The Effects of Breakfast Consumption and Composition on Metabolic Wellness with a Focus on Carbohydrate Metabolism[1–4]

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ABSTRACT

Findings from epidemiologic studies indicate that there are associations between breakfast consumption and a lower risk of type 2 diabetes mellitus (T2DM) and metabolic syndrome, prompting interest in the influence of breakfast on carbohydrate metabolism and indicators of T2DM risk. The objective of this review was to summarize the available evidence from randomized controlled trials assessing the impact of breakfast on variables related to carbohydrate metabolism and metabolic wellness. Consuming compared with skipping breakfast appeared to improve glucose and insulin responses throughout the day. Breakfast composition may also be important. Dietary patterns high in rapidly available carbohydrate were associated with elevated T2DM risk. Therefore, partial replacement of rapidly available carbohydrate with other dietary components, such as whole grains and cereal fibers, proteins, and unsaturated fatty acids (UFAs), at breakfast may be a useful strategy for producing favorable metabolic outcomes. Consumption of fermentable and viscous dietary fibers at breakfast lowers glycemia and insulinemia. Fermentable fibers likely act through enhancing insulin sensitivity later in the day, and viscous fibers have an acute effect to slow the rate of carbohydrate absorption. Partially substituting protein for rapidly available carbohydrate enhances satiety and diet-induced thermogenesis, and also favorably affects lipoprotein lipids and blood pressure. Partially substituting UFA for carbohydrate has been associated with improved insulin sensitivity, lipoprotein lipids, and blood pressure. Overall, the available evidence suggests that consuming breakfast foods high in whole grains and cereal fiber, while limiting rapidly available carbohydrate, is a promising strategy for metabolic health promotion. *Adv Nutr* 2016;7(Suppl):613S–21S.

Keywords: carbohydrate metabolism, dietary patterns, energy metabolism, breakfast, diabetes, metabolic syndrome

Introduction

Diabetes mellitus affects ~9.3% of people (26 million) in the United States (1), and an additional 79 million people have prediabetes (2). Type 2 diabetes mellitus (T2DM)[5], which accounts for 90–95% of all diagnosed cases of diabetes (3), is a multifaceted condition characterized by prolonged insulin resistance and eventual pancreatic β cell exhaustion, which is accelerated by the demand to produce compensatory hyperinsulinemia to overcome insulin resistance (4). Although there is a genetic contribution to its development (5), diabetes in the Western world is related to the twin pandemics of obesity and physical inactivity (6). Much focus has been placed on weight loss and regular physical activity for lowering T2DM risk (7–9). However, beyond energy content, the composition and timing of dietary intake may have important influences on metabolic health and risk factors for T2DM.

Although the breakfast meal is considered by some to be the most important meal of the day, its contributions to various facets of health and wellness are controversial. Epidemiologic investigation suggests that breakfast consumption, compared with breakfast skipping, is associated with a lower risk of T2DM and metabolic syndrome [reviewed in detail by Odegaard et al. (10)]. This paper summarizes the findings of a comprehensive literature review of randomized controlled trials that was conducted to assess the potential impact of breakfast consumption and breakfast type on

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[4] Supplemental Material is available from the "Online Supporting Material" link in the online posting of the article and from the same link in the online table of contents at http://advances.nutrition.org.
[5] Abbreviations used: GI, glycemic index; GL, glycemic load; T2DM, type 2 diabetes mellitus; UFA, unsaturated fatty acid.
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metabolic health, with a focus on carbohydrate metabolism and T2DM risk factors. For a detailed methodology of the literature review, refer to the **Supplemental Material**. A flow diagram of the study selection process is depicted in **Figure 1**. The studies identified for glucose and insulin responses and the major outcomes of these studies are outlined in **Table 1**. The strength of the available evidence based on the Academy of Nutrition and Dietetics Evidence Analysis criteria (76) is summarized in **Table 2**.

Breakfast Consumption Compared with Breakfast Skipping

Breakfast skipping is associated with weight gain and other adverse outcomes (10, 77), including increased risk of T2DM and metabolic syndrome (78–86). The relation observed between breakfast skipping and increased T2DM and metabolic syndrome risk may relate to a prolonged elevation in FFAs throughout the morning hours in breakfast skippers, resulting in reduced insulin sensitivity later in the day (11, 12). A second hypothesis is that there may be differences in the ability to handle carbohydrate loads in the morning compared with later in the day because of *1*) differences in sympathetic nervous system activity, or *2*) diurnal patterns in the release of incretin hormones (e.g., glucagon-like peptide 1 and gastric inhibitory polypeptide) in response to a meal (87–90).

The same foods, distributed differently throughout the day, appear to have differential effects on glycemic control in subjects with T2DM. In a randomized crossover trial conducted by Jakubowicz et al. (87), a meal pattern that included a high-energy breakfast plus a low-energy dinner (breakfast: 2946 kJ, lunch: 2523 kJ, and dinner: 858 kJ) significantly reduced postprandial hyperglycemia over the course of the day compared with a meal pattern with a low-energy breakfast plus a high-energy dinner (breakfast: 858 kJ, lunch: 2523 kJ, and dinner: 2946 kJ) in subjects with diabetes (**Figure 2**A and B) (87). These results are consistent with those from other studies showing diurnal variations in carbohydrate metabolism, with greater insulin sensitivity in the morning compared with mid-day or evening (88–90).

Breakfast Composition

In addition to breakfast size and skipping, the composition of the breakfast meal is an important consideration with regard to carbohydrate metabolism and metabolic health. For example, a breakfast higher in protein or unsaturated fatty acids (UFAs) may lower glucose and insulin responses by displacing glucose-generating carbohydrate from the meal. In addition, breakfast is a meal that often contributes significantly to the daily consumption of dietary fiber (91–94). Various types of dietary fiber may confer health benefits via effects on colonic fermentation, through displacement of rapidly available carbohydrate, and by slowing intestinal carbohydrate absorption (95). The subsequent sections will consider the effects of breakfast composition on glycemia, insulinemia, and other indicators of glucose homeostasis throughout the day.

Rapidly Available Carbohydrate at Breakfast

It is becoming increasingly clear that dietary patterns high in rapidly available carbohydrate are associated with an

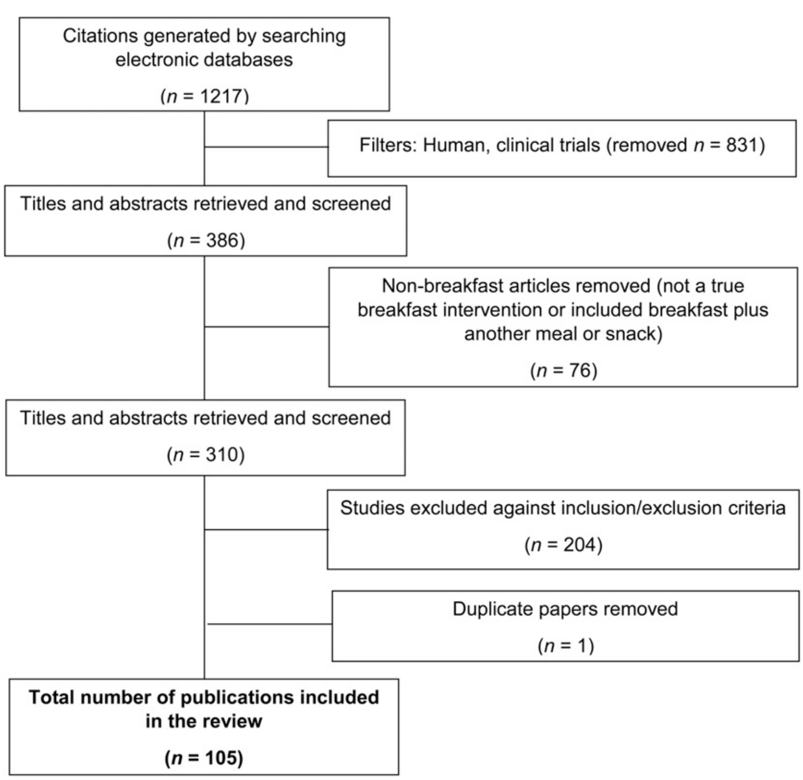

FIGURE 1 Flow diagram of the study selection process.

TABLE 1 Summary of findings for the effect of breakfast on glucose and insulin responses[1]

Variable	Breakfast consumption vs. skipping: Advantage of breakfast, *n* (refs)	Breakfast consumption vs. skipping: Equivocal, *n* (refs)	Breakfast consumption vs. skipping: Advantage of skipping, *n* (refs)	Protein level comparisons: Advantage of higher protein, *n* (refs)	Protein level comparisons: Equivocal, *n* (refs)	Protein level comparisons: Advantage of lower protein, *n* (refs)	Fiber level comparisons: Advantage of higher fiber, *n* (refs)	Fiber level comparisons: Equivocal, *n* (refs)	Fiber level comparisons: Advantage of lower fiber, *n* (refs)	Glycemic index comparisons: Advantage of lower glycemic index, *n* (refs)	Glycemic index comparisons: Equivocal, *n* (refs)	Glycemic index comparisons: Advantage of higher glycemic index, *n* (refs)	Fat level comparisons: Advantage of higher fat, *n* (refs)	Fat level comparisons: Equivocal, *n* (refs)	Fat level comparisons: Advantage of lower fat, *n* (refs)
Acute effects															
Glucose response studies	3 (11–13)	6 (14–18)	1 (19)[2]	3 (20–22)	1 (23)	0 (NA)	20 (24–43)	10 (44–53)	0 (NA)	15 (20, 23, 29, 54–65)	2 (53, 66)	0 (NA)	5 (46, 67–70)	1 (71)	1 (72)
Insulin response studies	1 (11)	6 (13–15, 17, 18, 73)	0 (NA)	2 (20, 21)	2 (22, 23)	0 (NA)	13 (24–27, 29–31, 36–38, 41, 44, 46)	7 (32, 33, 35, 39, 47, 49, 53)	0 (NA)	10 (20, 23, 29, 54, 56, 58, 62–65)	5 (53, 57, 59, 61, 66)	0 (NA)	5 (46, 67–70)	1 (71)	1 (72)
Second meal and later effects															
Glucose response studies	4 (13–15, 73)	1 (11)	0 (NA)	0 (NA)	1 (20)	0 (NA)	4 (27, 28, 45, 74)	3 (29, 30, 47)	0 (NA)	5 (54–56, 74, 75)	3 (20, 29, 57)	0 (NA)	1 (68)	1 (67)	1 (69)
Insulin response studies	2 (15, 73)	3 (11, 13, 14)[3]	0 (NA)	0 (NA)	1 (20)	0 (NA)	1 (45)	4 (29, 30, 47, 74)	0 (NA)	2 (74, 75)	5 (53, 57, 59, 61, 66)	0 (NA)	0 (NA)	3 (67–69)	0 (NA)

[1] Glucose and insulin responses generally refer to 24-h glycemia or insulinemia, respectively, or a fixed period comprising morning and/or morning plus postlunch timeframes. NA, not applicable; refs, references.

[2] Benefit of breakfast skipping observed in subjects with type 2 diabetes mellitus (and small sample size, n = 13).

[3] Chen et al. (14) and Jovanovic et al. (13) reported similar insulin responses after the lunch meal; however, this was observed concurrently with a greater reduction in glucose with breakfast consumption compared with skipping, possibly suggesting enhanced insulin sensitivity in these 2 studies.

increased risk of developing T2DM (96–98). In contrast, greater consumption of both cereal fibers and whole grains has been associated with a reduced risk of developing T2DM (86, 99–101). In a meta-analysis of 22 cohort studies conducted by Alhazmi et al. (102), consumption of total dietary carbohydrate in the highest compared with the lowest quintile was associated with a significant elevation in T2DM risk (RR: 1.11; 95% CI: 1.01, 1.22; P = 0.04). Carbohydrate type and the content of a meal are the principal determinants of the postprandial blood glucose response, and, consequently, the insulin secretion required to dispose of the absorbed glucose. Diets high in rapidly available carbohydrate typically have a high glycemic index (GI) and deliver a large glycemic load (GL), contributing to pancreatic β cell demand (103, 104). Dietary patterns with a high GI and/or GL have been associated with an increased risk of T2DM (104, 105). Methods by which the GL of a meal can be lowered include a reduction in rapidly available carbohydrate consumption through substitution with noncarbohydrate energy sources, such as UFAs and proteins; inclusion of viscous fibers to slow carbohydrate absorption; and/or use of low GI carbohydrate foods, which are often rich in nondigestible or partially digestible polysaccharides (fibers and resistant starches) (103). The 2015–2020 Dietary Guidelines for Americans recommend substitution with whole-grain foods for refined grains as part of a healthy eating pattern that also includes a variety of vegetables, whole fruits, low-fat or fat-free dairy foods, legumes, nuts, seeds, lean-protein foods, and nontropical oils (106). Healthful dietary patterns that have these characteristics have been associated with favorable health outcomes, including a reduced risk of type 2 diabetes (106).

Dietary Fiber at Breakfast

Dietary fiber may exert substantial benefits on carbohydrate metabolism through a variety of mechanisms. A prospective cohort study of 9702 men and 15,365 women aged 35–65 y showed that a higher cereal fiber intake was associated with a reduced risk of T2DM, independent of age, sex, and lifestyle risk factors (multivariate RR: 0.72; 95% CI: 0.56, 0.93 for the highest compared with the lowest quintile, P trend across quintiles = 0.02) (99). Regarding specific food sources of fiber, fruit fiber and vegetable fiber consumption have not been found to be significantly associated with a risk of diabetes (99). It should be emphasized that fruits and vegetables are important sources of essential nutrients that are underconsumed in the average US diet, and their consumption should be emphasized as part of a healthy dietary pattern (106). Nevertheless, the types of dietary fibers that show the most promise with regard to favorable effects on carbohydrate metabolism include those that create viscosity in the small intestine and those that are fermentable in the colon (e.g., certain cereal fibers such as those from oats, barley, and rye).

Consumption of some viscous fibers may slow gastric emptying and, in the small intestine, act as a barrier to access by digestive enzymes to starches, oligosaccharides, and disaccharides (107, 108). The viscous solution also acts as a physical barrier that slows the rate at which glucose

TABLE 2 Strength of available evidence for breakfast and glucose/insulin response[1]

	Breakfast consumption vs. skipping	Protein level comparisons	Fiber level comparisons	Glycemic index comparisons	Fat level comparisons
Acute effects					
Quality	Fair	Fair	Good	Good	Fair
Consistency	Fair	Fair	Fair	Good	Fair
Quantity	Fair	Fair	Good	Good	Fair
Clinical impact	Fair	Fair	Fair	Good	Fair
Generalizability	Fair	Good	Good	Good	Good
Overall	Fair	Fair	Good	Good	Fair
Second and later meal effects					
Quality	Good	Limited	Fair	Good	Fair
Consistency	Good	Limited	Fair	Fair	Limited
Quantity	Limited	Limited	Limited	Limited	Limited
Clinical impact	Good	Limited	Fair	Fair	Limited
Generalizability	Good	Limited	Good	Good	Fair
Overall	Good	Limited	Fair	Fair-Good	Limited

[1] Based on the Academy of Nutrition and Dietetics Evidence Analysis Manual (76).

molecules reach the intestinal brush border for absorption (109). The net result is that the ingestion of a sufficient quantity of viscous fiber with a meal will slow the rate of glucose absorption, thus lowering the GI of the meal and reducing the insulin response required to dispose of the absorbed glucose (25, 26, 105, 109, 110). Fibers with high viscosity include guar gum, pectin, psyllium, and β-glucan. In a randomized crossover study conducted by Kim et al. (44), obese women with an elevated risk of insulin resistance were given 5 breakfast cereal test meals containing wheat and/or barley to provide various levels of β-glucan. Consumption of 10 g β-glucan at breakfast significantly reduced peak postprandial glucose response compared with 0, 2.5, and 5 g doses, and increasing amounts of β-glucan reduced the postprandial insulin AUC in a dose-dependent manner (44). In a chronic feeding intervention (12 wk), men and women with elevated blood pressure who were randomly assigned to consume foods containing oat β-glucan demonstrated greater reductions from baseline in mean peak insulin concentration and postprandial incremental insulin AUC compared with the control group (111). Moreover, although the β-glucan intervention acutely lowered the postprandial incremental insulin AUC, further reduction was observed after the 12-wk intervention, suggesting that the effects of oat β-glucan were enhanced after chronic consumption. The potentiation of the acute effect of β-glucan to reduce postprandial insulinemia may be secondary to enhanced insulin sensitivity resulting from colonic fermentation (111–113).

Inclusion of fermentable fibers at breakfast may mitigate T2DM risk through the production of SCFAs that act on specific receptors (G protein–coupled receptor 43/free fatty acid receptor 2) in adipose tissue to lower the release of FFAs from adipose depots (114). In healthy subjects, experimentally increasing (with a lipid infusion) or reducing (with the drug acipimox) FFAs for several hours will reduce or increase insulin sensitivity, respectively (115, 116). Feeding studies in healthy humans consuming fermentable resistant starch have demonstrated enhanced insulin sensitivity in as little as 24 h (117), which appears to be maintained after longer periods of intake (118, 119).

Consuming breakfast, compared with skipping breakfast, appears to reduce postprandial glycemia without affecting insulinemia after a standard lunch meal (13–15, 73). Breakfast skipping is associated with a prolongation of the elevated concentration of FFAs observed during fasting. Thus, breakfast skippers have elevated concentrations of FFAs throughout the morning hours compared with breakfast consumers, and this is associated with relative insulin resistance, which manifests as an elevated glycemic response to a lunch meal.

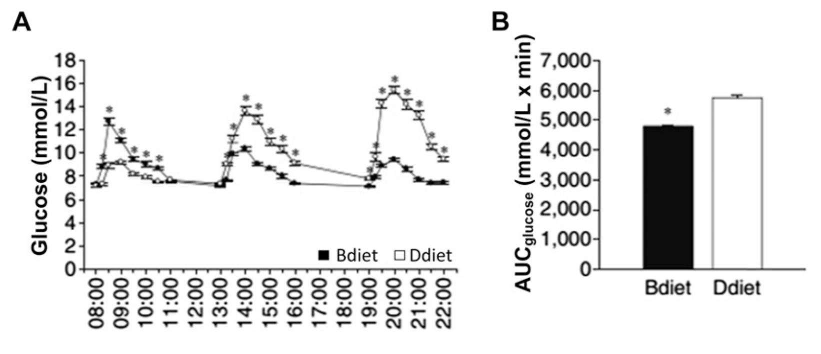

FIGURE 2 Differential effects of high-energy breakfast compared with high-energy dinner on blood glucose over the course of the day in individuals with type 2 diabetes mellitus. Glucose (A) and AUC for glucose (B). Bdiet—breakfast: 2946 kJ; lunch: 2523 kJ; dinner: 858 kJ. Ddiet—breakfast: 858 kJ; lunch: 2523 kJ; dinner: 2946 kJ. Values are means ± SEMs, $n = 18$; $*P < 0.05$. Bdiet, high-energy breakfast and reduced-energy dinner; Ddiet, higher-energy dinner and reduced-energy breakfast. Adapted from reference 87 with permission.

The "second meal effect" refers to the ability of one meal to alter the glucose and/or insulin responses to carbohydrates consumed at the following meal. With regard to breakfast type, low-GI and high-fermentable–fiber breakfasts appear to provide the greatest potential for reducing glycemic and/or insulinemic responses after a lunch meal (27, 28, 45, 54–56, 74, 75). The second meal effect may be driven, at least in part, by the effects of consuming fermentable carbohydrates on FFA concentrations after a breakfast meal. Consumption of fermentable fibers at breakfast reduces FFA concentrations throughout the morning and produces relative insulin sensitivity, resulting in lower glycemia and/or insulinemia after a standard lunch meal (27, 28, 45, 56). It should be noted that one challenge of summarizing the available literature is that a wide range of dietary fiber types has been used across breakfast intervention studies, each having unique physical/chemical properties and thus potentially producing different metabolic effects.

Protein at Breakfast

Protein at breakfast may induce beneficial metabolic effects through several mechanisms, including the displacement of rapidly available carbohydrate and high GI/GL foods from the meal, increased satiety, and greater diet-induced thermogenesis compared with carbohydrates (120). Dietary protein, when partially substituted for rapidly available carbohydrate, has been demonstrated to produce favorable changes to blood lipids and blood pressure in controlled feeding trials in humans (121, 122). In a recent randomized controlled crossover trial of overweight premenopausal women conducted by Rains et al. (123), postprandial glucose and insulin excursions were lower, and visual analog scale ratings of fullness (satiety) were higher after the provision of breakfast meals that included 30 or 39 g of dietary protein than with a low-protein (3 g), higher-carbohydrate meal. Protein displaced carbohydrates in the test meals, markedly lowering glucose and insulin responses. Longer-term substitution of 10% of dietary carbohydrates with protein has also been shown to lower circulating concentrations of TGs, as well as blood pressure (121). Many dairy products have a high protein content, and data from observational studies show an inverse association between dairy intake and the risk of metabolic syndrome and T2DM (124–126). However, in a study completed by our group, increasing dairy product consumption had a neutral effect on determinants of glucose tolerance (insulin sensitivity index and pancreatic β cell function) relative to subjects' habitual diets in subjects selected for having an elevated risk of the development of T2DM (127). An additional study by Turner et al. (128) showed lower insulin sensitivity after 4 wk of consuming a dairy diet than with a low-dairy control diet in women, but not in men. Thus, additional research is needed to assess whether dairy product consumption has advantages over other protein sources as a substitution for rapidly available sources of dietary carbohydrate.

Fats at Breakfast

Very little information is available regarding the role of dietary fats when consumed as part of the breakfast meal on carbohydrate metabolism. The majority of available randomized controlled trials, however, have demonstrated a favorable effect on the postprandial glucose response with higher- compared with lower-fat–containing breakfast meals (46, 67–69, 72). Findings from a meta-analysis of cohort studies (103) showed that increased vegetable fat consumption was associated with a significantly decreased risk of T2DM. Moreover, controlled feeding studies have shown that partial substitution of rapidly available carbohydrate with UFAs in the diet is associated with enhanced insulin sensitivity, as well as favorable changes in lipids and blood pressure (121, 122). The Mediterranean dietary pattern, characteristically rich in UFAs, has been associated with a decreased T2DM risk in both controlled feeding studies and observational investigations (129–131).

Conclusions

Epidemiologic research has shown associations between frequent breakfast consumption and a decreased risk of T2DM and metabolic syndrome compared with breakfast skipping or infrequent breakfast consumption (10). These associations have prompted interest in the assessment of the effects of breakfast consumption, as well as breakfast composition, on metabolic outcomes in randomized controlled trials. After a thorough review of the available literature, we concluded that breakfast consumption compared with breakfast skipping has favorable effects on indexes of carbohydrate metabolism and is associated with a lower T2DM risk. Results from a number of studies suggest that insulin sensitivity is higher in the morning than in the afternoon or evening, suggesting that consumption of carbohydrates at breakfast may produce lower demand on the pancreatic β cells than the same quantity and quality of carbohydrates consumed at other times of the day.

Excessive consumption of rapidly available carbohydrate may have adverse effects on carbohydrate homeostasis and T2DM risk. Potential options for partial replacement of rapidly available carbohydrate include slowly digested carbohydrates, dietary fibers, fats, and proteins. At this time, replacement of rapidly available carbohydrate with low-GI types of carbohydrates (especially whole grains rich in viscous and cereal fibers) at breakfast has the most evidence to support use as a dietary strategy for improving metabolic wellness. Displacement of rapidly available carbohydrate with UFAs and proteins also shows promise as a way to improve the metabolic profile.

It is not yet clear to what degree breakfast consumption per se is responsible for the observed relations between eating breakfast and favorable metabolic outcomes compared with other factors that may also influence metabolic risk, such as the effects of high-cereal-fiber foods consumed at breakfast. Additional research is needed to clarify these issues and to assess the impact of the types and quantities of fats and proteins consumed at breakfast. Finally, future investigation should provide greater insights on possible effect modification by variables such as sex, health status (e.g., insulin sensitivity and glucose tolerance), and behaviors (e.g., exercise/physical activity) on the relation between breakfast consumption, breakfast composition, and metabolic outcomes.

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