Comparison of the Effects of a High-Fat and High-Carbohydrate Soup Delivered Orally and Intragastrically on Gastric Emptying, Appetite, and Eating Behaviour

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CECIL, J. E., J. FRANCIS AND N. W. READ. Comparison of the effects of a high-fat and high-carbohydrate soup delivered orally and intragastrically on gastric emptying, appetite, and eating behaviour. PHYSIOL BEHAV 67(2) 299–306, 1999.—To investigate the effects of fat and carbohydrate on appetite, food intake and gastric emptying with and without the influence of orosensory factors, a group of nine healthy, fasted male subjects took part in two separate paired experiments involving high-fat and high-carbohydrate radiolabelled soup preloads. In the first experiment subjects received direct intragastric isocaloric infusions of either a high-fat tomato soup or a high-carbohydrate tomato soup (400 kcal in 425 mL) over 15 min, on two occasions. In the second paired experiment subjects ingested the same high-fat and high-carbohydrate soup over 15 min. In both experiments ratings of hunger and fullness were recorded over a period of 135 min and gastric emptying was measured by scintigraphy. Food intake was evaluated from a test meal (yoghurt drink) given 2 h after the end of the soup infusion/ingestion. When soup was administered intragastrically (Experiment 1) both the high-fat and high-carbohydrate soup preloads suppressed appetite ratings from baseline, but there were no differences in ratings of hunger and fullness, food intake from the test meal, or rate of gastric emptying between the two soup preloads. When the same soups were ingested (Experiment 2), the high-fat soup suppressed hunger, induced fullness, and slowed gastric emptying more than the high-carbohydrate soup and also tended to be more effective at reducing energy intake from the test meal. The results of these studies demonstrate that orosensory stimulation plays an important role in appetite regulation, and also indicate that subtle differences in orosensory stimulation produced by particular nutrients may profoundly influence appetite and gastrointestinal responses. © 1999 Elsevier Science Inc.

AN understanding of the factors that control appetite and eating behaviour is often confounded by differences in experimental methodology. Studies using meal preloads, for example, often yield very different results when compared with studies in which macronutrients are infused directly into the gut. Research into the relative satiating efficiency of fat and carbohydrate, a concept reflecting the relative abilities of different nutrients to suppress hunger, induce fullness and decrease subsequent food intake (2,24), illustrates this controversy.

Data supporting the hypothesis that carbohydrate has a greater physiological satiating efficiency than fat were derived from experiments using meal preloads (3,10,29,31,35). For example, in humans, isocaloric preloads (approximately 300 kcal) high in carbohydrate (pasta) suppressed hunger, increased fullness, and reduced food intake from a test meal 2 h later, to a greater extent than preloads of food high in fat (cream cheese) (29). These results were replicated in a later study (31) in which different amounts of fat and carbohydrate were covertly incorporated into yoghurt preloads. In another meal preload study (10), a light breakfast (440 kcal) was supplemented with either 90 g carbohydrate (365 kcal) or 40 g fat (362 kcal), and it was found that a carbohydrate-supple-

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mented breakfast reduced hunger and energy intake at a test meal presented 4.5 h later compared with the control breakfast, whereas a fat-supplemented breakfast had no effect.

Other studies based on a meal preload design have failed to show any differences in the satiating efficiency of carbohydrate and fat (11,12,14,30). In addition, no difference was reported in caloric intake or ratings of hunger and fullness in humans following oral administration of isocaloric (283 kcal) liquid preloads of either pure carbohydrate or fat when the sensory properties of the liquid nutrients were eliminated by the use of nose clips and topical anaesthesia of the mouth (18). Similar results are observed when orosensory stimulation is eliminated by infusing nutrients directly into the gastrointestinal tract. When fat and carbohydrate were administered as rapid isocaloric infusions directly into the stomach (5,32) or into the small intestine (7) at a rate that matched the reported rate of nutrient delivery from the stomach (4), the data consistently fail to demonstrate any differences in the short-term effects of fat and carbohydrate on hunger, fullness, and energy intake from a test meal. Moreover, when isocaloric solutions of pure nutrients were infused into the duodenum in the presence of an intragastric balloon, fat and carbohydrate had similar effects on gastric relaxation and on the gastric volumes required to induce a sensation of fullness (13).

Thus, attempts to elucidate the relative satiating efficiency of fat and carbohydrate using oral preloads and direct intragastric infusions have produced equivocal data. In addition, there is a growing body of evidence indicating that the effects of oral feeding on processes such as gastric emptying (6,28), insulin release (33), and even growth rate (1) differ from those of intragastric feeding. In a recent study conducted in our laboratory, soup fed orally suppressed hunger, induced fullness, and slowed gastric emptying to a greater extent than the same soup infused intragastrically at the rate of ingestion (6). In the light of these findings, we hypothesised that reported differences in the relative satiating effects of fat and carbohydrate may be related to their differential effects on the influence of orosensory mechanisms, both directly and indirectly on physiological processes. Meals varying in composition are likely to provide different orosensory cues and may, in turn, induce different appetite and gastrointestinal responses. The objective of this study, therefore, was to investigate the satiating effects of isocaloric high-fat and high-carbohydrate preloads on appetite and eating behaviour administered as a direct intragastric infusion and as a normal meal, using a similar experimental design. The study was also designed to investigate how the different methods of delivery of macronutrients might affect gastric emptying.

SUBJECTS

Studies were carried out on nine healthy male subjects aged between 21 and 35 years, all of whom were within the normal range for BMI (22.3 ± 0.70, mean ± SE) (17). Subjects were nonsmokers, had no reported medical condition or illness, and were not restrained eaters (1.56 ± 0.34, mean ± SE) according to the Three-Factor Eating Questionnaire (34). Prior to taking part in the study all subjects were familiarised to the presence of a nasogastric tube on two separate occasions. Any subjects who found the procedures uncomfortable were excluded. Subjects also sampled both the high-fat and high-carbohydrate soup preloads prior to the study, and were trained to consume the soup at a specific rate (see below). Only those subjects who found the soups appetising and conformed to the required rate of soup consumption were asked to take part. Each subject gave written informed consent for the studies to be carried out and the protocol was approved by the Sheffield Health Authority Ethics Committee (Northern General Hospital).

MATERIALS AND METHODS

Experimental Design

Each subject took part in two experiments of similar design. Experiment 1 consisted of paired studies whereby subjects received either a high-fat or a high-carbohydrate soup as a rapid infusion directly into the stomach. Experiment 2 consisted of paired studies whereby the same subjects ingested the same high-fat and high-carbohydrate soup as a normal meal. In each experiment studies were separated by at least 3 days, and the order of the studies was randomised.

Protocol

In both experiments, on each of the 2 test days, the subject arrived at the Centre for Human Nutrition at 1000 h. He was then intubated with a polyvinyl nasogastric tube (8 FR., Merck Biomaterial, Hampshire, UK) until the infusion port was positioned in the stomach 55 cm from the nostrils, and sat upright against a posteriorly positioned gamma camera (1971 model 1201 Pho Gamma Scintillation Camera, Siemens).

Experiment 1. At 1100 h either the high-fat or the high-carbohydrate soup (labelled with 1.5 MBq 99Tc Technetium tin colloid, Amersham International, Buckinghamshire, UK; and heated to a temperature of 57°C) was infused directly into the stomach over a period of 15 min at a rate of 28.3 mL/min, matching the mean rate of ingestion measured in our subjects. Subjects were informed in a standardised manner that the infusate was tomato soup (“you are now being infused with tomato soup”), but were unaware of the fat/carbohydrate manipulation. At the end of the infusion the feeding tube was removed.

Experiment 2. At 1100 h subjects ingested either the high-fat or the high-carbohydrate soup (labelled as above) as a normal meal over a period of 15 min using a 10-mL spoon. At the end of the meal the feeding tube was removed.

During both experiments, and on each of the test days, ratings of hunger and fullness and gastric emptying were measured for a period of 135 min. At the end of this period, at 1315 h, subjects were offered a test meal consisting of a strawberry-flavoured yoghurt drink (Yoplait Dairy Crest Ltd., Telford, UK; energy density and macronutrient composition per 100 g: energy = 77 kcal, protein = 2.9 g, carbohydrate = 12.4 g, fat = 1.8 g), and invited to consume as much as they wanted. Hunger and fullness ratings were completed before and just after the test meal, and the amount of yoghurt drink consumed was assessed by weighing the drink before and after ingestion. A monocomponent liquid test meal was used in order to increase the sensitivity of the measurement of food intake (25), while avoiding the difficulties of interpretation that may be encountered by a more naturalistic multicomponent solid-liquid meal.

Composition of Soups

The high-fat and high-carbohydrate soup preloads were designed to incorporate as much supplementary fat and carbohydrate as possible, whilst minimising differences in sensory properties. Both soups had a caloric value of 400 kcal (425 mL). The high-fat soup consisted of 365 g Campbell’s cream of tomato soup (Campbell Grocery Products Limited,
UK), 37 g Safeway double cream (Safeway, Middlesex, UK), and 25 g water. This resulted in a high-fat soup containing 68.9% energy from fat, 27.4% energy from carbohydrate, and 2.8% energy from protein. The high-carbohydrate soup was achieved by adding 48 g malto-dextrin (Polycal Powder, Cow and Gate Nutricia Ltd., Wiltshire, UK) to 296 g Baxters cream of tomato soup (Baxters of Speyside Limited, Moray, Scotland) and to 81 g Campbells half-fat tomato soup (Campbell Grocery Products Limited, Norfolk, UK). This high-carbohydrate soup contained 19.7% energy from fat, 77.0% energy from carbohydrate, and 3.2% energy from protein. Subjects were unaware of the way in which the nutrient composition of the soups had been manipulated, although they perceived that the soups, when ingested, were different.

Measurement of Hunger and Fullness

During the test days subjects were asked to rate subjective feelings of hunger and fullness on 100-mm line visual analogue scales. Each visual analogue scale was anchored by the descriptors “not at all” and “extremely” on the far left and right-hand sides, respectively. Ratings were completed before and after the soup preload, and then every 30 min, over a period of 135 min until the study ended. In Experiment 2, subjects also rated pleasantness of soup and perceived caloric and fat and carbohydrate content on one occasion immediately after ingestion of the soup preload. In addition, subjects were asked to rate feelings of nausea, dizziness, and tiredness on similar visual analogue scales to serve as a distraction from the real aims of the study, and to monitor the subjects’ general well-being.

Measurement of Gastric Emptying

In both experiments, gastric emptying was measured by collecting sequential images of abdominal distribution of radioactivity at 1-min intervals for the first 20 min, 2-min intervals for the next 60 min, and at 5-min intervals thereafter for a further 55 min when visual inspection of the computer image revealed that almost all the label had left the stomach. A left lateral image was obtained by asking the subject to drink 200 mL water containing 1 MBq Tc Tm colloid (9). The images were stored on a dedicated microcomputer (R. M. Nimbus PC, Research Machines Ltd., Oxford, UK) for subsequent construction of emptying profiles.

On completion of the study, the data was replayed and a region of interest was defined using the integrated image of the stomach from the first few frames. Radioactive counts in that region were used to produce a profile of counts in the gastric region throughout the whole study. The counts were corrected for decay of the isotope and also corrected for tissue attenuation, caused by the variation in depth of the radiolabelled soup moving down the stomach from the more posterior aspect of the fundus to the more anterior aspect of the antrum, by reference to the left lateral image of the stomach (8). Gastric emptying data were analysed to determine the time ($t_{1/2}$) for 50% of the labelled soup to exit the stomach.

Statistical Analysis

Data were analysed using SPSS for windows v.6.0 (SPSS Inc., USA), and results are expressed as the mean ± SE. Statistical significance was set at $p < 0.05$. Repeated-measures analysis of variance (two-way ANOVA) was used to test for significant differences between groups of data for ratings of hunger, fullness, and feelings of well-being, using pressou ratings as covariates, and time of rating and condition as within-subject factors. A significant effect was followed by a post hoc $t$-test. Gastric emptying profiles were also analysed using repeated measures, two-way analysis of variance followed by $t$-tests. Volume of the test meal consumed (mL), and ratings for “pleasantness of soup,” “perceived caloric total,” “perceived fat content,” and “perceived carbohydrate content” (Experiment 2 only) were analysed using paired $t$-tests.

Pearson’s correlation coefficients ($r$) were calculated to ascertain relationships for each condition between mean gastric content and mean ratings of hunger and fullness. Regression analysis was carried out to find the line of best fit. This was achieved by regressing mean ratings of appetite on the percentage of gastric contents at each VAS time point. In a second part of the analysis, for each individual subject, slopes of regression of ratings of hunger and fullness on gastric contents were calculated. ANOVA followed by post hoc tests (Student–Newman–Keuls) were used to determine the best-fit function. Repeated-measures $t$-tests were used to determine whether there were any significant differences between the slopes of best-fit function across conditions.

RESULTS

Experiment I: Intragastric Infusion of High-Fat and High-Carbohydrate Soup

Hunger, fullness, and well-being ratings. Similar degrees of hunger and fullness were experienced at baseline ratings (Fig. 1a and b). Comparisons of the effects of the two intragastric soup preloads on hunger ratings revealed no significant effect of condition, $F(1, 8) = 0.01, p = 1.00$, or time, $F(4, 32) = 1.35, p = 0.273$, and no condition by time interaction, $F(4, 32) = 1.23, p = 0.319$. For fullness ratings, there was no effect of condition, $F(1, 8) = 1.46, p = 0.262$, but a significant decrease of fullness over time following the preloads, $F(4, 32) = 7.42, p < 0.001$. There was no condition by time interaction, $F(4, 32) = 0.55, p = 0.702$, on fullness ratings.

Mean scores for nausea, dizziness, and tiredness were low in all conditions and at all time points. Two-way ANOVA revealed there were no significant effects of infusion on nausea, dizziness, or tiredness ratings.

Gastric emptying. There was no significant difference in the gastric emptying profiles between the intragastric high-fat and high-carbohydrate soup preloads, $F(60, 480) = 0.57, p = 0.996$ (Fig. 2). There was no significant difference in mean half gastric emptying time (min) between the high-fat (70.4 ± 5.7) and high-carbohydrate soup (73.3 ± 6.1), $t_{50} = 0.47$, or in rate of gastric emptying (kcal/min) between the high-fat (3.0 ± 0.3) and high-carbohydrate (2.9 ± 0.2) soup at this time, $t_{88} = 0.37$.

Intake from test meal. There was no significant difference in intake (mL) from the test meal following the two soup preloads, $t_{88} = 0.992$. Mean intake from the test meal following the high-fat soup preload (861.2 ± 109.0) was similar to intake following the high-carbohydrate soup (860.7 ± 111.8).

Relationship between appetite ratings and gastric content. Correlations of mean ratings of hunger and fullness against mean gastric content showed that following intragastric administration of high-fat soup, fullness was significantly and directly correlated with gastric content ($r = -0.97, p = 0.006$; Fig. 3a), but hunger was not significantly correlated with gastric content ($r = -0.79, p = 0.108$; Fig. 3b). Similar results were obtained following intragastric administration of high-carbohydrate soup (fullness: $r = 0.90, p = 0.037$, Fig. 3a; hunger: $r = -0.79, p = 0.109$, Fig. 3b). Regression analysis
showed that cubic functions accounted for more of the variance than did other functions.

In the second part of the analysis, for each individual subject, slopes of regression of appetite ratings on gastric content were analysed to determine whether there were any significant differences in the slopes of regression between the conditions. Linear, quadratic, cubic, and exponential functions were fitted separately for individual subjects between hunger, fullness, and gastric content. ANOVA followed by post hoc tests showed that overall, cubic functions accounted for significantly ($p < 0.05$) more variance than did the linear and exponential models for both hunger and fullness in both the intragastric high-fat and high-carbohydrate conditions. There were no significant differences in regression lines of either hunger or fullness against gastric content between the conditions.

**Experiment 2: Oral Ingestion of High-Fat and High-Carbohydrate Soup**

**Hunger, fullness, and well-being ratings.** Ratings of hunger were suppressed following both soup preloads (Fig. 4a). Comparison of the effects of the different soup preloads revealed a significant effect of condition, $F(1, 8) = 8.92, p = 0.017$, and time, $F(4, 32) = 3.38, p = 0.021$, for hunger ratings, but no condition by time interaction, $F(4, 32) = 1.35, p = 0.272$. Post hoc tests revealed that the high-fat soup significantly reduced hunger compared with the high-carbohydrate soup immediately after the soup had been consumed, $t(8) = 0.015$, and then again at 60 min, $t(8) = 0.010$, and 90 min, $t(8) = 0.020$, min subsequent to that time.

Ratings of fullness were increased following both soup preloads (Fig. 4b). There were significant effects of condition, $F(1, 8) = 8.51, p = 0.019$, and time, $F(4, 32) = 8.00, p < 0.001$, for fullness ratings, but no condition by time interaction, $F(4, 32) = 1.47, p = 0.234$. Post hoc tests indicated that the high-fat soup significantly increased fullness compared with the high-carbohydrate soup 30 min after the end of the soup meal, $t(8) = 0.010$ and during the subsequent hour to that, $t(8) = 0.052, t(8) = 0.045$.

Analysis of “pleasantness of soup” ratings revealed that there was no significant difference between the rated “pleasantness” of the high-fat and the high-carbohydrate soup, $t(8) =$
0.314. There was no significant difference in rated total caloric value of the two soups, $t(8) = 0.107$, or in rated carbohydrate, $t(8) = 0.889$, or fat, $t(8) = 0.363$, content of the two soups (Table 1).

Mean scores for nausea, dizziness, and tiredness were low in all conditions and at all time points. Two-way ANOVA revealed there were no significant effects of infusion on nausea, dizziness, or tiredness ratings.

**Gastric emptying.** Gastric emptying profiles between the oral high-fat and high-carbohydrate soup preloads differed significantly, $F(60, 480) = 4.39, p < 0.001$ (Fig. 5). Examination of the gastric emptying profiles revealed that the high-carbohydrate soup emptied more rapidly from the stomach compared with the high-fat soup. There was a significant difference in mean half gastric emptying time (min) between the high-fat ($91.9 \pm 4.3$) and high-carbohydrate soup ($76.1 \pm 3.9$), $t(8) = 0.021$, and in rate of gastric emptying (kcal/min) between the high-fat ($2.2 \pm 0.1$) and high-carbohydrate ($2.7 \pm 0.2$), $t(8) = 0.040$, soup at this time.

FIG. 3. Best-fit functions between mean fullness (a) and hunger (b) ratings against gastric content following intragastrically delivered high-fat (— —) and high-carbohydrate (— -- —) soup preloads.

FIG. 4. The effects of orally delivered high-fat (●) and high-carbohydrate (○) soup on hunger (a) and fullness (b) ratings. Values expressed as mean ± SE ($n = 9$). *$p < 0.05$. 

FIG. 5.
Mean intake from the test meal. Mean intake from the test meal (mL) was lower following the high-fat soup preload (685.3 ± 92.8) than after the high-carbohydrate soup (776.3 ± 70.1), but this did not reach statistical significance, $t_{5(8)} = 0.032$, and cubic, $t_{4(6)} = 0.051$, coefficients. There were no significant differences in regression lines between conditions relating fullness to gastric content.

**Relationship between appetite ratings and gastric content.** Correlations of mean appetite ratings against mean gastric content showed that following oral administration of high-fat soup, fullness was significantly and directly correlated with gastric content ($r = 0.99$, $p = 0.002$; Fig. 6a) but there were no significant correlations between hunger and gastric content ($r = -0.70$, $p = 0.188$; Fig. 6b). Regression analysis showed that cubic functions accounted for more of the variance than did other functions.

### TABLE 1

**RATED PLEASANTNESS AND MACRONUTRIENT CONTENT OF THE ORAL HIGH FAT AND HIGH CARBOHYDRATE SOUP PRELOADS**

<table>
<thead>
<tr>
<th>Ratings: Oral Soup</th>
<th>High-Fat Soup</th>
<th>High-CHO Soup</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pleasantness</td>
<td>69.7 ± 4.7</td>
<td>71.7 ± 4.1</td>
</tr>
<tr>
<td>Caloric content</td>
<td>52.8 ± 7.4</td>
<td>43.1 ± 3.8</td>
</tr>
<tr>
<td>Carbohydrate content</td>
<td>47.4 ± 5.6</td>
<td>53.2 ± 7.4</td>
</tr>
<tr>
<td>Fat content</td>
<td>37.8 ± 8.6</td>
<td>36.1 ± 6.9</td>
</tr>
</tbody>
</table>

Values expressed as mean ± SE.

Previous studies using meal preloads have suggested that high-carbohydrate foods have a greater relative satiating efficiency than high-fat foods (10,35). This has been explained on the basis that carbohydrate stores, unlike fat stores, are finite, and satiation is triggered by hepatic oxidation of surplus macronutrient. Data from the first experiment show that when a high-fat or high-carbohydrate soup is infused directly into the stomach, there are no differences in ratings of hunger and fullness or in energy intake from the test meal between the different soups. These results confirm recent studies using direct intragastric infusions of pure nutrients (5,32), and suggest that reported differences in short-term satiating efficiency between fat and carbohydrate are not related to postabsorptive effects. Since the rate of delivery of energy to the small intestine is similar with the two infusions, the data also suggest that differences in gastrointestinal control of gastric emptying are not responsible for the reported greater satiating efficiency for carbohydrate.

When the high-fat and high-carbohydrate soups were ingested orally (Experiment 2), there was a significant difference in appetite ratings, but it was the high-fat soup that showed the greater satiating efficiency. These data are supported by measurement of energy intake from the test meal, which revealed an average 100 g reduction (although not significant) following the high-fat soup compared with the high-carbohydrate soup. Thus, our data fail to support the notion that carbohydrate is more satiating than fat when given orally, and might indicate that satiating efficiency does not depend on a particular macronutrient per se, but may depend more on the cognitive and or orosensory responses to the particular type of food. In our study, we chose a single variable preload in the form of a tomato soup. The different soups were designed to incorporate as much supplementary fat and carbohydrate as possible, while minimising differences in sensory properties and appearance. Although our subjects perceived that the soups were not identical, they rated soup pleasantness, caloric total, carbohydrate and fat content as no different. This might suggest that cognitive factors did not directly account for the differences in satiation, and instead may implicate orosensory factors. Cotton et al. (10) used very different meal preloads to elicit a greater satiating efficiency for carbohydrate. Their high-fat and high-carbohydrate breakfasts were based on orange juice, strawberry yoghurt, a scone with margarine and jam, and a hot beverage. Although their subjects reported no differences in pleasantness for most foods, the perceived fat and carbohydrate content was not evaluated and, therefore, it is not possible to eliminate the influence of cognitive factors on their results.
As well as inducing a greater effect on appetite, oral administration of the high-fat soup slows gastric emptying more than the high-carbohydrate soup. This would have the effect of prolonging gastric distension. Previous experiments have implicated gastric distension in the reduction of food intake (19), and we have recently shown, using a similar soup meal, that the influence of gastric distension on regulation of hunger and fullness was modulated by orosensory stimulation (6). Thus, the present study suggests that subtle differences in orosensory stimulation following oral administration of either high-fat and high-carbohydrate soups may also be responsible for the observed differences in gastric emptying. This notion is supported by the observation that there were no significant differences in gastric emptying or ratings of hunger and fullness when the same soups were infused into the stomach (Experiment 1), bypassing orosensory stimulation. The steeper slopes for the relationships between gastric content and ratings of hunger and fullness following oral administration of the high-fat soup compared with the high-carbohydrate soup suggest that hunger and fullness are not just simply related to the degree of gastric distension, but are, to some extent, independently influenced by orosensory stimulation. This impression is supported by close examination of Fig. 4a and b, which shows that hunger was already suppressed immediately and fullness increased 30 min after the soup had been ingested, but there was little difference in gastric emptying at these time points. Previous studies have indicated that there is a close relationship between fullness and antral distension (21), and that fat causes antral relaxation and an inverted intragastric distribution. It is possible, therefore, that antral relaxation following ingestion of the high-fat soup, and possibly mediated by cholecystokinin (CCK), might explain the steeper relationship between fullness and gastric content compared with ingestion of the high-carbohydrate soup. Unfortunately, neither intragastric distribution nor CCK were measured in these studies.

Although the experimental design precluded a direct statistical comparison of these data, it is important to note that the high-carbohydrate soup empties at a similar rate, whether ingested normally or given as a direct intragastric infusion. In contrast, the high-fat soup had a significantly slower rate of gastric emptying when given orally compared with intragastric administration. These results are supported by data on gastric emptying of pure nutrients in animal studies. In rats, gastric emptying of fat is slowed when fat is ingested, compared with when it is given as a direct intragastric infusion (23,27,28). In contrast, glucose empties at a similar rate when infused intragastrically or ingested (22). It is possible that our results and data on gastric emptying of fat in rats (23,27,28) might be explained by amplification of the release of CCK by orosensory mechanisms. CCK, released from the small intestine in response to ingested fat (20), is known to delay gastric emptying (26). Previous studies have shown that ingestion of a high-fat soup produces a greater release of CCK compared with a low-fat soup, and empties from the stomach more slowly (16). Moreover, in humans, modified sham feeding is associated with an increase in CCK release (36), while previous research in rats suggests that orosensory stimulation enhances the effects of CCK (15) on satiation and gastric emptying. Thus, in the present study, the orosensory stimulation produced by the high-fat soup may enhance the effect of CCK, which in turn may be responsible for both the observed delay in gastric emptying and changes in hunger and fullness.

In summary, these results suggest that orosensory factors play a key role in determining the relative satiating efficiency of fat and carbohydrate foods. Moreover, these differences are accompanied by corresponding differences in gastric emptying, which may or may not mediate the differences in satiation.

ACKNOWLEDGEMENTS

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