Sugar Alcohols and Diabetes: A Review

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ABSTRACT

Many foods sweetened with sugar alcohols (also known as polyols), such as isomalt, lactitol, maltitol, mannitol, sorbitol and xylitol, are available today. Because of concerns about possible harmful effects, we reviewed government regulations and scientific literature on sugar alcohols. Although some sugar alcohols do not raise plasma glucose (PG), no long-term benefits regarding their ingestion have been established for people with diabetes. Replacing carbohydrates with sugar alcohols in foods may alter diet composition and adequacy. Since sugar alcohols are only partially digested and metabolized, intakes >10 to 20 g/day may cause flatulence, diarrhea and other gastrointestinal (GI) symptoms. Individuals relying on product label information to assist in carbohydrate counting could overestimate the amount of insulin required for a carbohydrate load. Further research is required to understand the health effects of sugar alcohols. In the meantime, it is recommended that the use of products containing large amounts of sugar alcohols be approached with caution and discussed with healthcare professionals on an individual basis.

RÉSUMÉ

De nombreux aliments sucrés aux alcools de sucre (aussi appelés polyols) tels le sorbitol, le xylitol, le maltitol, le lactitol et l'isomalt, sont sur le marché. En raison de craintes sur les effets néfastes possibles des alcools de sucre, nous avons passé en revue les règlements gouvernementaux et la documentation scientifique à leur sujet. Certains alcools de sucre n'augmentent pas la concentration plasmatique de glucose, mais on n'a pas décelé de bienfaits à long terme chez les personnes atteintes de diabète. Le remplacement des glucides dans les aliments par des alcools de sucre peut modifier la composition du régime alimentaire et la rendre inadéquate. Puisque les alcools de sucre ne sont que partiellement digérés et métabolisés, un apport supérieur à 10 à 20 g/jour peut causer flatulence, diarrhée et autres symptômes gastro-intestinaux. Les personnes qui se fient aux renseignements qui figurent sur les étiquettes pour calculer leur apport de glucides pourraient surestimer la quantité d'insuline nécessaire pour une charge en glucides donnée. Chez les personnes atteintes de diabète, la consommation d'aliments contenant de grandes quantités d'alcools de sucre commande la prudence et une discussion à ce sujet avec un professionnel de la santé s'impose.

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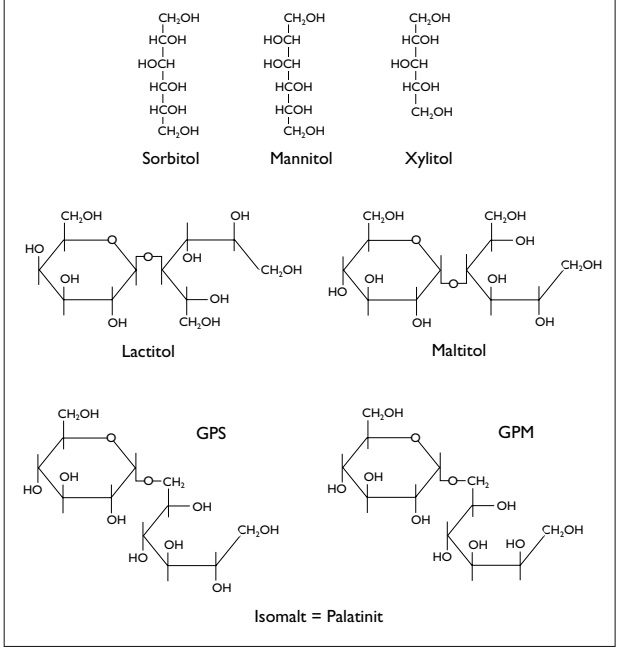
INTRODUCTION

Products sweetened with sugar alcohols (also known as polyols) are appearing on the market more frequently and are often targetted toward people with diabetes. With food labelling regulations currently under review, Health Canada approached the National Nutrition Committee (NNC) of the Canadian Diabetes Association (CDA) to seek its current position on the use of sugar alcohols. In preparing a response, the NNC reviewed existing government regulations and scientific literature on the metabolism, absorption and gastrointestinal (GI) symptoms associated with the use of sugar alcohols. The NNC's purpose was to fully understand the role and effects of sugar alcohols in the diets of people with diabetes, paying special attention to possible harmful effects, to develop a scientifically valid CDA position on the use of sugar alcohols.

DEFINITION OF SUGAR ALCOHOLS

Sugar alcohols are chemically defined as saccharide derivatives in which a ketone or aldehyde group is replaced by a hydroxyl group (1). They are classified according to the number of saccharide units present in the molecule (Figure 1). Sorbitol, mannitol and xylitol are monosaccharides derived from glucose, mannose and xylose, respectively. They are naturally present in small amounts in some fruits and vegetables and are commercially produced by hydrogenation of glucose, mannose and xylose. Maltitol and lactitol are disaccharides derived from hydrogenation of maltose and lactose, respectively. Isomalt (also known as palatinit) is a 1:1 mixture of alpha-D-glucopyranosyl-[1-6]-D-sorbitol (GPS) and alpha-D-glucopyranosyl-[1-6]-D-mannitol (GPM) (Figure 1). Oligo- and polysaccharide sugar alcohols are derived from hydrogenated starch hydrolysates (HSHs) (2), although these compounds are often not included in discussions about sugar alcohols (1,3).

Figure 1. Structures of common sugar alcohols



GPM = alpha-D-glucopyranosyl-[1-6]-D-mannitol
GPS = alpha-D-glucopyranosyl-[1-6]-D-sorbitol

Digestion, absorption and metabolism

After ingestion, lactitol, maltitol and isomalt are first hydrolyzed by intestinal disaccharidases to their monosaccharide components, glucose, fructose and/or sorbitol. The monosaccharides are then absorbed by passive diffusion. Sorbitol absorption may be enhanced if glucose is present, as in a mixed meal or resulting from maltitol hydrolysis (4).

Sugar alcohols are only partially absorbed from the human small intestine. The percentage of absorption varies with each sugar alcohol, ranging from 0% for lactitol to nearly 80% for sorbitol (Table 1) (5-8). Sugar alcohols that are not absorbed from the small intestine reach the colon, where they are fermented by colonic bacteria to produce the short-chain fatty acids acetic, propionic and butyric acids, as well as gases such as hydrogen and methane (9,10). Short-chain fatty acids are absorbed and provide energy to the body, the reason why even lactitol, which is completely malabsorbed in the small intestine, has an energy value of approximately 2 kcal/g (1 kcal=1 Cal) (Table 2) (11). The gases produced can cause such GI symptoms as flatulence, abdominal cramping, abdominal bloating and diarrhea, which have been reported in subjects without diabetes (12,13) and those with diabetes (14).

Sugar alcohols are incompletely metabolized in humans. For example, it has been shown that 10 to 20% of ingested sorbitol and xylitol and 30 to 40% of ingested mannitol, were recovered in the urine (15).

Sugar alcohols are metabolized in humans in an insulin-independent fashion (16) and have little or no effect on plasma glucose (PG). After oral administration of lactitol or xylitol, there is little or no change in glucose or lipid oxidation (17), presumably due to their low absorption and incomplete metabolism, suggesting that these sugar alcohols do not provide carbohydrate to the body for metabolism. However, the glucose moiety of maltitol is absorbed and provides carbohydrate to the body for metabolism. In a study conducted by Felber and colleagues, carbohydrate oxidation increased and lipid oxidation decreased after normal subjects consumed 30 g of maltitol, although the magnitude of these effects was smaller than that observed after consumption of 30 g of sucrose (18).

Neither intravenous (IV) nor oral administration of sorbitol, lactitol or xylitol in normal subjects resulted in any appreciable rise in PG or insulin (16,17,19). Similarly, in subjects with diabetes, neither xylitol nor sorbitol caused any acute rise in PG (19-21). However, maltitol, which is hydrolyzed to sorbitol and glucose before absorption, elicited small glucose and insulin responses in normal subjects. The glycemic response after maltitol administration was approximately 25% of that observed after administration of

an equal amount of glucose (22) and 55% of that after an equal amount of sucrose (18). In normal subjects and subjects with type 2 diabetes, an HSH containing 78% hydrogenated malto-oligosaccharides elicited a lower glycemic response than did glucose, but a higher glycemic response than an HSH containing 60% maltitol (2). This may reflect the fact that more glucose is absorbed after consumption of hydrogenated malto-oligosaccharides than after maltitol. The difference in glycemic response between the 2 forms of HSHs was not observed in 6 subjects with type 1 diabetes (2). It is not known if this effect was due to a lack of experimental power, or if it reflects a true difference in metabolism between patients with type 1 and type 2 diabetes.

Sugar alcohols and GI symptoms

The frequency and severity of GI symptoms increase as the amount of sugar alcohol consumed increases (23,24) and are also related to the source of sugar alcohol consumed. In 1 study, significantly more GI symptoms were reported after consumption of milk chocolate sweetened with lactitol vs. isomalt, and after consumption of isomalt vs. maltitol (23).

GI symptoms after consumption of sorbitol were found to be more severe in subjects who were low methane producers compared to high methane producers (25). The likelihood of sorbitol causing symptoms due to gas production is similar in people with or without diabetes (14). When subjects with diabetes and without diabetes consumed 10 and 20 g of sorbitol dissolved in water, few experienced discomfort after 10 g of sorbitol, and abdominal discomfort and distension were observed in only one-third of subjects after 20-g loads (14). These results led the authors to suggest that sorbitol was unlikely to play a role in inducing diarrhea in people with diabetes and that an intake of ≤10 g was not contraindicated in people with type 2 diabetes (14).

The GI response to sugar alcohols may depend on the composition of the meal in which they are consumed, as their absorption may be altered by the presence of other nutrients (8). Furthermore, the presence of sugar alcohols in a meal has been shown to result in malabsorption of other energy nutrients, such as fat and carbohydrate, in addition to the sugar alcohol itself (5). These factors may increase or decrease the likelihood or severity of GI symptoms after consumption of foods containing sugar alcohols. There is also a potential for the occurrence of severe GI symptoms when sugar alcohols in dietetic foods interact with drugs taken to inhibit the digestion of fat (e.g. orlistat [Xenical®]) or carbohydrate (e.g. acarbose [Prandase®]), which may be used by people with diabetes to control weight or PG.

Table 1. Absorption of sugar alcohols from the human small intestine (adapted from references 5-8)

Compound	*% absorbed*
Isomalt	50–60%
Lactitol	0%
Maltitol	≈50–75%
Mannitol	50%
Sorbitol	≈50–79%
Xylitol	50%

Table 2. Energy values for sugar alcohols and related carbohydrates for labelling purposes (adapted from reference 11)

Sugar alcohol	*Energy value (kcal/g)*
HSH	3.2
Isomalt	2.0
Lactitol	2.0
Maltitol	3.0
Mannitol	1.6
Polydextrose	1.0
Sorbitol	2.6
Xylitol	3.0*

*The value for xylitol is tentative
HSH = hydrogenated starch hydrolysate

SUGAR ALCOHOLS IN FOOD PRODUCTS

Until recently, the use of sugar alcohols in manufactured foods was limited mainly to their presence in small amounts in candy and chewing gum, foods that also have few calories. However, high-calorie products sweetened with sugar alcohols, such as chocolates, cookies and ice cream, are coming to the market. Many of these products contain much larger amounts of sugar alcohols, often more than the 10 to 20 g/day previously considered safe. For example, an average 50-g maltitol-sweetened chocolate bar, with a total carbohydrate content of 23.2 g, contains 21.6 g of maltitol; a 40-g serving of sucrose-free fudge contains 30 g of carbohydrate, with 11 g of fructose and 18 g of isomalt; 15 mL of a no-sugar-added grape spread contains 15 g of carbohydrate as sorbitol. Other foods containing sugar alcohols are listed in Table 3. It is easily possible to consume well in excess of 20 g of sugar alcohols at one time, e.g. by choosing 1 no-sugar-added chocolate bar or 2 no-sugar-added cookies.

HEALTH CLAIMS FOR SUGAR ALCOHOLS

Some people may believe that products sweetened with sugar alcohols allow for more variety in food choices and, hence, increased quality of life for people with diabetes. However, there is no evidence that sugar alcohol-sweetened products have any benefit on long-term glycemic control in people with diabetes. In addition, they may be higher in fat and calories and are often higher in cost.

Dental caries

It is well established that chewing gums sweetened with sugar alcohols do not cause dental caries (26) and may reduce the risk

of developing dental caries (27). Use of these chewing gums by people with diabetes is of no concern because of the small amount of sugar alcohols and energy obtained from them.

Weight management

The rationale behind the use of sugar alcohol-sweetened products for weight management is that they reduce both the energy and sugar contents of confectionery. However, the reduction in energy content is not large, and the evidence that sugar causes obesity is unconvincing. Table 2 shows the energy content of sugar alcohols as outlined by Health Canada (11). Most sugar alcohols have an energy content 1.0 to 2.0 kcal/g less than sucrose or other carbohydrates, and since tolerance for sugar alcohol intake is limited, their impact on overall energy balance is likely to be, at most, approximately 20 to 40 kcal/day. This would be a useful reduction if it occurred, but it assumes that the replacement of sucrose with sugar alcohols is associated with no change in the intake of all other nutrients. There is no evidence that no-sugar-added products sweetened with sugar alcohols are effective in reducing overall energy intake or promoting weight maintenance.

The popular notion that sugar causes weight gain has been reinforced by recent studies showing that consumption of regular, sugar-sweetened soft drinks increases the risk of obesity in children (28). However, the evidence that a high intake of sugars as a percentage of energy is related to obesity is not strong (29), and in most studies, a high intake of sugars was associated with a low prevalence of obesity (30-36). A recent clinical trial showed that advice to reduce fat intake is more effective for successful weight management than is advice to reduce sugar intake (37). Overweight subjects who consumed a diet low in fat but high in simple carbohydrates for 6 months lost statistically significant amounts of weight (0.9 kg) and body fat (1.3 kg). These amounts were not significantly different from those lost by subjects who consumed a diet low in fat and low in simple carbohydrates (weight loss: 1.8 kg, loss of body fat: 1.8 kg). In contrast, a group of subjects who consumed a high-fat, typical Western diet gained 0.8 kg of weight and 0.6 kg of body fat.

Excessive energy intake in any form leads to weight gain, and ingestion of energy-dense foods, whether high in fat or carbohydrate, promotes overconsumption (38). Many sugar alcohol-sweetened foods are high in fat and energy dense. However, because they are labelled "sugar-free," such products may be perceived as being healthy, which may promote excessive use. Such a phenomenon has been observed with products labelled "low in fat." A recent study showed that subjects consumed less energy from low-fat yogurt than from regular yogurt when they did not know which yogurt was which; however, when the products were identified as regular or low in fat, subjects consumed more energy from the low-fat yogurt (39).

Table 3. Nutrition information for sample products containing sugar alcohols

					Carbohydrate		
	Serving size	**Energy (kcal)**	**Fat (g)**	**Protein (g)**	**Total (g)**	**Fibre (g)**	**Sugar alcohol (g)**
No-sugar-added vanilla ice cream	1 scoop (50 g)	95	5.0	1.5	11.2	0.3	5.9 (m)
No-sugar-added strawberry ice cream	125 mL (73 g)	80	0.9	2.6	19.0	0	9.0 (p: 4.5, s: 4.5)
No-sugar-added caramel candy	1 piece (10 g)	33	0.8	0.5	6.0	0	5.0 (HSH)
No-sugar-added wafer cookie	1 cookie (20 g)	69	2.6	0.9	13.1	0.2	5.6 (m: 5.3, s: 0.3)
No-sugar-added candy cane	2 candies (6.7 g)	12.5*	0	0	6.5	0	6.5 (i)
No-sugar-added chocolate bar	1 bar (35 g)	197	12.6	2.2	18.6	2.1	15.8 (l)
No-sugar-added chocolate wafer bars	3 bars (47 g)	196	14.0	2.9	28.0	0.3	21.7 (i: 20.0, p: 1.7)

*The expected energy value of this product (4 kcal/g carbohydrate) is 26 kcal, but is declared here at a lower value (2 kcal/g for isomalt)

HSH = hydrogenated starch hydrolysate
i = isomalt
l = lactitol
m = maltitol
p = polydextrose
s = sorbitol

PG control

The PG-raising potential of most products containing sugar alcohols has not been established; however, research suggests that the glycemic effect of sugar alcohols depends on the type of sugar alcohol and on the nature of the food into which it is incorporated. Sorbitol, lactitol and xylitol do not raise PG (17,19,21); however, maltitol and HSHs have demonstrated a modest effect on PG (2,22). In fact, chocolate sweetened with maltitol elicited the same PG response in normal subjects as did chocolate sweetened with sucrose (40). Foods sweetened with sugar alcohols contain other ingredients that may affect acute glycemic response and long-term glycemic control. The long-term effects of sugar alcohols or products containing sugar alcohols on overall PG control in people with diabetes is not known.

Another concern related to PG control is the potential for hypoglycemia. If people with type 1 diabetes base their preprandial insulin dose primarily on the amount of carbohydrate consumed, they may inject too much insulin prior to consumption of a snack or meal containing predominantly sugar alcohols, which may result in an unexpected hypoglycemic episode. This is of particular concern because of the following recent recommendation by the American Diabetes Association (ADA): "With regard to the glycemic effects of carbohydrates, the total amount of carbohydrate in meals or snacks is more important than the source or type" (41). This recommendation carries a lot of weight, because it is reported to be based on level A evidence. However, the recommendation could be interpreted to imply that the source of carbohydrate can be ignored when calculating the insulin dose. There are few studies on the effects of sugar alcohols in people with type 1 diabetes (2,21) and none that address the issue of adjusting insulin dose. Therefore, the authors recommend caution for people with type 1 diabetes who may require less insulin prior to consumption of foods containing substantial amounts of sugar alcohols.

Nutritional composition

The effect of using foods sweetened with sugar alcohols on food intake is not known, but it is possible that their use may alter the composition or nutritional adequacy of the diet. Consumption of sugar induces satiety by a variety of mechanisms, leading to a reduction in energy intake at a subsequent meal (42). It is not known if sugar alcohols induce satiety; however, beverages sweetened with non-nutritive sweeteners provide no satiety and do not reduce intake at subsequent meals (43). Therefore, if sugar intake is reduced through the use of a non-nutritive sweetener, intake of other foods will increase to compensate for the reduction in energy from sugar. If the compensatory energy comes from the mixture of fat, protein and carbohydrate found in the remainder of the diet, the result of using non-nutritive sweeteners will be a diet containing less energy from carbohydrate and more from fat than if a sugar-sweetened product had been used (43). This is consistent with studies demonstrating that intakes of sugars and fat as a percentage of energy are strongly inversely related to each other, i.e. low sugar intakes are associated with high fat intakes (44). The effects of sugar alcohols on appetite regulation and food intake require elucidation.

SUGAR ALCOHOLS AND NUTRITION LABELLING

Sugar alcohols are often used to replace sucrose in products, either alone or in combination with fructose and/or other sugar alcohols, and are labelled as either "no sucrose added" or "no added sugars." In the United States (US), products labelled "sugar-free" contain less than 0.5 g of sugars per serving but may contain sugar alcohols and are not required to be low in calories (45). This is very different from Canadian regulations, where the "sugar-free" label is restricted to "foods for special dietary use" and is defined as "a carbohydrate-reduced food that, when ready to serve, contains: ≤0.25% available carbohydrate; and ≤1 kcal/100 g or 100 mL (except chewing gum)" (11).

Health Canada regulations

For labelling purposes in Canada, carbohydrates include mono- and disaccharides, sugar alcohols, polydextrose, starch and dietary fibre. All are expressed in grams per stated serving size and are rounded to the nearest whole number for quantities ≥10 g or to the nearest 0.1 g for quantities <10 g. The declaration of 1 carbohydrate component does not trigger the declaration of any other carbohydrate components. The label of a food containing 1 or more sugar alcohols or polydextrose must declare the specific name and amount of each in grams per stated serving size in the list of ingredients, in a list in immediate proximity to the list of ingredients or in the nutrition panel. When sugar alcohols are deemed to be naturally occurring in products, manufacturers are not required to label their presence.

Food labels of products containing sugar alcohols can be confusing. Manufacturers may declare energy values for sugar alcohols at either the average level for carbohydrates (i.e. 4 kcal/g) or at a lower level according to the energy values for each sugar alcohol based on their absorption and metabolism, as provided in the *Guide to Food Labelling and Advertising* (Table 2) (11). These energy values are only estimates based on studies in man and animals (primarily pigs and rats). The absorption and metabolism of sugar alcohols may differ not only between different individuals but also within the same individual under different circumstances (e.g. meal composition, metabolic state of the individual, prior exposure to sugar alcohols) (46). The energy values ascribed to sugar alcohols may differ geographically, as some countries have chosen to average the values. Because of these lowered energy-value claims, manufacturers may assert, for example, that their candies have "less than half the calories of regular candies" (Table 3). Dietitians and knowledgeable

consumers expect 8 g of carbohydrate to have an energy value of 32 kcal and may be confused by a listing of only 16 kcal in a product sweetened with isomalt, since most people do not know the energy values for the individual sugar alcohols. There also may be confusion in individuals who are using the carbohydrate counting method of controlling food intake about how much insulin to use for the amount of carbohydrate shown on the food label.

CDA Food Choice Values

The CDA's current approach to assigning Food Choice Values for foods containing sugar alcohols is that for products containing <2.5 g of sugar alcohols (sorbitol, mannitol, maltitol, isomalt, xylitol and lactitol), the sugar alcohols are assigned as "extras." For foods containing 2.5 to 5 g of sugar alcohols, the sugar alcohol content is assigned as ½ a "sugars" choice. Food Choice Values are not assigned to products that contain >5 g of sugar alcohols per serving. Sugar alcohols, including polydextrose, are calculated at their reduced energy values instead of at 4 kcal/g due to the individual differences in the absorption and metabolism of these carbohydrates and their ultimate effect on PG.

CONCLUSION

The rationale for using sugar alcohols is based on the perceived benefit that they do not raise PG in the short-term. However, no long-term benefits have been established for sugar alcohol-containing foods, and their use may be associated with a number of potential side effects. Replacing carbohydrates in foods with sugar alcohols may alter the composition or nutritional adequacy of the diet and result in loss of other nutrients. Intake of sugar alcohols of >10 to 20 g/day may be associated with flatulence, diarrhea and other GI symptoms due to increased colonic fermentation, as they are not digested or metabolized to the same extent as the usual dietary sugars. In addition, individuals who use product labels to count carbohydrates could potentially overestimate the amount of insulin to use for a carbohydrate load. Complicating this issue is a lack of consistent labelling, both nationally and internationally, for products containing sugar alcohols.

Further research is required to gain a true picture of the health effects of sugar alcohols. In the meantime, it is recommended that the use of products containing large amounts of sugar alcohols be approached with caution and discussed with healthcare professionals on an individual basis. Furthermore, healthcare professionals should lobby for clearer labelling of products containing sugar alcohols so that people with diabetes will not be confused or misled regarding the amount and types of carbohydrates in their foods.

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