL- 1, are released as pro-inflammatory markers local [30]. These markers will then produce IL-6, which acts in a pro-inflammatory nature during severe inflammation like sepsis, but anti-inflammatory during exercise [30]. Although many inflammatory markers are released in physical activity, monitoring IL-6 is worthwhile for its multiple effects. The dual-action of IL-6 should be highlighted to reduce inflammation by triggering IL-1ra and IL-10, more anti-inflammatory agents, and inhibiting TNF- α [30]. The significance of IL-6 to promote further reduction in inflammation and reduce a key marker for metabolic diseases, TNF-α, shows the impact of exercise. With more TNF mRNA seen in diabetic myocytes compared to nondiabetics, the reduction of this inflammatory marker is vital in the pathogenesis and progression of this metabolic syndrome [31]. This significant study contributed to the understanding of where inflammation can also occur in diabetics, not just in the pancreas with beta cells, but also in muscle.

4. Conclusion

To summarize, type 2 diabetes is a growing concern globally as it is interrelated to many other chronic diseases, often making it difficult to prevent or manage. Moreover, the pathogenesis of diabetes is well understood when isolated, but that is usually not the case. As discussed in this review, many diabetics are overweight or obese, contributing to their insulin resistance. However, some diabetics have their insulin resistance not related to weight, but their habits like diet and exercise. Again, obesity and diabetes are usually correlated, but the scope of this paper is on diabetes prevention, so obesity is mentioned as a comorbidity. Fortunately, exercise can be implemented as a prevention or treatment method for diabetes, to lose weight. With more weight loss, the odds for developing diabetes decreases significantly, as the goal of this paper is to highlight prevention methods. Additionally, inflammation can contribute or result from diabetes, with a multitude of cytokines and immune cells creating this chronic state. Again, regular physical activity can combat this inflammation and can begin to restore insulin sensitivity to optimal range. The emphasis of exercise cannot be ignored and should be implemented as early as possible as a prevention method for diabetes before it progresses. The benefits of exercise are beyond just preventing diabetes, but for multiple metabolic conditions involved in this disease.

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