The Long-Term Effects of Feeding Honey Compared with Sucrose and a Sugar-Free Diet on Weight Gain, Lipid Profiles, and DEXA Measurements in Rats

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ABSTRACT: To determine whether honey and sucrose would have differential effects on weight gain during long-term feeding, 45 2-mo-old Sprague Dawley rats were fed a powdered diet that was either sugar-free or contained 7.9% sucrose or 10% honey *ad libitum* for 52 wk (honey is 21% water). Weight gain was assessed every 1 to 2 wk and food intake was measured every 2 mo. At the completion of the study blood samples were removed for measurement of blood sugar (HbA1c) and a fasting lipid profile. DEXA analyses were then performed to determine body composition and bone mineral densities. Overall weight gain and body fat levels were significantly higher in sucrose-fed rats and similar for those fed honey or a sugar-free diet. HbA1c levels were significantly reduced, and HDL-cholesterol significantly increased, in honey-fed compared with rats fed sucrose or a sugar free diet, but no other differences in lipid profiles were found. No differences in bone mineral density were observed between honey- and sucrose-fed rats, although it was significantly increased in honey-fed rats compared with those fed the sugar-free diet.

Keywords: HDL-cholesterol, honey, obesity, sugars, weight gain

Introduction

Several aspects of health are known to deteriorate as a natural part of the aging process. However, many physiological disorders that can occur in later life, including obesity, cardiovascular disease, and diabetes, are influenced both by genetics and by factors that have accumulated over the span of a lifetime. Most age-related disorders have complex etiologies and are not due to a single factor. In particular, dietary choices often have a significant impact on disease development and progression, and recent evidence suggests that diseases such as obesity, diabetes, atherosclerosis, hyperlipidemia, insulin resistance, and cognitive deterioration can be influenced by long-term dietary changes.

Overwhelming research now shows that diets containing substantial amounts of high glycemic index (GI) foods may actually be detrimental to health because of prolonged or elevated postprandial hyperglycemia. Observational studies have suggested that diets with a high glycemic load (GI × carbohydrate content) are associated with increased risks of type 2 diabetes and cardiovascular disease (Brand-Miller 2003). Similarly, the DECODE study, a meta-analysis of more than 20 studies, has shown that increased rates of mortality and morbidity are associated with high blood glucose levels and high GI diets in both diabetic and nondiabetic patients (The DECODE Study Group 1999). In addition, links have been made between a high GI diet and atherosclerosis in nondiabetic subjects (Balkau and others 1998) as well as with colon (Francheschi and others 2001; Michaud and others 2005) and breast (Augustin and others 2001) cancers. Hyperglycemia has also been shown to correlate to the development of hyperinsulinemia (excess levels of circulating insulin in the blood) and insulin resistance (Augustin and others 2002).

Low GI foods are now being suggested as a replacement for high GI foods as they induce a lower glycemic response, and this is thought to equate to a lower insulin demand, better long-term blood glucose control, and a reduction in blood lipids (Brand-Miller 2003). Epidemiological evidence suggests that low GI diets may also decrease the risk of cardiovascular disease (Liu and others 2000; Stampfer and others 2000) as well as promote satiety (because of an increase in fiber content), minimize postprandial insulin secretion, and increase fat oxidation (Liljeberg and others 1999; Augustin and others 2002). Furthermore, recent studies have also shown that dietary carbohydrate content (particularly GI) may have a large impact on weight gain as the number of individuals who are overweight or obese in the United States has increased, despite the fact that fat intake has decreased during the last 20 y (Bell and Sears 2003). It has been suggested that this is likely to be due to the high GI component in the diet, as carbohydrates in the current American diet come primarily from sugars, refined starches, and grains (Bell and Sears 2003).

With the role that postprandial glycemia can have on disease etiology, much research has been undertaken comparing the differential blood sugar response to ingestion of glucose, fructose, and sucrose (Swan and others 1966; MacDonald and others 1978; Bohannon and others 1980; Reiser and others 1986; Shambaugh and others 1990). However, there appears to be little investigation into the use of other sugars as low GI alternatives. Honey is a naturally occurring sweetener that contains a mix of both simple and complex sugars, as well as vitamins, minerals, acids, and enzymes (Molan 1996). Limited clinical studies have demonstrated

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that honey has a lower GI than sucrose (Shambaugh and others 1990), and that honey, sucrose, and fructose do have differential effects on blood glucose levels (Samanta and others 1985; Al-Waili 2003, 2004). In addition, the beneficial effects of consuming honey are well established in the literature. These include improved antioxidant capacity (Taormina and others 2001; Gheldof and others 2003; Schramm and others 2003), enhanced gut motility (Ladas and Raptis 1999), enhanced cytokine production (Tonks and others 2003), and a prebiotic effect (Sanz and others 2005; Ezz El-Arab and others 2006). In addition, short-term feeding in rats has demonstrated that honey leads to less weight gain than sucrose after only 6 wk (Chepulis 2007).

This trial was therefore designed to ascertain what effect honey might have on weight gain, lipid profiles, and bone mineralization levels after long-term feeding, as compared with those fed a sucrose diet. A 3rd treatment group, fed a sugar-free diet, was also included in this trial as a control.

Materials and Methods

Experimental design

Fifty-five Sprague Dawley rats, aged approximately 8 wk at the start of the trial, were sourced from the small animal research facility at AgResearch, Hamilton, New Zealand. The trial was carried out in the Animal Behaviour Research Facility at Waikato Univ., Hamilton, New Zealand. The research room was maintained at 22 ± 1 °C with a 12 h reverse light/dark cycle (lights off 0700 hours). This study was approved by the Waikato Univ. Animal Ethics Committee.

Experimental diets

A honeydew honey (HD19) with a high antioxidant content (TEAC = 3.1 mmol/L) was chosen for use in this study. Three experimental diets were prepared to contain no sugar (diet nr 1), 7.9% sucrose (diet nr 2), or 10% honey (diet nr 3). All diets were prepared to contain a minimum of 5% water. An additional 21 mL of water was also added to each kilogram of the nonhoney diets to account for the fact that the honey contained 21% water (measured using a refractometer).

In this study, the diets were prepared such that they approximated the composition of a typical New Zealand diet. Based upon data from the 1997 Natl. Nutrition Survey (New Zealand Ministry of Health 1999), the diets were formulated so that of 100% total energy, 15% to16% came from protein, 35% came from fat, and 45% to 47% came from carbohydrate (CHO). In addition, skim milk powder (SMP; Fonterra Co-Operative Group Ltd., New Zealand) was added to the diets at a level of 8% of the total daily kilojoule intake. This level of SMP (8%) was chosen as it was equivalent to approximately 350 to 400 mL of milk or dairy in an average person's daily diet (assuming a total kJ intake of 11000 to 12000 per day). The SMP used in these diets had the following specifications: energy 1520 kJ/100 g, protein 36.1 g/100 g, and fat 0.8 g/100 g. A low-GI starch product (amylose) was used in the sugar-free diet as a replacement for the sucrose/honey rather than standard high-GI starch.

To enhance the possible levels of oxidative damage that may occur in these animals, the diets were prepared using used cooking oil rather than virgin oil as the source of fat. The cooking oil was sourced from various commercial kitchens in Palmerston North, New Zealand, and well mixed prior to inclusion in the diets.

Diets were prepared monthly and were kept in the dark at 4 °C or −15 °C for the duration of the study. Standard rodent vitamin and mineral mixes were prepared as described previously (Chepulis 2007); however, the mineral mix was modified to reflect the amounts of calcium (1.33 g/100 g) and phosphate (1.05 g/100 g) added to the diet from the SMP (cellulose was added instead to make up the final weight). The composition of the diets is given in Table 1.

Subsamples of the 3 diets were analyzed by the Nutrition Laboratory at Massey Univ., Palmerston North, New Zealand, for measurement of energy (bomb calorimetry). The percentage dry matter of these samples was determined monthly during the trial by drying preweighed samples (in triplicate) at 105 °C for 16 h.

Experimental procedures

Animals were weighed upon receipt, and the 5 smallest and 5 largest discarded from the trial. The remaining 45 animals were randomly allocated to 1 of 3 experimental diets and housed individually in standard rat cages with plastic bottoms and metal grid tops (final measurements 45 × 25 × 30 cm high). A 10- to 12-cm-long piece of 90-mm PVC tubing was placed into each cage to allow the animals a place to "hide." Enrichment devices (including small plastic containers, pegs, sticks, and pieces of doweling) were routinely added to the cages. Food jars containing the appropriate diet were placed into the respective cages and new diet added to the jars every 2 d so that food was available *ad libitum*. Water was freely available, and replaced twice weekly.

For assessment of food intake, the animals were removed from their home cages and placed into raised stainless steel cages that had 2 mm^2 mesh flooring. Numbered blotter papers were placed on shaving-filled trays beneath each cage to catch the spilled diet and feces and absorb the urine. The animals were allowed to acclimatize to the new cages for 4 d (animals had *ad libitum* access to their food and water but intake was not recorded) before beginning the food intake assessment. To assess food intake, food jars containing the appropriate diet were weighed and placed into each cage. New food was weighed and added to each food container daily for 7 d. On day 11, the food pots were removed and weighed. The blotter papers were allowed to dry at 25 °C for 3 to 4 d. Once dry, the spilled diet was scraped off the blotters, separated from the feces/hair and so on by passing through a 2-mm sieve and weighed.

All animals were weighed every 1 to 2 wk, and food intake was assessed every 2 mo (including the start of the trial).

Table 1—Composition of the experimental diets (g/kg).

Ingredient	Sugar-free diet	Sucrose diet	Honey diet
Skim milk powder[a]	95	95	95
Casein[b]	120	120	120
Used oil	160	160	160
Amylose[c]	79	—	—
Sucrose[d]	—	79	—
Honey	—	—	100
Cellulose[e]	50	50	50
Modified mineral mix[f]	50	50	50
Sugar-free vitamin mix[g]	5	5	5
Starch	365	365	365
Water (mL)	76	76	55

[a]Fonterra Co-Operative Group Ltd., New Zealand.
[b]80 mesh, New Zealand Milk Products.
[c]Davis Trading Co., Palmerston North, New Zealand.
[d]Sigma Chemical Co.
[e]Avicel PH102, Commercial Minerals Ltd., Auckland, New Zealand.
[f]A mixture supplying (g/kg diet) Ca 4.96, Cl 7.79, Mg 1.06, P 3.81, K 5.24, Na 1.97; (mg/kg diet) Cr 1.97, Cu 10.7, Fe 424, Mn 78.0, Zn 48.2; (μg/kg diet) Co 29.0, Mo 152, Se 151.
[g]A mixture supplying (mg/kg diet) retinol acetate 5.0, DL-α-tocopherol acetate 200.0, menadione 3.0, thiamin hydrochloride 5.0, riboflavin 7.0, pyridoxine hydrochloride 8.0, D-panothenic acid 20.0, folic acid 2.0, nicotinic acid 20.0, D-biotin 1.0, myo-inositol 200.0, choline chloride 1500; (μg/kg diet) ergocalciferol 25.0, cyanocobalamin 50.0.

Sample analyses

On days 364 and 365 (half of each treatment group on each day), the rats were anaesthetized using CO_2 gas. Each animal underwent a cervical dislocation before approximately 10 mL of blood was removed from the heart via cardiac puncture using 19-gauge needles. Approximately 3 mL of the removed blood was added to an EDTA blood collection tube and the remainder added to a standard vacutainer. These latter blood samples were allowed to clot before centrifuging at 3000 × *g* for 10 min and removing the serum (for fasting lipid profiles). Both the EDTA-collected blood and the serum were then analyzed at Waikato Hospital (Hamilton, New Zealand) using standard laboratory procedures for measurement of glycated hemoglobin (HbA1c) (HPLC Biomate Affinity column) and fasting lipid profiles (Roche Method using P800 Hitachi). The bodies were then stored at −18 °C for later analysis.

After approximately 3 wk in the freezer, 36 rat bodies (12 from each treatment) were sent to the Dept. of Nutrition and Health at Massey Univ., New Zealand, for DEXA analysis. Bone mineral measurements were taken using a fan beam Hologic QDR Discovery bone densitometer (Bedford, Mass., U.S.A.). A quality control (QC) scan of an anthropomorphic spine phantom was taken to ensure the unit's precision. The rat whole body was scanned using collimator size 10.24 × 0.10 with point resolution of 0.064 cm and 0.1512 cm line spacing. Regional high-resolution scans of the lumbar spine, right and left femurs were performed using 5.69 × 0.03 collimator. Point resolution and line spacing were 0.0311 cm. Rats were positioned supine with right angles between the spine and femur and between femur and tibia.

For the *ex vivo* scans the left femurs were stripped of extraneous tissue, leaving about 1 cm of flesh attached. These were submerged in a 1.5-cm-deep dish of PBS. Regional high-resolution scans of the left femurs were performed using 5.69 × 0.03 collimator. Point resolution and line spacing were 0.0311 cm.

Statistical analyses

A 1-way analysis of variance (ANOVA) was performed on all parameters to determine if there were statistical differences between the 3 dietary treatments. Where ANOVA was significant, post hoc tests using a Bonferroni correction were carried out to determine which groups differed. These results are presented below. All analyses were carried out using SPSS version 12 (SPSS, Chicago, Ill., U.S.A.).

Results

For reasons unrelated to diet (2 animals turned out to be female rather than male, and 2 animals died from a fall after escaping from their cages), 4 rats had to be excluded from the study, resulting in final numbers of 13 in the sugar-free group, 14 in the sucrose groups, and 14 in the honey group.

Weight gain and food intake

The results of this study (presented in Table 2) suggest that honey does affect weight gain in adult rats. Mean overall percentage weight gain in honey-fed rats was similar to that observed in rats fed a sugar-free diet, and was significantly reduced by 23.4% compared with those fed sucrose after 52 wk ($P = 0.015$). Overall percentage

Table 2—Endpoint data (mean ± SD) for rats fed diets that were either sugar-free, or contained 7.9% sucrose or 10% honey (honey is 21% water).

		Diet		
Result	Unit	Sugar-free (Diet nr 1)	Sucrose (Diet nr 2)	Honey (Diet nr 3)
Overall weight gain	%	102.5 ± 19.7†	130.6 ± 26.7*	107.2 ± 13.8†
Overall food intake[a,b]	g/7 w	1246.4 ± 85	1243.6 ± 111	1244.8 ± 89
Overall kilojoule intake	kJ/7 w	23182 ± 1580	23019 ± 2053	22730 ± 1620
Fecal output[b]	g/7w	131.4 ± 6.9	124.7 ± 12.6	133.1 ± 10.9
HbA1c	mmol/L	4.07 ± 0.17	4.19 ± 0.14	3.97 ± 0.12†
Total cholesterol	mmol/L	2.79 ± 0.45	2.98 ± 0.59	3.12 ± 0.37
LDL cholesterol	mmol/L	0.09 ± 0.09	0.10 ± 0.14	0.06 ± 0.14
HDL cholesterol	mmol/L	2.32 ± 0.33	2.44 ± 0.51	2.82 ± 0.30*†
Triglycerides	mmol/L	0.85 ± 0.24	0.96 ± 0.34	0.86 ± 0.33

*Significant ($P < 0.05$) compared with sugar-free diet. †Significant ($P < 0.05$) compared with sucrose diet.
‡Significant ($P < 0.05$) compared with honey diet.
HbA1c = glycated hemoglobin; HDL = high-density lipoprotein; LDL = low-density lipoprotein.
[a]Food intake corrected for percentage dry matter (determined by heating duplicate samples for 16 h at 105 °C).
[b]Data collected from the 7 wk of food intake assessment only.

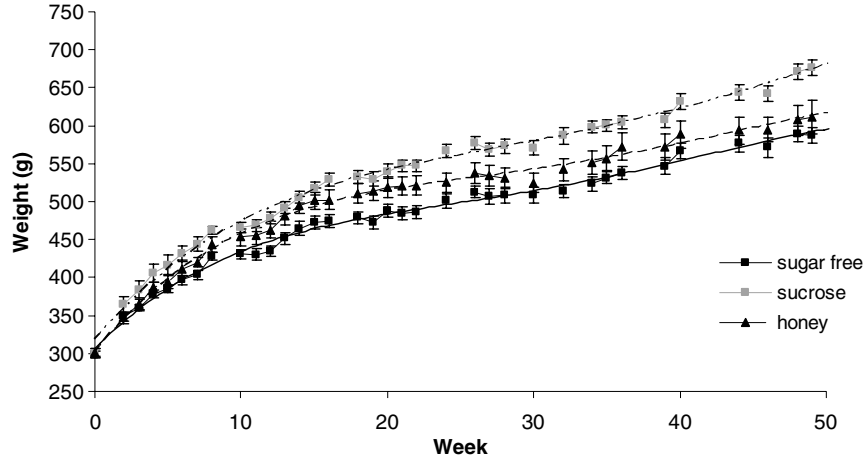

Figure 1—Actual mean weight gain (± SEM) for rats fed diets that were either sugar-free or contained 7.9% sucrose or 10% honey. All diets were formulated to contain equivalent amounts of honey/sugar/amylose and water (the honey was 21% water).

weight gain was also significantly reduced in rats fed the sugar-free diet compared with the sucrose-fed rats ($P = 0.004$). Figure 1 shows the overall percentage weight gain over the duration of the study.

Food intake was assessed during 7-wk-long periods, each measurement period being 2 mo apart. No differences were observed between treatments at any of these endpoints, or in the 7-wk actual or total kilojoule intake.

Blood sugar (HbA1c) and cholesterol levels

HbA1c levels were significantly lower in rats fed the honey diet compared with those fed the sucrose diet ($P = 0.001$), but there were no differences observed between the sucrose and sugar-free treatment groups (see Table 2). No differences in total cholesterol, LDL cholesterol, or triglyceride levels were observed after 52 wk of feeding between any of the respective treatments; however, HDL cholesterol was shown to be 16% to 21% higher in honey-fed rats than in those fed the sucrose ($P = 0.044$) or sugar-free ($P = 0.006$) diets.

DEXA scans

Full body scans by DEXA revealed a small number of differences in the body composition of the animals in the 3 dietary treatments (see Table 3). Lumbar spine area was greater in both sucrose- and honey-fed rats compared with those given a sugar-free diet (both $P < 0.05$); and whole body area ($P = 0.02$) and bone mineral composition ($P = 0.002$) were higher in rats fed sucrose compared with those given the sugar-free diet. Honey-fed rats exhibited a slight, but significant, increase in mean whole body bone mineral density (BMD) compared with those fed a sugar-free diet ($P = 0.009$).

Mean total percent body fat was higher in sucrose-fed rats (34.7%) than in honey-fed rats after 12 mo (25.5%; $P = 0.025$). No significant differences were observed between sucrose-fed rats and those given a sugar-free diet, although percentage body fat levels were similar for animals given honey and the sugar-free diet (26.5%).

Discussion

As the results from this study demonstrate, there do appear to be health benefits associated with consuming honey for a prolonged period of time. Weight gain was substantially reduced in honey-fed rats compared with those given a sucrose-based diet, and this agrees with the earlier work of Chepulis (2007) that showed that honey reduced weight gain compared with sucrose in short-term feeding. Importantly, these comparable data suggest that the weight regulating property of honey is not restricted to only young animals (animals were aged 6 to 12 wk in the earlier study) but instead may occur throughout the lifetime of the animal, regardless of the age of the individuals involved. In the earlier work (Chepulis 2007), however, reduced weight gain occurred in honey-fed rats even though the overall 6-wk food intake was significantly higher in these animals compared with those fed the sugar-free diet. In contrast, food intake in the current study appears to be similar for all treatments groups throughout the duration of the study. Food intake in the current study was assessed during 7-wk-long periods and not for the total duration of the study, as occurred in the earlier study. Due to the need to house the animals individually long term, it was not ethically viable to use food assessment cages for everyday housing. These cages are smaller than those required by the Waikato Univ. Ethics Committee, and as they have a mesh floor, they are unsuitable for long-term use. However, given the standard housing conditions used throughout the 12-mo period, it is unlikely that food intake would have varied between the 3 dietary treatments during the times that food intake was not measured. In the work by Chepulis (2007), food intake (and kilojoule intake) was significantly higher in the sucrose and honey groups compared with the sugar-free animals and it was suggested that this was due to the extra kilojoules provided by the honey or sugars in the diet. In the present study, however, kilojoule intake was the same for all 3 dietary treatments. This suggests that both the sugar-free and honey-based diets in the present study demonstrated a reduced weight gain/kJ compared with the sucrose-fed group.

It must be noted though that the sugar-free diet prepared in the current study was not entirely sugar-free as it contained nearly 10% SMP. SMP contains, on average, 52% lactose; therefore, even the sugar-free diet contained approximately 5% sugars by weight. This may have been sufficient to increase the sweetness of the diet, thereby improving palatability. An increase in palatability may account for why food intake was not reduced in rats fed the sugar-free diet in the current study, whereas it was in the trial presented by Chepulis (2007). However, a higher kilojoule intake should have led to more weight gain and clearly this was not seen in the animals

Table 3—Mean DEXA data (mean ± SD) for rats fed diets that were either sugar-free or contained 7.9% sucrose or 10% honey (honey is 21% water).

		Diet		
Result	Unit	Sugar-free (Diet nr 1)	Sucrose (Diet nr 2)	Honey (Diet nr 3)
Left femur				
Area	cm^2	1.94 ± 0.07	2.04 ± 0.11	2.07 ± 0.12*
BMC	g	0.59 ± 0.04	0.64 ± 0.07	0.65 ± 0.07
BMD	g/cm^2	0.30 ± 0.01	0.31 ± 0.02	0.31 ± 0.02
Right femur				
Area	cm^2	1.98 ± 0.13	2.02 ± 0.11	2.09 ± 0.07
BMC	g	0.60 ± 0.05	0.64 ± 0.07	0.65 ± 0.05
BMD	g/cm^2	0.30 ± 0.01	0.32 ± 0.02	0.31 ± 0.01
Lumbar spine				
Area	cm^2	2.67± 0.07	2.84 ± 0.14*	2.83 ± 0.15*
BMC	g	0.65± 0.04	0.71 ± 0.11	0.72 ± 0.07
BMD	g/cm^2	0.24 0.01	0.25 ± 0.03	0.25 ± 0.02
Whole body				
Area	cm^2	82.9 ± 5.3	90.1 ± 6.9*	85.1 ± 3.9
BMC	g	12.5 ± 0.6	14.4 ± 1.6*	13.7 ± 0.65
BMD	g/cm^2	0.15 ± 0.01	0.16 ± 0.01	0.16 ± 0.01*
Percent fat	%	26.5 ± 5.4	34.7 ± 9.1‡	25.5 ± 6.4†

*Significant ($P < 0.05$) compared with sugar-free diet. †significant ($P < 0.05$) compared with sucrose diet; ‡significant ($P < 0.05$) compared with honey diet.
BMC = bone mineral composition, BMD = bone mineral density.

fed the sugar-free diet. This suggests that differences in kilojoule intake are not solely responsible for the weight gains (or lack thereof) observed in this study.

Importantly, the 3 diets only differed in the content of the amylose, sucrose, and honey. Given that both amylose and honey are low GI ingredients, whereas sucrose is a high GI ingredient, these findings lend weight to the theory that glycemic index and the resultant blood sugar levels may be responsible for the reduced weight gain. These data are further supported by the finding that blood sugar (HbA1c) levels were indeed reduced in both sugar-free and honey-fed rats compared with sucrose-fed animals, although this difference did not reach significance for the animals fed the sugar-free diet. Glycated hemoglobin (HbA1c) is routinely used as a measure of long-term serum glucose regulation as it is easily quantifiable, with the hemoglobin occurring in large quantities in the blood. However, glycation is a nonenzymic, free-radical process, and the presence of antioxidants can reduce the frequency of this reaction, thereby reducing the amount of HbA1c present. The honey used in this study had a high antioxidant content and it is possible, therefore, that the antioxidant content of the honey, rather than its low GI properties, was responsible for the reduced HbA1c level detected in these animals. HbA1c levels were not reduced in honey-fed rats (nor in any of the other treatment groups) in the trial in Chepulis (2007), and it is difficult to explain why this is so, given that similar honeydew honeys with similar antioxidant contents (TEAC = 2.7 and 3.1) were used. It could be that the earlier trial simply did not run for a long enough period of time to be able to detect a difference (HbA1c is a marker of the level of hemoglobin glycation occurring over the previous 4 to 12 wk), or that other factors (either diet- or age-related) affected the level of glycation that occurred.

Certainly, the aforementioned results agree with the literature that low GI foods can improve weight regulation compared with their higher GI counterparts (Agus and others 2000; Spieth and others 2000; Dumesnil and others 2001; Brand-Miller and others 2002), and the World Health Organization has even issued an extensive report detailing the use of low GI foods as an appropriate way for preventing obesity (Joint FAO/WHO Expert Consultation 1998). However, it must be noted that fructose is metabolized through very different pathways to glucose, and the 2 sugars elicit very different hormonal responses after ingestion (Wylie-Rosett and others 2004). In particular, fructose consumption has been associated with increased lipogenesis and reduced satiety compared with glucose (Teff and others 2004), and it has been suggested that high levels of fructose intake may actually contribute to the obesity epidemic seen in Western populations rather than reduce it. Thus, the idea that honey-fed rats exhibit less weight gain than sucrose-fed rats simply because of differences in GI may not be entirely accurate. Unpublished work in our laboratory has shown that rats fed 60% honey exhibit weight gains that are lower than those fed an equivalent amount of mixed sugars (as in honey) and that weight gains are similar for animals given the sucrose and mixed sugars diets. This suggests that the difference in weight gain between sucrose- and honey-fed rats is not simply due to the different sugars present in the diet, but that other factors may be involved. As discussed in Chepulis (2007), the reduced weight gain seen in honey-fed rats may be due to the insulin-mimetic effects of hydrogen peroxide produced by the honey. No studies have been undertaken to assess whether hydrogen peroxide could reach sufficient levels *in vivo* to elicit such a response, although it warrants further investigation.

Interestingly, cholesterol parameters were also altered in this study, with honey-fed rats exhibiting HDL cholesterol levels that were 15% to 20% higher than those fed the sugar-free and sucrose diets. No other long-term feeding studies have investigated the effects of honey on lipid profiles; however, short-term animal feeding studies have shown no increases in HDL cholesterol levels, either compared with baseline levels or with other dietary treatments (Al-Waili 2004; Chepulis 2007). It is possible that the changes in HDL cholesterol observed in the present study occurred gradually over a prolonged period of time rather than occurring in only a few weeks. Research has shown that there is a strong link between high GI diets and low HDL cholesterol levels (Frost and others 1999; Luscombe and others 1999; Buyken and others 2001; Ford and Liu 2001; Liu and others 2001); thus, it is possible that the low GI of the honey diet may have contributed to the increase in HDL cholesterol levels. However, as HDL cholesterol levels were comparable between the low GI sugar-free diet and the high GI sucrose diet, it is unlikely that dietary GI played a significant role. Several factors have been reported to improve HDL cholesterol levels in humans, including aerobic exercise, weight loss, cessation of smoking, and supplements such as omega 3, monounsaturated fat, and nicotinic acid (Drexel 2006), although it is hard to see how any of these factors may be relevant to the current study, except maybe the weight loss. Van Gaal and others (1997) reported that a weight reduction of as little as 5% to 10% can significantly improve HDL cholesterol levels in overweight individuals. Similarly, several authors have reported specific improvements in HDL cholesterol levels in both men and women after 12 to 18 mo of weight-reducing diets (Wood and others 1991; Williams and others 1994; Wing and Jeffery 1995; Stefanick and others 1998). It is possible, therefore, that the increase in HDL cholesterol levels seen in honey-fed rats was directly related to the reduced levels of body weight compared with animals fed the sucrose diet. However, if the improvement in HDL cholesterol was purely due to reduced body fat levels, then animals fed the sugar-free diet should also have demonstrated increases in HDL cholesterol levels compared with sucrose-fed animals, and this did not occur. Thus, it would seem that there are other factors responsible for the improvement in HDL cholesterol levels observed in honey-fed rats.

It is important to note, though, that rodents are generally not an appropriate model to assess lipoprotein concentrations in blood as plasma lipid levels are only minimally affected by modifications of dietary fat and cholesterol compared with their response in humans (Hegsted 1975). Indeed, it has been suggested that guinea pigs may be a better model for cholesterol and lipoprotein metabolism (Fernandez 2001). However, the data reported in the present study were a part of a larger investigation that assessed the effects of honey, sucrose, and the sugar-free diet on cognition (Chepulis and Starkey 2007), and rats are a well-accepted model for behavioral endpoints (Ingram and others 1994; Benton and others 2003).

The finding that consuming honey increases HDL cholesterol levels is still a significant result though. In clinical trials, there have been strong associations seen between low HDL cholesterol levels and the increased risk of cardiovascular disease (Drexel 2006). Several large studies (Carlson and Rosenhammer 1988; Rubins and others 1999; Canner and others 2003) have also investigated the use of HDL-cholesterol-raising agents as a therapeutic strategy for improving cardiovascular outcomes in high-risk populations, and the findings have been impressive. The risk of death, myocardial infarction, stroke, or revascularization was reduced by up to 90% with only minimal improvements in HDL cholesterol levels. The ability to improve HDL cholesterol through simple dietary means is therefore a valuable tool, particularly in individuals that are high risk for the development of cardiovascular disease.

Few differences between treatments were found in the bone-related DEXA measurements performed in this study, and this agrees with unpublished work from our laboratory that honey does not improve bone calcium levels during normal feeding regimes. Certainly, no differences in any of the DEXA endpoints were observed between rats fed sucrose and honey, suggesting that the type of sugars ingested long term may have little impact on bone density or mineralization levels. No other long-term data are available for the effects of honey on bone density measures, but evidence suggests that long-term feeding of high sucrose diets can alter the calcium balance in humans (Lemann and others 1970; Thom and others 1978; Ericsson and others 1990) and negatively affect bone mineralization levels (Li and others 1990; Saffar and Markis 1992; Salem and others 1992). Such decreases in bone density and mineralization were not seen in sucrose-fed rats in the present study, but it may be that the levels of sugars were not high enough to induce reductions in bone strength and density (sugar levels in the aforementioned studies were up to 65%). In addition, the addition of SMP to the diets in this current study may have aided calcium absorption in all 3 dietary treatments due to the presence of casein and the possible formation of casein phosphopeptides in the gut.

Conclusions

Honey appears to have a number of health benefits associated with long-term feeding, including improved weight regulation and reduced blood glucose levels as well as increased HDL-cholesterol levels. These effects may result from differences in GI compared with sucrose and because of its antioxidant content, although other factors may also be involved. Honey may therefore be an effective replacement for sucrose in individuals who suffer from poor glycemic control or who are high risk for CHD.

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