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REVIEW

Independent and combined effect of diet and exercise in adults with prediabetes

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Abstract: Prediabetes is defined as impaired fasting glucose and/or impaired glucose tolerance. Impaired fasting glucose is usually defined as fasting blood glucose between 5.6 mmol/L and 6.9 mmol/L (100.8–124.2 mg/dL), and impaired glucose tolerance is the 2-hour oral glucose tolerance test of 7.8–11.0 mmol/L (140.4–198.0 mg/dL). Most individuals with prediabetes are overweight or obese and are at greater risk of type 2 diabetes (T2D). The first line of treatment for individuals with prediabetes is lifestyle modification, including diet and exercise. The aim of this review, through the revision of primarily randomized control trials, is to discuss the independent and combined effect of diet and exercise on the incidence of T2D, glycemic control, and weight loss in adults with prediabetes. Based on the available literature, lifestyle modification combining both diet and exercise is effective at reducing the incidence of T2D and improving glycemic control, even without a significant reduction in body weight. Thus, it is unclear whether weight loss, through lifestyle modification, is a cornerstone for improving glycemic control in individuals with prediabetes. The independent effect of diet or exercise alone on the improvement in glycemic control and/or reduction in body weight in individuals with prediabetes still requires more studies to draw a clear conclusion, considering the quality and quantity of available studies. As of now, the best diet and/or exercise program to improve glycemic control and body weight in adults with prediabetes is unknown.

Keywords: diabetes, glycemic control, weight loss, nutrition, physical activity, obese

Introduction

Based on the International Diabetes Federation, the prevalence of type 2 diabetes (T2D) in adults is 6.9% and will increase to 17% by 2030.[1] Despite the widely funded research in the past decades to reduce the prevalence and the incidence of T2D, it remains one of the most costly chronic conditions to treat.[2] The prevalence of T2D is especially high in overweight and obese individuals.[3] For example, obese individuals are 42.1 times more likely to develop T2D after a 5-year follow-up compared to normal weight individuals.[4] Interestingly, this association seems to persist and strengthen over time. As proof of this statement, a prospective study of 10,920 men and 8,227 women showed that an overweight adult is 2.7 (2.1–3.6) times more likely to develop T2D and that risk increases to 7.2 (5.3–10.0) after 30 years.[5] One of the strategies to reduce the incidence of T2D is to intervene before the development of the disease in a population at high risk for T2D; this is commonly referred to as prediabetes. Management of prediabetes is highly relevant considering that between 29% and 93% of individuals with prediabetes will develop T2D in the years following their diagnosis.[6]

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What is prediabetes?

As of now, there is no worldwide unified definition for prediabetes. Impaired fasting glucose (IFG) and/or an impaired glucose tolerance (IGT) measured after a 2-hour oral glucose tolerance test (OGTT) is generally used to identify individuals with prediabetes. The cut-points for IFG and IGT diverge across countries, but usually IFG is defined as a fasting plasma glucose ranging between 5.6 and 6.9 mmol/L (100.8–124.2 mg/dL), while IGT is defined by values of plasma glucose ranging between 7.8 and 11.0 mmol/L (140.4–198.0 mg/dL) 2 hours following an OGTT.[7] Recently, the American Diabetes Association suggested that glycosylated hemoglobin (HbA_{1c}) between 5.7% and 6.4% should also be used to identify individuals with prediabetes.[7] The use of different criteria to identify individuals with prediabetes leads to a wide variation in the magnitude of risk associated with the development of T2D.[7] Despite different criteria to identify individuals with prediabetes, a better understanding of modifiable risk factors (diet and exercise) is needed to better manage prediabetes given that individuals with IFG are 4.6 times more likely to have T2D[8] and that risk increases to 6.3 for individuals with IGT and reaches 12.1 if an individual presents both IFG and IGT.[8]

Many studies have aimed to identify the best intervention to improve glycemic control in individuals with prediabetes.[9,10] This included pharmacotherapy[11–13] and/or lifestyle modification with diet, exercise, or both.[14–17] Even though lifestyle modification seems to offer a more holistic approach and significant short- and long-term results,[15] clinicians still struggle to find the right program that would be cost effective,[18,19] well tolerated by patients, and available in different settings.[10,20] Lifestyle modification is the primary intervention with overweight and obese individuals with prediabetes because a healthy lifestyle is associated with a high risk of T2D as well as many other chronic diseases.[21] Nonetheless, drug therapy to prevent T2D in people with prediabetes is constantly being studied.[22] A systematic review reported that no single agent could be recommended to delay or prevent T2D. In addition, the authors of the review suggested that longer follow-up studies are needed in order to assess safety and efficacy.[23] Since then, the DREAM study reported that the use of rosiglitazone (8 mg daily) reduced T2D incidence after 3 years in patients with prediabetes and recommended its clinical usage.[24]

Selection of articles

Using mostly randomized controlled trials (RCTs), this review aims to discuss the current literature on the benefits of lifestyle modifications in reducing the incidence of T2D and body weight, and improving glycemic control in individuals with prediabetes. Even though a few articles included in the current review did not exclusively recruit individuals who were considered overweight or obese at baseline, all studies aimed to reduce body weight as part of their objectives, and most did subanalysis with body mass index (BMI) subcategories. All studies included in this review had individuals with prediabetes defined by either IFG and/or IGT. The originality of this review resides in the fact that it distinguishes the independent and combined effect of diet and exercise in individuals with prediabetes.

A PubMed search was done in March 2014 using the following Boolean phrases: prediabetes AND lifestyle intervention; prediabetes AND exercise intervention; prediabetes AND diet intervention. From these searches, 6, 30, and 72 articles, respectively, were found. Filters pinpointed articles that were published in English and involved human adults, and participants were overweight or obese and classified as having prediabetes either by IFG or IGT. Additional search material was located by scrutinizing the reference section of previously identified articles. Articles with an intervention exploring the impact of diet, exercise, or both were included in this review. The focus was placed, but not restricted to, RCT studies. This review will start by discussing the impact of lifestyle modification (diet + exercise) on the incidence of T2D, glycemic control, and weight loss. Second, the impact of diet alone on the same outcomes is discussed, and, finally, the impact of exercise alone on the incidence of T2D, glycemic control, and weight loss is discussed. Some studies overlapped by having the three types of intervention in the same study. If that was the case, the results of these studies were discussed in all three sections (diet + exercise, diet, exercise) of the review.

Lifestyle modifications, glycemic control, and body weight

In the past 20 years, a growing interest on the effect of exercise and diet in the reduction of prevalence and incidence of T2D has been observed in the scientific literature. The Diabetes Prevention Program (DPP),[14] the Finnish Diabetes Prevention Study (DPS),[17] and the Da-Qing trial[25] are seen as milestones in the field because of their strong design, large sample size, and long-term follow-up. Together, they have significantly enhanced the knowledge with regard to the impact of lifestyle (exercise + diet) modifications on the incidence of T2D and glycemic control in individuals with prediabetes. Even though some argue that these lifestyle

interventions were cost effective,[26] others have reported that the cost was too high and the required resources were too considerable to implement them widely.[27] Some even criticized that the results observed in those large trials were optimistic because those studies included volunteers.[28]

In the DPP study,[14] 3,234 overweight individuals with prediabetes were recruited and randomized to one of three groups: 1) placebo, 2) metformin, and 3) lifestyle intervention. The lifestyle intervention group was asked to reduce their body weight by 7% by creating an energy deficit with diet (healthier diet) and exercise (>150 minutes per week) by using a one-on-one approach for 24 weeks with weekly meetings, and then monthly contacts afterward. The main goal was to compare the incidence of T2D across the three groups with the hypothesis that the lifestyle intervention would provide a greater reduction in incidence of T2D. After 2.8 years, the lifestyle intervention group had a reduction of 58% in the incidence of T2D compared to the placebo group. When performing a subanalysis, obese individuals had a slightly greater reduction in the incidence of T2D (61%). Interestingly, the benefit of the lifestyle intervention was maintained after 10 years' follow-up where the reduction in the incidence of T2D was still 34% lower in the lifestyle group compared to the placebo group.[15] In terms of glycemic levels, both fasting plasma glucose and HbA_{1c} were lower in the lifestyle modification group compared with the control group after the initial study lasting a mean of 2.8 years.[14] Exactly the same findings were reported after 10 years of follow-up.[15] Together, these results strongly suggest that lifestyle intervention is a cornerstone in the management of prediabetes in both overweight and obese individuals. In 2006, Ramachandran et al[29] reported similar results when replicating the method with native Asian Indians who are known to be at high risk of T2D. Over a follow-up of 30 months, including a total of 531 native Asian Indians with prediabetes, the study has shown that it was possible to reduce the incidence of T2D in this high-risk population when combining diet and exercise, compared to the control group (incidence of 39.3% vs 55.0%, respectively).

Similarly to the DPP, the DPS study included 522 overweight men and women with IGT randomized to either a control or a lifestyle group (diet + exercise) in Finns instead of Americans. The lifestyle intervention aimed at reducing the body weight by a minimum of 5% by reducing total calories from fat, saturated fat, and increasing fiber, in addition to doing 30 minutes more of physical activity per day.[17] After a follow-up of 3.2 years, the incidence of T2D was reduced by 58% in the lifestyle group. The reduction of T2D incidence was directly associated with changes in lifestyle. Compared to the control group, in which a mean reduction of 0.8% was observed in fasting glucose and 5.4% on the 2-hour OGTT, a mean change in fasting glucose of 3.6% ($P \leq 0.001$) and a mean change of 15.3% on the 2-hour OGTT ($P=0.003$) was observed in the lifestyle group. When followed for another 7 years, the reduction in relative risk for T2D was still 36% lower in the lifestyle group compared to the control group.[30] In 2009, the European Diabetes Prevention Study extended the DPS to different European populations using the same study design and found similar results.[31] After a mean duration of 3.1 years, the absolute incidence of T2D was 32.7 per 1,000 person-years in the lifestyle intervention group compared with 67.1 per 1,000 person-years in the control group.

In the Da Qing study,[25] 577 individuals with IGT were recruited, from whom 322 (55.8%) were overweight or obese. They were randomized to a control group, a diet group, an exercise group, or a group combining both (lifestyle group). Participants were instructed to increase physical activity by one to two units per day, one unit equaling 30 minutes of light exercise, 20 minutes of moderate intensity exercise, 10 minutes of strenuous exercise, or 5 minutes of very strenuous exercise. A total of 30 visits were scheduled for each group: weekly for the first month, monthly for the next 3 months, and once every 3 months thereafter. The diet targeted a reduction of 0.5–1.0 kg/month by caloric restriction. As a result, the incidence of T2D in participants who received the lifestyle intervention had a mean of 46%, the diet group 44%, and the exercise group 41% when compared to the control group, in which the incidence was 68%. More details about the independent impact on the groups using only diet and only exercise are given in the next sections. After 6 years, the values of fasting glucose and the 2-hour OGTT increased in both lifestyle and control groups, but a smaller increase was observed in the group of participants receiving the lifestyle modification program. For example, the OGTT result increased by 29.7% in the control group compared to 19.4% in the intervention group. When evaluating this intervention over a 20-year follow-up,[16] the authors combined all participants receiving one or the other treatment in the initial study (diet, exercise, and both) and compared them with the control group. The results showed a 43% lower incidence of T2D, and participants in the lifestyle group spent 3.6 fewer years with diabetes compared with participants in the control group. Both the fasting glucose and the 2-hour glucose level following an OGTT were significantly different between participants in the lifestyle modification program and

participants in the control group. For example, fasting glucose was 7.9±4.2 mmol/L (142.2±75.6 mg/dL) in the intervention group versus 8.7±4.2 mmol/L (156.6±75.6 mg/dL) ($P<0.05$) in the control group.

Despite the convincing results of the benefits of lifestyle modification using diet and exercise to reduce T2D incidence, there is some concern about the high cost and the necessary resources to conduct these interventions. As a result, many studies have tried to reproduce similar findings with a cost-effective approach since then. For example, Saito et al[32] conducted an RCT study with 641 overweight individuals. The control group received lifestyle advice once per year, while the intervention group received lifestyle advice four times in 12 months (7.5 times less than the DPP study). The goal was to create a caloric deficit by exercise and diet and reduce body weight by about 5%. The results have shown that lifestyle modification could prevent the incidence of T2D in individuals with prediabetes by 59%. Both the fasting glucose ($P=0.02$) and the 2-hour glucose level following an OGTT ($P=0.001$) were significantly different between participants in the lifestyle modification group and the control group. After 12 months of intervention, an increase in walking time was observed in the intervention group, but no difference was observed in total caloric intake, suggesting that exercise such as walking was the cornerstone of better glycemic control in the intervention group. These results also suggest that lifestyle modification is effective in reducing T2D incidence, even with a less intensive intervention. Another study tried to replicate the DPP findings in a cost-effective way[33] by focusing on changing the participant's lifestyle using a combination of individual and group meetings. Individuals with prediabetes were randomized to either a 1-year lifestyle modification which included individualized counseling every 6 weeks and 25 weekly optional group seminars or to a group receiving only access to group seminars. The last group was considered as the control group because no individual sessions were offered. While both groups significantly improved their fasting blood glucose, only a significant reduction on the 2-hour OGTT ($P\leq0.05$) was observed in the intervention group (receiving individual sessions in addition to group seminars). In addition, noone developed T2D in the group + individualized sessions during the intervention compared with 11.5% in the control group. Gagnon et al[33] concluded that the cost of their program combining group and individual sessions was about $81 per year, which is much less than the yearly estimated cost of the DPP ($926 per year).[34] Controversially, using a longer follow-up, and more individual appointments compared with the study of Gagnon et al,[33] Oldroyd et al[35] conducted a lifestyle modification program randomizing participants with IGT to a control or an intervention group. The intervention group aimed to reduce BMI to 25 kg/m^2 through diet and exercise (>20–30 minutes daily). Over the first 6 months, individuals in the lifestyle intervention group received twelve individual appointments with a dietitian and a physiotherapist, while no advice was provided for individuals in the control group. After a total of 24 months, the incidence of T2D was not significantly different between groups (22% in each group), which means that there was no improvement between groups in both fasting glucose and the 2-hour plasma glucose after 12 months and 24 months. Even though the authors argued that their results were similar to those observed in more intensive trials because of a significant change in insulin sensitivity, this study suggests that the intervention in lifestyle modification programs needs more than 12 individual visits to optimize the reduction in T2D incidence. A recent study also tried to implement a lifestyle modification program similar to the DPP in 301 overweight and obese adults with prediabetes in a cost-effective way using community resources.[36] The study design compared the group undergoing the lifestyle modification program to a control group. The lifestyle intervention aimed to reduce body weight by 7% by increasing physical activity levels and reducing energy intake. After 24 months, the authors showed a significant decrease in fasting blood glucose (mean difference 2.0%; $P<0.01$) compared with the control group. This study highlights that an intervention held in community-based sites and administrated by registered dietitians and community health workers is efficient in improving glycemic control in individuals with prediabetes with a modest weight loss. However, even though the intervention was mostly group meetings and run by community workers, participants in the intervention group were also met weekly for the first 24 weeks, had three individual meetings, and were contacted biweekly thereafter.

The typical weight loss recommendation to improve metabolic health, specific to overweight and obese individuals with prediabetes, ranges between 5% and 10% of the initial body weight.[37] One study has reported that weight loss is one of the most important predictors of change in glucose tolerance, suggesting that even a slight weight loss is enough to improve glycemic control in individuals with prediabetes.[38] Most studies including individuals with prediabetes show that lifestyle modification programs using diet and exercise are effective in reaching that recommendation. For example, the lifestyle intervention group in the DPP study reduced their body weight by a mean of 5.6 kg (6.3%).[14] In a sample of

slightly older subjects (mean =55±7 years vs 51±11 years),[17] the DPS study reported a mean weight loss of 4.2±5.1 kg (4.7%) following a lifestyle intervention program. These results are meaningful because they were observed after 2.8 years and 3.2 years, respectively. Similarly, the Da Qing Study reported a meaningful decrease in BMI after a 6-year follow-up, but after a 20-year follow-up the body weight was not significantly different between the control and the intervention group, even though the incidence of T2D was reduced by 51%,[16] suggesting that initial weight loss is important despite slow weight regain over many years.

To sum up, most studies investigating the impact of modifying diet along with exercise in individuals with prediabetes, in order to improve glycemic control, support that lifestyle modification is effective in reducing the progression of prediabetes toward T2D. However, more studies are needed to determine how intense (eg, the number of meetings, group/individual) those interventions need to be in order to observe optimal benefits, and whether exercise or diet alone can offer similar benefits. In addition, it is still unclear how to deliver such interventions at the population level in a cost effective way.

Diet, glycemic control, and body weight

In this section, we pinpoint interventions that independently evaluated how dietary modification might impact glycemic control or body weight in individuals with prediabetes. Surprisingly, only a few well-designed studies have looked at diet alone[25,39–42] as a strategy to improve glycemic control or body weight in individuals with prediabetes.[22,35–38] Nonetheless, some studies with both diet and exercise interventions showed significant changes in glycemic control or body weight in individuals with prediabetes. For example, the DPP study focused on a low-calorie diet and a low-fat diet by doing one-to-one meetings on a weekly basis for the first 24 weeks, and monthly group meetings afterward to reinforce behavioral changes.[14] The DPS[17] focused on the diet intervention on the total intake of fat, and more particularly on saturated fat (<10%) and fiber intake (≥15 g/1000 kcal). For example, they recommended the consumption of whole-grain products, fruits, low-fat milk, low-fat meat, soft margarines, and monosaturated oils.

The following section reports studies that have looked at the impact of diet alone on glycemic control or body weight in individuals with prediabetes. Watanabe et al[42] randomized individuals with prediabetes to either a dietary education program aimed at reducing total daily energy intake by reducing energy intake at dinner time or a control group who received general recommendations on healthy eating. The purpose of this 1-year study was to investigate whether the dietary education program was capable of reducing body weight and improving glycemic control in individuals at high risk of diabetes. The results showed that the diet group significantly reduced energy intake by 15.3% compared to 6.0% in the control group. This reduction was associated with a 15% improvement in glucose tolerance in the diet group. Therefore, they concluded that reducing the overall calories improves glycemic control in individuals with prediabetes.

Specific to diet quality, Swinburn et al[41] investigated the long-term effect of a diet aimed at reducing fat intake, using an ad libitum diet, on body weight and glycemic control in individuals with prediabetes. After a 1-year dietary intervention, they observed a significant reduction in body weight for participants in the intervention group (−3.3 kg; P=0.03). This change in body weight was associated with a reduction in the proportion of individuals who developed T2D in the diet group compared to the control group (47% vs 67%). Despite this interesting result, the body weight that was lost was regained 5 years following the intervention. In addition, the difference in incidence of T2D between both groups did not remain statistically different. At year 5, secondary analysis was performed and an overall effect of the intervention on glucose tolerance was found in compliant participants (still eating less fat), but this difference disappeared when controlling for the total calorie intake. Therefore, this study suggests that the long-term effect of a diet on the incidence of T2D is mainly driven by the total caloric intake, in individuals with prediabetes.

Controversially, a subanalysis of the DPS study[39] showed that specific diet components were important to predict T2D incidence in people with prediabetes. The authors teased out the contribution of fat and fiber as independent predictors of weight loss and the incidence of T2D in individuals with IGT. They reported that individuals in the highest quartile of fat consumption were 55% less likely to reach a minimum weight loss of 5%, while individuals in the highest quartile of fiber were 2.6 times more likely to reach 5% weight loss after 3 years of follow-up. Similarly, a 62% decrease in the risk of incidence of T2D was observed for individuals in the highest quartile of fiber, while individuals in the highest quartile of fat were 2.1 times more likely to develop T2D. When fiber and fat were combined into a single variable, the authors compared high fat/low fiber to the reference group (low fat/high fiber) and observed an 89% increase in the likelihood of developing T2D over the follow-up period. These results

strongly suggest that the management of macronutrients such as fat and fiber is an important factor to be considered in the prevention of T2D.

In the Da Qing study,[25] the independent effect of diet was studied. The diet was composed of 55%–65% carbohydrates, 10%–15% proteins, and 25%–30% fats. During the counseling sessions, it was suggested to increase vegetables consumption, control alcohol intake, and reduce simple sugar in order to reduce total caloric intake. The weight loss goal was 0.5–1.0 kg per month until participants reached a BMI of 23 kg/m^2. Change in body weight was not significant in the diet group compared with the control group, which might be explained by the fact that the diet group did not decrease the total energy intake despite a change in macronutrients. Nevertheless, the diet group had a significantly lower incidence of T2D compared with the control group (43.8% vs 67.7%; $P<0.05$) after 6 years of follow-up. When the findings were restricted to the overweight and obese individuals, the results were similar, with a 6-year lower incidence of diabetes (100 person-years) in the diet group: 11.5 (8.0–15.0) compared to the control group 17.2 (13.3–21.3) $P<0.05$. This study concluded that diet is an intervention that significantly reduces the incidence of T2D in overweight and obese individuals with IGT, despite the absence of weight loss.

A study in 2013 by Gagnon et al[33] looked at whether an individualized dietary intervention of 3 months, in 65 individuals with prediabetes, had the same impact on fasting blood glucose and body weight compared to a group receiving group sessions during the same period. Both groups significantly improved their fasting blood glucose without any significant change in body weight after 12 months. However, it should be noted that HbA_{1c} improved in the group receiving individual sessions, but not in the other group. This suggests that some advantage might be obtained by doing individual versus group sessions if the resources are available.

To sum up, dietary interventions evaluating the ability to induce a significant reduction on body weight and improve glycemic control in individuals with prediabetes are scarce, as the main focus has been on caloric restriction. There is a gap to be filled in understanding the benefits on modifying macronutriments and/or micronutriments to influence glycemic control with or without weight loss in individuals with prediabetes. For the moment, the literature available suggests that reducing caloric intake can lead to an improvement in glycemic control despite no or modest weight loss. In addition, one well-designed study has provided information that reducing fat intake and increasing fiber intake might be a strategy that could lead to a reduction in T2D incidence in people with prediabetes.[39]

Exercise, glycemic control, and body weight

This section discusses how increasing exercise levels impacts glycemic control and body weight in individuals with prediabetes. Surprisingly, even though exercise is considered a cornerstone in the management of obesity[43] and T2D,[44] not many well-designed studies have investigated the independent effect of exercise and the best mode (eg, resistance training, walking) of exercise on body weight and glycemic control in individuals with prediabetes. Another lacking component is whether the intensity of exercise is an important factor in optimizing the health benefits. Despite the lack of such information, most physical activity guidelines suggest doing two types of exercises: aerobic and resistance training.[45,46] A recent meta-analysis provided insight into whether a combination of lifestyle interventions including diet, aerobic exercise, and resistance training was effective at reducing body weight and improving glycemic control to prevent T2D[47] and concluded that doing resistance training on top of aerobic exercises and diet did have additional benefits.

Even though the independent impact of exercise is unknown in studies using diet + exercise to reduce T2D incidence, in people with prediabetes some studies showed significant changes in glycemic control or body weight in individuals with prediabetes, and their exercise program must be noted. Even though not many details were given on the exercise recommended in the DPP study,[14] it was reported that information was given on a one-on-one basis to participants so that they would reach a minimum of 150 minutes weekly of moderate intensity aerobic exercises. On the other hand, the DPS[17] gave more details about physical activity. Their goal was to increase physical activity by 30 minutes each day. Aerobic exercises were recommended, but supervised resistance training sessions were also offered. In both of the DPP and the DPS, no detail was given of how the exercise intensity was monitored. The DPS also reported, later in 2010, that, as participants increased their physical activity level (highest tertile of change), they were more likely to reduce their fasting glucose even when the results were adjusted for changes in dietary intake and change in body weight.[48]

Some studies have compared the impact of resistance training, aerobic training, and both on glycemic control and body weight. For example, a study explored the impact of

different exercise modalities in individuals with prediabetes.[49] In this study, 26 sedentary men were recruited and randomized in the resistance training group, aerobic group, or control for an intervention lasting 20 weeks. Both exercise modalities showed results that were successful at normalizing glucose levels compared with the control group, with no difference between the exercise modality groups. Using a 6-year follow-up, Pan et al,[25] with the Da Qing study, tested the independent impact of exercise on individuals with IGT. The exercise intervention consisted of encouraging the 141 participants in that group to increase aerobic physical activity by a minimum of one to two exercise units, defined as 30 minutes of light exercise, 20 minutes of moderate intensity, 10 minutes of vigorous intensity, or 5 minutes of very strenuous exercise per day, for 6 years. Counseling sessions were conducted once a week for the first month, monthly for the next 3 months, and every 3 months for the remainder of the study. The exercise units went from 3.4±2.8 to 4.0±3.0 in the exercise group during the 6-year follow-up, which turned out to be a nonsignificant increase. Changes in BMI were not different in the exercise group compared to the control group (–0.9 unit in each group), but the incidence of T2D was about three times lower in the exercise group compared with the control group (5.1 [95% confidence interval {CI}: 2.6–7.6] vs 13.3 [95% CI: 8.9–17.7]); $P<0.01$). The exercise group has even reported a smaller incidence of T2D compared with the diet + exercise group (41% vs 46%).[25] Secondary analysis restricted to overweight and obese individuals showed a lower incidence of T2D in the exercise group compared to the control group (11.5 [95% CI: 8.0–15.0] vs 17.2 [95% CI: 13.3–21.3]; $P<0.01$). The conclusion made was that exercise alone was as effective as diet + exercise to reduce diabetes incidence in individuals with IGT despite no significant change in body weight. This conclusion is aligned with studies showing the benefits of exercise without weight loss[50] or with the concept of "fit-fat" which suggests that high fitness attenuates the risk of T2D and cardiovascular diseases independent of body weight.[51]

In 2012, Malin et al[52] recruited individuals with prediabetes with 32 participants in four different groups: exercise + placebo, metformin, exercise + metformin, or placebo. The goal was to evaluate the benefits of combining metformin and exercise. Exercise sessions included aerobic exercise and resistance training. All groups increased insulin sensitivity compared to baseline ($P<0.05$), but the exercise + placebo group had a greater improvement (25%–30%) compared to the other groups. In addition, the improvement in insulin sensitivity was only significantly different in the group exercise + placebo compared to the control group, while no such difference was observed in the group exercise + metformin, which suggests that the benefits of exercise were even counteracted when consuming metformin.

More recently, a study aimed at testing whether walking alone was sufficient to influence glycemic control and whether there was an advantage in combining both resistance training and walking in individuals with prediabetes.[53] Sixty-one participants (age 49.8±4.8 years) with prediabetes were randomized to the control group, the walking group, or the walking group + resistance training for a 24-week duration. The walking group was exercising at 60%–70% of maximum heart rate for a duration of 50 minutes, four times per week, while the walking group + resistance training was walking for 20 minutes and doing resistance training for 30 minutes using seven different exercises (two to three series of 15 repetitions). The results showed that both intervention groups showed a significant improvement in glycemic control as reflected by glucose disposal, fasting insulin, and insulin resistance, compared with the control group, but no difference was observed between the two exercise interventions. The authors concluded that walking was sufficient to improve glycemic control in individuals with prediabetes.

To sum up this section, the current literature supports the use of exercise alone to reduce T2D incidence in people with prediabetes, even when no significant weight loss is observed. However, not many details on the optimal intensity, duration, or type of exercise to optimize the effect are available. In general, the successful studies have combined 1–2 days of resistance training in addition to aerobic exercise at moderate intensity for about 150 minutes weekly.

Conclusion

In conclusion, there are currently many well-designed studies that show that lifestyle modifications, including exercise and diet, are associated with improvement in glycemic control, which translates into a reduction in T2D incidence in individuals with prediabetes. The current literature suggests that the reduction of T2D incidence observed during lifestyle modification is not necessarily associated with a significant reduction in body weight. The independent effects of diet and exercise in individuals with prediabetes on glycemic control and body weight need to be addressed in more detail. Currently, it is not clear whether we should target a specific macronutrient or what exercise modality should be emphasized to optimize the benefits for individuals with prediabetes. More rigorous studies with long-term follow-up are needed to evaluate the impact of different macronutrients

and exercise modality on glycemic control and weight loss in such individuals. This would help in providing better management for adults living with prediabetes. However, despite the lack of details, lifestyle modifications definitely improve short- and long-term glycemic control and need to be promoted in clinical settings.

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