The role of dietary fiber in satiety, glucose, and insulin: studies with fruit and fruit juice


ABSTRACT Healthy volunteers ingested sugar-equivalent meals of oranges and orange juice and of grapes and grape juice. Satiety, assessed by two subjective scoring systems, was greater after whole fruit than after juice and the return of appetite was delayed. With oranges, as previously reported with apples, there was a significantly smaller insulin response to fruit than to juice and less postabsorptive fall in plasma glucose. With grapes, the insulin response to the whole fruit was, paradoxically, more than that to the juice, while postabsorptive glucose values were similar. The glucose in grapes appeared to be more insulinogenic than that in oranges and apples. Conversely, grape juice evoked less insulin than expected, possibly because its high osmolality delayed gastric emptying. However, diluting it did not increase its insulinogenicity. The plasma insulin and glucose responses to fruit appear to depend on the fiber as well as the glucose content of the fruit.

KEY WORDS Fiber, satiety, glucose, insulin

Introduction

Previous studies with whole apples and apple juice (1) suggested that the fiber present in fruit reduces the insulin response to the sugar within it and prevents rebound hypoglycemia. To test this hypothesis further and to determine whether the findings were reproducible with other fruits we have examined the plasma glucose and insulin responses to sugar-equivalent meals of oranges and orange juice and of grapes and grape juice in healthy volunteers. Anomalous findings with grapes and grape juice led us to examine the effects of diluting the grape juice. We have sought also to confirm the satiating effect of fruit fiber.

Subjects and Methods

Healthy volunteers (aged 20 to 43 yr) were recruited from departmental staff and medical students. All were within 12% of ideal body weight and had normal dentition. Before each test meal they abstained from alcohol for 24 h and fasted overnight. The grapes used for all the test meals were of a black Spanish (Napoleon) variety. Juice was made by crushing and pressing 8.6 kg of fruit with subsequent enzyme depectinization (Ultrazyme 100 10 mg/L). The fiber content of the grapes was estimated as the residue after extraction of macerated grape pulp with 75% absolute alcohol. By this method, fiber comprised 2.65% of whole grapes, the pips accounting for 1.29%, leaving a fiber content of 1.36% in the edible portion. On chemical analysis grapes contained 17.7 g/100 ml available carbohydrate (glucose 8.9%, fructose 8.8%) and the juice 18.6 g/100 ml (glucose 9.3%, fructose 9.3%). Test meals contained 60 g available carbohydrate (glucose 30 g and fructose 30 g) and were of two types: 339 g of grapes (whose pips were spat out) and 323 ml of grape juice, respectively.

In a subsequent series of experiments, the effect of diluting the grape juice was investigated. Test meals were again of two types: commercial grape juice adjusted to the same sugar composition as that used previously and juice diluted to an osmolality equal to that of the apple juice used in our previous study (1) (497 mosm/L). Addition of 5 g xylose as a nonmetabolized marker required that the usable sugar content of the test meals was not 60 g as previously, but 54 g (glucose 27 g, fructose 27 g) in order to maintain unchanged the osmolality and volume of the "standard" juice meal (1032 mosm/L and 323 ml, respectively). The volume of the diluted juice test meal was 670 ml and its osmolality 497 mosm/L.

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The oranges used were of a South African Navel variety, juice being obtained with a domestic orange reamer and then depectinized with enzyme. Fiber content of the fruit was estimated as the residue after alcohol extraction of macerated fruit, with an average value of 2.51% of edible portion (range 2.19 to 2.91). Analysis of the juice showed a total sugar content of 8.2 g/100 ml (glucose 2.3%, fructose 2.6%, and sucrose 3.3%). Analysis of the fruit showed a wide inter-fruit variation even between segments of the same fruit. Consequently, the sugar content of each orange used in the test meals was estimated immediately prior to ingestion by measuring the refractive index (degrees Zeiss) of drops of juice squeezed from three randomly selected segments. Conversion of the mean refractive index, with an appropriate correction for nonsugar solids into mean percentage total sugar allowed the actual weight of available sugar in that orange to be estimated and thus the required weight of fruit for each meal. In view of the low sugar content of the fruit, the available carbohydrate content of the test meals was reduced to avoid the meals being excessively large. The meals contained 50 g monosaccharide (glucose 12 g, fructose 15 g, monosaccharides in sucrose 23 g) and were again of two types—peeled, depithed oranges, mean weight 626 g (range 566 to 694 g), and 610 ml of orange juice.

In both orange and grape studies the fruit meal was consumed first because of the limited keeping properties of whole fruit, and the time taken for the meal was recorded. This was 18.6 ± SE 1.7 min for oranges and 19.0 ± 1.7 min for grapes. Each subject was required to consume the juice test meal gradually over the same number of minutes as has been taken to eat the fruit meal.

The interval between studies was usually less than 1 month and never greater than 2 months. In the grape/ grape juice study 10 subjects (5 male and 5 female) were studied. In the orange/orange juice study and in the comparison between standard and diluted grape juice the subjects were all male (10 and 9, respectively). Studies in women were always performed at the same point in the menstrual cycle.

The satiating capacity of the test meals was assessed using two scoring systems. In the first, subjects were shown a graduated scale with the words “painfully hungry” at one end (minus 10) and “full to nausea” at the other (plus 10) and asked to indicate how they felt in respect of hunger or satiety by pointing to an appropriate place along the scale (“scale score”). In the second system, subjects were shown a list of statements, numbered 1 to 9 (Table 1) and asked to choose the most appropriate one (“verbal score”). Hunger/satiety scores were recorded using both systems before each meal, immediately after it and at 60, 120, and 180 min after starting it. From these data curves were drawn to show the meal’s satiating effect.

Venous blood was collected via an indwelling needle in the fasting state and at 10, 20, 30, 40, 50, 60, 75, 90, 105, 120, 150, and 180 min after the start of the meal. Plasma was assayed for glucose by an “Auto-Analyzer” glucose oxidase method. Serum was frozen at −20°C for later radioimmunoassay of immunoreactive insulin by a dextran charcoal method.

The statistical significance of differences was assessed by Student’s paired t test or the Wilcoxon rank-sum test for paired data as appropriate. Values for p of <0.05 were taken as significant.

### Results

#### Satiating effect (Table 2)

The results obtained with two scoring systems were highly correlated (r = 0.95, p < 0.0001). Oranges and grapes both evoked considerably more satiety than the corresponding amount of juice. The differences in hunger-satiety scores were maximal immediately after the meal but were still significant at 60 and 120 min. At 60 min subjects were on average beginning to feel hungry after juice but not after fruit. In the comparison between standard and diluted grape juice, satiety scores were higher with the diluted juice immediately after the meal (scale score 4.4 ± 0.8 and 2.7 ± 0.5, respectively, p < 0.02; verbal score 7.3 ± 0.4 and 6.3 ± 0.3, p < 0.001) but there was no significant difference at 60, 120, or 180 min.

#### Plasma glucose

**Orange study (Fig. 1).** No significant difference was found between fruit and juice in plasma glucose values during the initial rise, in the time (30 min) or amplitude of the peak value or in the descent within the 1st h. Subsequently, there was after both fruit and juice meals, reactive hypoglycemia compared with fasting values. However, while this was short-lived with fruit (75, 90, and 105 min values versus fasting, p < 0.005) it was sustained to the end of the experiment with juice (75 to 180 min values versus fasting, p < 0.005). Postjuice glucose values were significantly lower than postfruit ones from 105 to 180 min (p < 0.05).

<table>
<thead>
<tr>
<th>How hungry or full do you feel?</th>
<th>Table 1 Hunger/satiety scale as it was presented to the subjects (“verbal score”)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Please choose the answer which is most appropriate</td>
<td></td>
</tr>
<tr>
<td>1. Painfully hungry</td>
<td></td>
</tr>
<tr>
<td>2. Very hungry</td>
<td></td>
</tr>
<tr>
<td>3. Hungry want to eat</td>
<td></td>
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<tr>
<td>4. Not hungry, but ready to eat</td>
<td></td>
</tr>
<tr>
<td>5. No particular feeling</td>
<td></td>
</tr>
<tr>
<td>6. Partially satisfied</td>
<td></td>
</tr>
<tr>
<td>7. Pleasantly full</td>
<td></td>
</tr>
<tr>
<td>8. Unpleasantly full</td>
<td></td>
</tr>
<tr>
<td>9. Full to nauseas</td>
<td></td>
</tr>
</tbody>
</table>

**TABLE 1** Hunger/satiety scale as it was presented to the subjects (“verbal score”)

How hungry or full do you feel?

Please choose the answer which is most appropriate

1. Painfully hungry
2. Very hungry
3. Hungry want to eat
4. Not hungry, but ready to eat
5. No particular feeling
6. Partially satisfied
7. Pleasantly full
8. Unpleasantly full
9. Full to nauseas

for paired data as appropriate. Values for p of <0.05 were taken as significant.
TABLE 2
Mean hunger/satiety scores in subjects following test meals of fruit and juice

<table>
<thead>
<tr>
<th>Time</th>
<th>Oranges</th>
<th></th>
<th>Grapes</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Food</td>
<td>Scale</td>
<td>Verbal</td>
<td>Scale</td>
</tr>
<tr>
<td></td>
<td>Fruit</td>
<td>score</td>
<td>score</td>
<td>Fruit</td>
</tr>
<tr>
<td></td>
<td>Juice</td>
<td></td>
<td></td>
<td>Juice</td>
</tr>
<tr>
<td>0</td>
<td>-4.5 ± 0.8</td>
<td>3.0 ± 0.2</td>
<td>2.8 ± 0.2</td>
<td>-4.9 ± 0.9</td>
</tr>
<tr>
<td>Postprandial</td>
<td>6.4 ± 0.7*</td>
<td>7.4 ± 0.2†</td>
<td>5.8 ± 0.5</td>
<td>4.2 ± 1.1‡</td>
</tr>
<tr>
<td>60</td>
<td>2.1 ± 0.8‡</td>
<td>6.2 ± 0.4†</td>
<td>4.7 ± 0.5</td>
<td>1.2 ± 0.8*</td>
</tr>
<tr>
<td>120</td>
<td>-1.3 ± 0.8</td>
<td>-2.7 ± 1.1</td>
<td>4.4 ± 0.4‡</td>
<td>-1.6 ± 0.6†</td>
</tr>
<tr>
<td>180</td>
<td>-3.7 ± 1.0</td>
<td>-5.2 ± 1.0</td>
<td>3.3 ± 0.3</td>
<td>-4.9 ± 0.9</td>
</tr>
</tbody>
</table>

Compared with juice *p < 0.001; †p < 0.01; ‡p < 0.05.

**Dietary Fiber in Satiety, Glucose, and Insulin**

**FIG. 1.** Mean plasma glucose levels in 10 normal subjects after ingesting 50 g carbohydrate as whole oranges and orange juice. Asterisks indicate glucose values significantly lower (p < 0.05) after juice than at the corresponding times after fruit.

**Grape study (Fig. 2).** One subject was excluded from analysis because of exaggerated and prolonged insulin and glucose responses suggesting she had prediabetes.

With grape juice the rise in plasma glucose was significantly greater than for fruit at 10 and 20 min (p < 0.005) but the peak values were similar and occurred at the same time (30 min). The subsequent fall in glucose was similar until 60 min, but after this there was significant hypoglycemia compared with the fasting value for grape juice from 75 to 180 min (p < 0.05) whereas no statistically significant hypoglycemia occurred after fruit.

Nevertheless, values after grape juice were never significantly lower than after fruit. In one subject the juice meal produced a plasma glucose of 1.0 mmole/L at 75 min without symptoms.

**Serum insulin**

**Orange study (Fig. 3).** Serum insulin rose after both fruit and juice meals with peak values at 30 min. The peak value after juice was significantly greater than after fruit (43.0 ± 7.2 and 28.4 ± 3.8 mU/L, respectively) as were the values at 40, 50, 75, 120, and 150 min. The area under the insulin curve was
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FIG. 3. Mean serum insulin levels in 10 normal subjects after ingesting 50 g carbohydrate as whole oranges and orange juice. Asterisks indicate insulin values significantly higher (p < 0.05) after juice than at the corresponding times after fruit.

significantly greater after juice than fruit (2509 ± 252 and 1678 ± 241 mU/min, respectively p < 0.002).

Grape study (Fig. 4). Insulin concentrations tended to be greater after fruit than juice but this was statistically significant only at 40 and 120 to 180 min. The area under the insulin curve was significantly greater after fruit than juice (3189 ± 261 and 2415 ± 124 mU/min, respectively p < 0.02) in contrast to the findings in oranges.

Effect of diluting grape juice

There was no significant difference in the rise of plasma glucose, nor in the peak values obtained (Fig. 5). Reactive hypoglycemia compared with fasting values was found with both meals but this occurred earlier with diluted juice (90 min) than with the standard juice (105 min). Subfasting glucose levels were maintained until the end of the study (180 min) in both cases but was significantly greater with diluted juice at 90 min (p < 0.05). The insulin response was not significantly different between standard and diluted juices (Fig. 6), the area under the insulin

FIG. 4. Mean serum insulin levels in nine normal subjects after ingesting 60 g carbohydrate as whole grapes and grape juice. Asterisks indicate insulin values significantly higher (p < 0.05) after fruit than at the corresponding times after juice.

FIG. 5. Mean plasma glucose levels in nine normal subjects after ingesting 54 g carbohydrate as standard and diluted grape juice. Asterisk indicates glucose value significantly lower (p < 0.05) after diluted juice than at the corresponding time after standard juice.
Discussion

Hunger and satiety are subjective sensations and there is no generally accepted way of measuring them. In this study we have used two different scoring systems. Both relied on subjective feelings but there was a close correlation between their results which supports their validity.

The satiety data are very similar to those obtained in our apple study (1). In all three comparisons of whole fruit and fruit juice, the fruit evoked considerably greater feelings of satiety and the return of appetite was delayed. Fruit differs from juice in two respects—it is solid rather than liquid and it contains dietary fiber. It is impossible to state dogmatically which of these differences accounts for the extra satiating capacity of fruit. In the apple study, removing the solidity of fruit by homogenizing it into a drinkable puree did reduce this extra satiety but did not abolish it. Of course, the solidity of fruit is entirely due to its fiber content.

Few other studies on fiber and satiety have been published. A single-meal comparison of wholemeal and white bread showed the wholemeal to be more satiating (2), but another study failed to confirm this (3). Several mechanisms have been suggested whereby fiber could make food more satiating (4, 5), but these are applicable mainly to situations where fiber influences the texture of food. Long-term studies are desirable to determine whether changes in short-term satiety affect overall energy intake. The limited evidence available suggests that energy intake does fall when fiber-depleted foods are replaced by fiber-rich ones (6–9). Simply adding a fiber concentrate or isolate to an unchanged diet has little or no effect (10, 11).

The glucose and insulin findings after oranges and orange juice were comparable to those after apples and apple juice, namely a greater insulin response to the juice than to the fruit and lower plasma glucose values during the postabsorptive period with the juice. In a similar comparison of oranges and orange juice, Kay (12) also found lower plasma glucose values during the postabsorptive period. Thus, the findings with oranges agree with the hypothesis that dietary fiber (at least, that present in fruit) reduces the insulin response to carbohydrate. Rebound hypoglycemia (by comparison with fasting levels) was marked with orange juice and only slight with whole oranges. The fact that it occurred at all with whole oranges, whereas it was absent with apples, may be related to the ease with which juice can be expressed from an orange. In addition the fiber content of our oranges was slightly less than that of our apples.

The insulin response to oranges was higher than it had been to apples and the response to orange juice was higher than it had been to apple juice. This can be explained by the greater amount of glucose (as such, and in sucrose, as opposed to fructose which is non-insulinogenic (13)) in oranges than in apples. Thus the orange based meals contained 42% more glucose (23.5 versus 16.5 g) and the mean insulin area was 34% greater after orange juice than after apple juice (2509 and 1867 mU/min, respectively).
The findings with grapes and grape juice were paradoxical in that the insulin response to the whole fruit was not less but more than that to the juice. Despite this, there was no difference between juice and fruit in the postabsorptive plasma glucose values. The fact that there was significant hypoglycemia compared with the fasting level after juice but not after fruit, was presumably a statistical accident, since the two sets of plasma glucose values were closely similar. The anomalous insulin findings can perhaps be attributed to both a greater response to the fruit and a lesser response to the juice than expected from the findings with apples and oranges. The mean insulin response to the glucose in fruit was 76.4 mU/min/g with the apples and 71.4 mU/min/g with the oranges, but 106.3 mU/min/g with grapes. These data must be interpreted with caution since they are derived from nonidentical groups of volunteers (though four of the volunteers were the same in the apple and grape studies and in both studies there were five females and five males), but they do suggest that the glucose in grapes is more insulinogenic than that in the other two fruits. This may be related to the low fiber content of grapes (1.36 g/100 g edible portion compared with 2.51 in oranges and 2.90 in apples) and to the fact that juice is very easily squeezed out of grapes.

The insulin response to grape juice was relatively low—80.5 mU/min per gram of glucose, compared with 115.2 with apple juice and 106.8 with orange juice. This is difficult to explain. A possible cause is the high osmolarity of the grape juice (more than twice that of apple juice and nearly three times that of orange juice), since hypertonic solutions are emptied slowly from the stomach (14). To test this hypothesis we compared the responses of volunteers after drinking grape juice adjusted to two different osmolarities—that of the original grape juice and that of the much more dilute apple juice previously studied. The diluted grape juice did lead to an earlier and greater postabsorptive hypoglycemia. However, the difference was not great and the insulin responses were the same. There was also no difference in the plasma xylose responses to a standard dose of xylose in the juice meals. It is unlikely therefore that there was any gross difference in the rate of gastric emptying, but formal tests of emptying would be necessary to settle this point.

Other workers have shown that the addition of dietary fiber concentrates to a liquid test meal reduces the glucose and insulin response to the meal (15, 16), probably because of the viscosity of artificially fiber-enriched meals (16). More viscous meals are probably emptied more slowly from the stomach (17) but carbohydrate absorption could also be slower because of slower diffusion of solutes through a viscous medium. In our fruit and juice studies the fiber naturally present in the fruit rendered it solid rather than viscous, at least in the mouth. Swallowed lumps of fruit probably retain their solidity in the stomach, at least for a time, and solids are known to be emptied from the stomach more slowly than liquids (18). By the time fruit reaches the small intestine it must be largely liquefied but trapping of juice within intact cells or clumps of cells may be an additional factor delaying sugar absorption and so reducing the stimulus to insulin secretion.

The present studies, taken together with the previous apple study, suggest that the plasma insulin and glucose responses to whole fruit depend on both the glucose and fiber contents of the fruit. The removal of fiber in the production of fruit juice can usually be expected to enhance the insulin response and result in "rebound hypoglycemia."

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References
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