Sucrose Versus Saccharin as an Added Sweetener in Non-insulin-dependent Diabetes: Short- and Medium-term Metabolic Effects

P. L. Cooper, M. L. Wahlqvist, R. W. Simpson

Medical Research Centre, Prince Henry's Hospital, Melbourne, Australia

Seventeen non-insulin-dependent diabetic patients were randomly allocated to their usual diet supplemented daily with either 28 g sucrose or 30 g starch (isoenergetic with sucrose) and saccharin (equivalent sweetness). After 6 weeks, the supplements were reversed. No significant treatment effects were observed on fasting concentrations of blood glucose, plasma insulin or serum triglycerides, or on urinary excretion of glucose, sodium or potassium. Following a standard breakfast with either sucrose or saccharin and starch, no differences between meal responses were observed. This study demonstrates no medium-term metabolic contraindications to including a moderate amount of sucrose in the diets of patients with non-insulin-dependent diabetes mellitus.

KEY WORDS Diabetic diet Sucrose Saccharin Blood glucose control Insulin Lipids

Introduction

The use of sucrose has been restricted in the diets of most diabetic patients on the premise that it causes rapid rises in blood glucose levels.[1] Sucrose has also been implicated in the development or exacerbation of hypertriglyceridaemia[2] and hypertension.[3] The non-nutritive sweetener, saccharin, is a frequently suggested sucrose-substitute for use in the diabetic diet. However, to 25 to 33 % of the population, it has a bitter aftertaste and is therefore unsatisfactory.[4]

In the short-term studies which have compared the isoenergetic exchange of sucrose and starch in diabetic patients there have been no differences in glucose and insulin responses between test meals.[5,6] In a recent medium-term study, Chantelau *et al.* have shown that moderate dietary intake of sucrose does not affect metabolic control in pump-treated insulin-dependent diabetic outpatients.[7] Similarly, in a study of both insulin-dependent and non-insulin-dependent diabetic patients, Peterson *et al.* failed to observe any metabolic effects of the isoenergetic substitution of 45 g sucrose for complex carbohydrate when the background diet was low in fat and high in fibre.[8]

The effects of using moderate amounts of sucrose as a sweetener for non-insulin-dependent diabetic patients who are consuming their usual 'diabetic diets' at home are unknown. The aim of this study was to compare both the short- and medium-term metabolic effects of sucrose supplementation with those of saccharin and starch supplementation in non-insulin-dependent diabetic outpatients.

Patients and Methods

Patients

Seventeen non-insulin-dependent diabetic volunteers (11 females, 6 males) were studied, aged 62.2 ± 14.0 ($\pm$SD) years and with a BMI of 26.0 ± 3.0 kg m^{-2}. Fasting blood glucose was 8.9 ± 2.8 mmol l^{-1}. The investigations were performed in accordance with the principles of the Declaration of Helsinki and were approved by the Research Advisory and Ethics Committee of Prince Henry's Hospital. None of the patients was in renal failure and none suffered any acute illness for more than 1 week of the study or during the last week of each dietary period. Ten patients were taking sulphonylureas and 1 subject was also taking a biguanide. Three patients were taking antihypertensive medication and two patients were on diuretics. All drug therapy remained constant throughout the study.

Diets and Meals

The usual dietary prescription in use at the time of the study was high carbohydrate (50 % of energy) and low fat 30 % of energy). However, the composition of most patients' diets tended to reflect past principles of dietary management, namely low carbohydrate ($\leq$40 % energy) and high fat ($\geq$40 % energy).

The usual diet of each patient was supplemented daily with either 28 g sucrose (sucrose diet) or saccharin and

Correspondence to: P. L. Cooper, Department of Nutrition, St Vincent's Hospital, Victoria Parade, Fitzroy, Victoria, Australia, 3065.

676 0742–3071/88/070676–05 $05.00

Accepted 13 June 1988
DIABETIC MEDICINE, 1988; **5:** 676–680

Table 1. Metabolic and blood pressure control in 17 patients with Type 2 diabetes at the three stages of the study

	Pre-study	Sucrose diet	Saccharin diet
Weight (kg)	69.1 (65.4–72.8)	69.3 (65.2–72.9)	68.9 (64.9–72.7)
Fasting blood glucose ($mmol\ l^{-1}$)	8.9 (7.5–10.2)	9.2 (7.9–10.7)	8.9 (7.4–10.4)
Fasting plasma insulin ($mU\ l^{-1}$)	14.4 (10.9–17.8)	16.5 (12.7–20.2)	17.3 (13.9–20.6)
Glycosylated haemoglobin (%)	8.1 (7.3–8.9)	6.8 (6.2–7.3)[a]	8.0 (7.5–8.5)
Glucose excretion ($mmol\ 24\text{-}h^{-1}$)	91 (0–197)	121 (0–266)	117 (0–251)
Fasting triglycerides ($mmol\ l^{-1}$)	2.0 (1.6–2.4)	2.0 (1.6–2.5)	2.0 (1.6–2.5)
Fasting total cholesterol ($mmol\ l^{-1}$)	6.2 (5.7–6.7)	5.8 (5.4–6.2)[b]	5.8 (5.3–6.3)[b]
Fasting LDL cholesterol ($mmol\ l^{-1}$)	4.10 (3.64–4.56)	3.75 (3.32–4.12)[b]	3.78 (3.32–4.24)[b]
Fasting HDL cholesterol ($mmol\ l^{-1}$)	1.10 (0.91–1.27)	1.08 (0.92–1.24)	1.06 (0.90–1.22)
Systolic blood pressure	139 (131–146)	131 (125–138)[b]	132 (126–138)[b]
Diastolic blood pressure (mmHg)	81 (77–86)	76 (72–80)[b]	75 (70–80)[b]
Na^+ excretion ($mmol\ 24\text{-}h^{-1}$)	164 (133–196)	131 (107–155)	144 (116–172)
K^+ excretion ($mmol\ 24\text{-}h^{-1}$)	64 (53–75)	61 (51–71)	58 (46–68)

Mean (95 % confidence limits).
[a]Significantly lower than pre-study ($p < 0.01$).
[b]Significantly lower than pre-study ($p < 0.05$).

starch (saccharin diet). The saccharin and starch supplements were equivalent to about 28 g sucrose in sweetness and energy, respectively. Since adherence to usual diet was an important condition of this study, it was strongly emphasized that there should be no change in usual eating pattern, other than by the addition of the supplements. Food records were kept throughout the study and no variation in eating patterns was detected.

The sucrose content of the background diet was estimated using food composition tables and ranged from 5 to 45 g. This estimation included added sucrose, sucrose in manufactured foods, and naturally occurring sucrose, and indicates how strictly these patients were adhering to their dietary guidelines. It is nevertheless recognized that these estimations may be unreliable.

The supplements were divided amongst each of three main meals and in the case of sucrose, an evening supper. The usual foods to which the supplements were added were hot beverages, fruit juice, milk, cereals, and stewed fruit.

The test meals consisted of a standard breakfast (cereal, whole milk, wholemeal bread, polyunsaturated margarine, and tea, coffee or water) to which either 8 g sucrose or 1 saccharin tablet plus 10 g cornflour were added. The test meals provided 1.5 MJ (15 % protein, 33 % fat, 52 % carbohydrate, 3.3 g fibre). The sucrose supplement was the sole source of sucrose in the test meal and it represented 8.2 % of total meal energy.

Study Protocol

The study was of cross-over design and patients were randomly allocated to each 6-week dietary sequence (11 sucrose diet first and 6 saccharin diet first). Patients were visited weekly for delivery of supplements, weight recording, and encouragement of compliance. At the beginning and end of each dietary period they visited hospital on two consecutive mornings for metabolic assessment with the test meals given in random order.

For test meals, patients were fasted overnight and rested throughout the experimental procedure. Two baseline fasting blood samples were taken at −10 and 0 min and at regular intervals (over 3 h) after consumption of the test meal. All meal studies commenced between 0830 and 1000 h. The time taken for meal consumption was kept constant for each patient and ranged between 8 and 15 min.

Systolic and diastolic blood pressures were recorded prior to each meal study using a blood pressure monitor (Critikon Dinamap, Critikon, Johnson and Johnson,

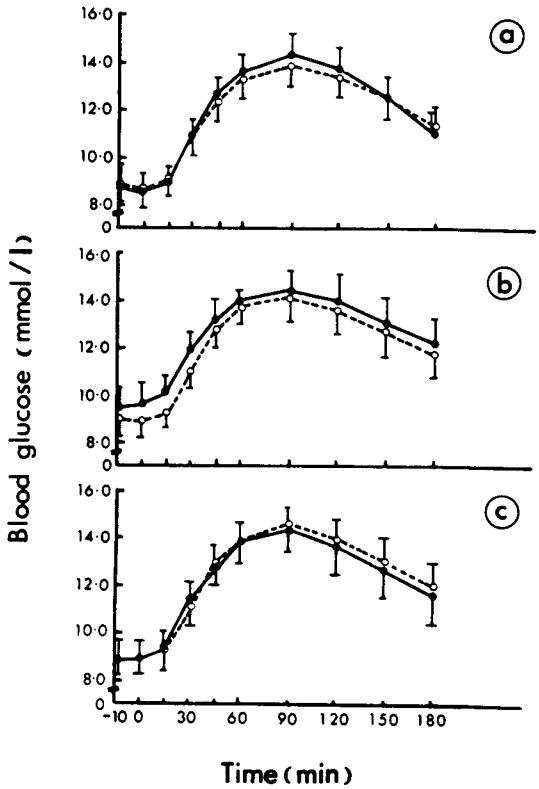

Figure 1. Blood glucose responses (± SE) to test meals at (a) the start of the study, (b) after the sucrose diet, and (c) after the saccharin diet. At each time two test meals were tested on different days, one with sucrose (●——●) and one with saccharin and starch (○- - -○)

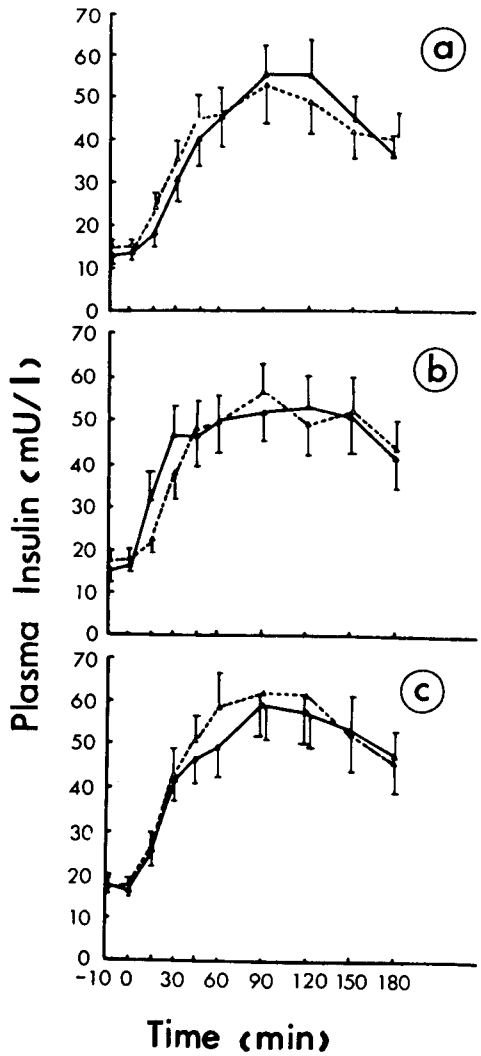

Figure 2. Plasma insulin responses to the test meals. Details as for Figure 1

Tampa, Florida, USA). Conditions were standardized so that each patient was fasting and had rested for 10 to 15 min. Consecutive minute readings were taken over 5 min and the mean of the last three readings was recorded.

Two 24-h urine collections were made by each patient on consecutive days, at the beginning of the study and at the end of each dietary period, before the test meal, for determination of sodium, potassium, and glucose excretion.

Analytical Techniques

Blood and urinary glucose were assayed on a Yellow Springs glucose analyser (Yellow Springs Instruments, Yellow Springs, Ohio, USA). Insulin was estimated by radioimmunoassay.[9] Serum lipids were estimated in fasting serum by established clinical assays, serum triglycerides by a glycerol kinase method (Human Diagnostica Kit, Human, Taunusstein, FRG), HDL cholesterol after separation by polyethyleneglycol 6000 precipitation of LDL and VLDL, and cholesterol estimated by a colorimetric method (enzymatic Boehringer CHOD-PAP (high performance) kit, Boehringer, Mannheim, FRG). LDL cholesterol was derived arithmetically from total cholesterol, serum triglycerides, and HDL cholesterol.[10] Glycosylated haemoglobin was determined by a commercial small column cation exchange chromatographic technique (Biorad Glycosylated (Fast Fraction) Hemaglobin Quik Column Kit, Biorad Laboratories, Clinical Division, Hercules, California, USA).

Statistical Analysis

All results were expressed as mean and 95 % confidence interval. Statistical comparison between different time points and different meals was by two-way analysis of variance.

Results

Neither the sucrose diet nor the saccharin diet resulted in a significant change in fasting concentration of blood glucose ($p > 0.25$), plasma insulin ($p > 0.10$), serum triglyceride ($p > 0.25$), or HDL cholesterol ($p > 0.25$) when

compared with pre-study levels (Table 1). Although fasting serum cholesterol was significantly lower after each diet ($p<0.05$), there was no significant difference in serum cholesterol between the two diets ($p>0.25$). Glycosylated haemoglobin was significantly lower after the sucrose diet ($p<0.01$), but not significantly different after the saccharin diet ($p>0.25$). There was no significant effect of either diet on the blood glucose or plasma insulin responses to the two test meals ($p>0.25$) (Figures 1 and 2).

Both systolic and diastolic blood pressures were significantly greater at the start of the study than after each diet ($p<0.05$), but there was no difference in blood pressure between diets ($p>0.25$). Neither diet significantly affected sodium ($p<0.10$), potassium ($p>0.25$) or glucose excretion ($p>0.10$).

Discussion

Many diabetic patients appear unwilling to do without added sweeteners[6,11] and it has been reported that adherence to the fat restriction now recommended for people with and without diabetes becomes increasingly difficult as sucrose is eliminated from the diet.[12] As discussed above, the commonly recommended sucrose alternative, saccharin, has major limitations.

In our study, the incremental areas of blood glucose and plasma insulin response after a test meal supplemented with sucrose (8 % of meal energy) and a test meal supplemented with saccharin and starch (8 % of meal energy) were similar. These findings are consistent with the recent observations in Type 2 diabetic patients that meals containing sucrose cause no greater rise in plasma glucose or insulin than do meals containing an isoenergetic amount of potato or wheat starch, or rice starch and saccharin.[5,6] It is noteworthy that both of these studies used cooked starch in the test meal, while in our study, the starch supplement was uncooked (raw) cornflour. Since uncooked starch is reported to cause a lower postprandial response than cooked starch,[13] the protocol of the present study might be biased towards bringing out any difference between the two test meals in favour of the saccharin supplementation.

Our finding that the sucrose content of the background diet had no effect on either blood glucose or plasma insulin responses to the two different test meals is consistent with earlier studies in non-diabetic subjects.[14,15] Although Reiser *et al.* reported that the insulin response to a sucrose load in normal subjects was always greater after a sucrose diet than after a saccharin diet, his study used considerably more sucrose.[16] Currently there are no other studies which have examined these aspects in people with diabetes.

Similarly, the sucrose content of the background diet did not significantly affect fasting levels of blood glucose or plasma insulin, a finding consistent with other studies in both diabetic patients[8,17] and normal subjects.[15,18] The observed lowering of glycosylated haemoglobin after the sucrose diet, but not after the saccharin diet, also suggests that the sucrose supplement had no detrimental effect on diabetic control.

Our finding that neither diet had any significant effect on fasting serum triglycerides is consistent with other studies in both diabetic patients[7,8,17] and normal subjects.[14,15,19,20] In contrast, there was a significant lowering of both fasting serum cholesterol and LDL cholesterol after both dietary periods compared with pre-study concentrations, but this finding is not attributable to the carbohydrate supplements. The observation that neither dietary period had any significant effect on fasting serum HDL cholesterol levels is consistent with the findings of other studies.[18,21]

Although substitution of starch with sucrose at moderate levels has been shown to elevate blood pressure in rats,[22] there was no difference between blood pressures after the two dietary periods in our study, and there are no other comparable studies in humans. The observation that blood pressure was higher at the beginning of the study can probably be explained by the general observation that subjects often take time to familiarize themselves with new surroundings.[23] There was no evidence that moderate sucrose supplementation affected urinary sodium or potassium excretion.

Acknowledgements

The authors are indebted to the patients who participated in this study for their general support and helpfulness. The technical assistance of L. Atley and the nursing assistance of B. Morieson and J. Honey are gratefully acknowledged. The authors also thank A. Saunders for artistic assistance and the Clinical Photography Department, St Vincent's Hospital. This work was generously supported by a grant from the Australian Sugar Industry in cooperation with CSR and Millaquin Sugar.

References

1. Nuttall RQ. Diet and the diabetic patient. *Diabetes Care* 1983; **6:** 197–207.
2. Nuttall FQ, Gannon MC. Sucrose and disease. *Diabetes Care* 1981; **4:** 305–310.
3. Ahrens RA. Sucrose, hypertension and heart disease: An historical perspective. *Am J Clin Nutr* 1974; **27:** 403–422.
4. Briggs DR. Food Additives. In: Wahlqvist ML, ed., *Food and Nutrition in Australia*. Sydney: Methuen, 1982: 121–130.
5. Bantle JP, Laine DC, Castle GW, Thomas JW, Hoogwerf BJ, Goetz FC. Postprandial glucose and insulin responses to meals containing different carbohydrates in normal and diabetic subjects. *N Engl J Med* 1983; **309:** 7–12.
6. Slama G, Jean-Joseph P, Goicolea I, *et al.* Sucrose taken during mixed meals has no additional hyperglycemic action over isocaloric amounts of starch in well-controlled diabetics. *Lancet* 1984; **ii:** 122–125.
7. Chantelau EA, Gösseringer G, Sonnenberg GE, Berger M. Moderate intake of sucrose does not impair metabolic

control in pump-treated diabetic out-patients. *Diabetologia* 1985: **28:** 204–207.
8. Peterson DB, Lambert J, Darling P, Carter RD, Jelfs R, Mann JI. Sucrose in the diet of diabetic patients—just another carbohydrate? *Diabetologia* 1986; **29:** 216–220.
9. Albano JDM, Ekins RP, Maritz G, Turner RC. A sensitive, precise radioimmunoassay of serum insulin relying on charcoal separation of bound and free hormone moietes. *Acta Endocrinol* 1972; **70:** 487–509.
10. Friedenwald WT, Levy RI, Frederickson DS. Estimation of the concentration of low density lipoprotein cholesterol in plasma without the use of the preparative centrifuge. *Clin Chem* 1972; **18:** 499–502.
11. Arvidsson Lenner R. Specially designed sweeteners and food for diabetics—a real need? *Am J Clin Nutr* 1976; **29:** 726–733.
12. Weinsier R, Seeman A, Herrera MG, Simmons JJ, Collins ME. Diet therapy of diabetes. Description of a successful methodologic approach to gaining diet adherence. *Diabetes* 1974; **23:** 669–673.
13. Collings P, Williams C, MacDonald I. Effects of cooking on serum glucose and insulin responses to starch. *Br Med J* 1981; **282:** 1032.
14. Dunningan MG, Fyfe T, McKiddie MT, Crosbie SM. The effects of isocaloric exchange of dietary starch and sucrose on glucose tolerance, plasma insulin and serum lipids in man. *Clin Sci* 1970; **38:** 1–9.
15. Mann JI, Truswell AS. Effects of isocaloric exchange of dietary sucrose and starch on fasting serum lipids, postprandial insulin secretion and alimentary lipaemia in human subjects. *Br J Nutr* 1972; **27:** 395–405.
16. Reiser S, Handler HB, Gardner LB, Hallfrisch JG, Michaelis OE, Prather ES. Isocaloric exchange of dietary starch and sucrose in humans. II: Effect on fasting blood glucose and on insulin and glucose response to a sucrose load. *Am J Clin Nutr* 1979; **32:** 2206–2216.
17. Jellish WS, Emanuele MA, Abraira C. Graded sucrose/carbohydrate diets in overtly hypertriglyceridemic diabetic patients. *Am J Med* 1984; **77:** 1015–1022.
18. Liu G, Coulston A, Hollenbeck C, Reaven G. The effect of sucrose content in high and low carbohydrate diets on plasma glucose, insulin and lipid responses in hypertriglyceridemic humans. *J Clin Endocrinol Metab* 1984; **59:** 636–642.
19. Keys A, Anderson JT, Grande F. Diet type (fats constant) and blood lipids in man. *J Nutr* 1960; **70:** 257–266.
20. Bossetti BM, Kocher LM, Moranz JF, Falko JM. The effects of physiologic amounts of simple sugars on lipoprotein, glucose and insulin levels in normal subjects. *Diabetes Care* 1984; **7:** 309–312.
21. Reiser S, Hallfrisch J, Michaelis OE, Lazar FL, Martin RE, Parther ES. Isocaloric exchange of dietary starch and sucrose in humans. I. Effects on levels of fasting blood lipids. *Am J Clin Nutr* 1979; **32:** 1659–1669.
22. Ahrens RA, Demuth P, Lee MK, Majkowski JW. Moderate sucrose ingestion and blood pressure in the rat. *J Nutr* 1980; **110:** 725–731.
23. Mancia G, Grassi G, Pomidossi G, *et al.* Effects of blood pressure measurement by the doctor on patient's blood pressure and heart rate. *Lancet* 1983; **ii:** 695–698.