COMPARISON OF THE ABSORPTION AND METABOLIC PRODUCTS OF SUCROSE AND ITS MONOSACCHARIDES IN MAN

G. C. COOK*

Department of Medicine, The Royal Free Hospital, London

(Received 11 September 1969)

SUMMARY

1. In order to compare the absorption products of sucrose with those of its constituent monosaccharides in man, constant intrajejunal infusions of sucrose and of fructose and glucose were given to six cirrhotic patients with portal-systemic collateral vessels or surgical porta-caval anastomoses. To investigate further the subsequent metabolic fate of fructose and glucose, two further groups of four patients with normal liver function were given constant intravenous infusions of (1) fructose and glucose and (2) fructose, or (1) fructose and glucose and (2) glucose.

2. Solutions containing 292 m-mole/l sucrose, and 277 m-mole fructose and 277 m-mole glucose/l, were used for the intrajejunal infusions. Solutions containing 555 m-mole fructose and 555 m-mole glucose/l, 555 m-mole/l fructose, or 555 m-mole/l glucose, were used for the intravenous infusions. All of the intrajejunal and intravenous infusions were given at 6-0 ml kg⁻¹ hr⁻¹ for 3 hr.

3. During the intrajejunal infusions, blood concentrations of fructose, glucose, insulin, pyruvate, lactate and triglyceride-glycerol were similar with both sugar solutions. In most they were very slightly higher during the sucrose than the fructose and glucose infusions. These differences can be largely accounted for by the small difference in the quantities of the monosaccharides given during the two infusions.

4. The blood concentrations of fructose, glucose, insulin, pyruvate and lactate during the intravenous infusions did not seem to be influenced by the presence of the other monosaccharide. These findings are entirely consistent with the view that in man the constituent monosaccharides of sucrose are handled by separate metabolic paths.

Sucrose and maltose (from starch) are the major dietary disaccharides of adult man in developed areas of the world. There are only a few studies comparing the absorption of these disaccharides with that of their constituent monosaccharides. Most available evidence in man has been reported on luminal concentrations during intestinal perfusion studies rather than on

*Present address: Department of Medicine, The University of Zambia, P.O. Box 2379, Lusaka, Zambia.
the absorption products (Gray & Ingelfinger, 1965, 1966). Fructose is absorbed largely unchanged (Cook, 1969); it is not, however, usually ingested as the monosaccharide, and the effect of the glucose component of sucrose on its absorption has not been adequately investigated. On the basis of oral sucrose, and of glucose and fructose tolerance tests, it has been claimed that much higher blood concentrations of fructose are obtained after sucrose than after fructose and glucose ingestion (MacDonald & Turner, 1968). Whether or not fructose and glucose are metabolized entirely independently after absorption and whether a high blood concentration of each monosaccharide influences metabolism of the other in man is also not clear (McGandy, Hegsted & Stare, 1967; Sols, 1968; Irwin & Staton, 1969).

In the present study, constant intrajejunal infusions of sucrose, and of fructose and glucose, were given on consecutive days to a group of cirrhotic patients with portal-systemic collateral vessels or surgical porta-caval anastomoses. The object was to compare the absorption products of sucrose with those of fructose and glucose. The metabolism of fructose and glucose was further studied by giving constant intravenous infusions of these monosaccharides, either individually or together, on consecutive days to two groups of relatively normal patients.

PATIENTS AND METHODS

Table 1 gives the details of the patients who had intrajejunal infusions. Six patients (group A) with proven cirrhosis and portal-systemic collateral vessels, two of whom (Nos. 5 and 6) had had a surgical porta-caval anastomosis 8 years and 7 months respectively before, were studied. It has previously been shown that patients with both cirrhosis and collateral vessels and those with surgical portal-systemic anastomoses have high levels of fructose in the systemic circulation after intrajejunal fructose infusions (Cook, 1969). Patient 4 also had clinical diabetes mellitus and Nos. 1 and 3 had mild ascites during the study. None was on corticosteroid treatment. All had a sucrose, and a fructose and glucose infusion into the first jejunal loop (between 10 and 20 cm from the ligament of Treitz) on consecutive days. Sucrose was given first in Nos. 1, 2 and 5 and fructose and glucose in the other three.

Table 2 gives details of the patients who had constant intravenous infusions. Eight patients were studied and they all had normal liver function assessed by biochemical tests, and no evidence of diabetes mellitus. Four (group B) had an intravenous fructose and glucose infusion on one day, and on a consecutive day fructose; two had the fructose and glucose first and two had the fructose first. Four (group C) had fructose and glucose one day, and glucose on a consecutive day; two had fructose and glucose first and two the glucose first.

The purpose of the study was made clear to the patients who agreed to take part.

Intrajejunal infusions were given through a radio-opaque Portex tube (internal diameter 1·0 mm) (Cook, 1969); the position of the tube was confirmed radiologically before and after each infusion. Infusion was with a solution containing 292 m-mole/l (10·0 g/100 ml) sucrose, or one containing 277 m-mole fructose and 277 m-mole anhydrous glucose/l (5·0 g fructose and 5·0 g anhydrous glucose/100 ml) during a 3 hr period after a 10–12 hr overnight fast. Two fasting blood samples (capillary and venous) were taken at 10 min intervals, and also at 30, 60, 90, 120, 150 and 180 min after the start of the infusions. Intravenous infusions were given through a plastic cannula into the median cubital vein (Cook, 1969). Infusion was with a solution containing 555 m-mole fructose and 555 m-mole glucose/l (10·0 g fructose and 10·0 g glucose/100 ml), or one containing 555 m-mole/l (10·0 g/100 ml) glucose, or one
<table>
<thead>
<tr>
<th>No.</th>
<th>Age (years)</th>
<th>Sex</th>
<th>Diagnosis</th>
<th>Serum bilirubin (mg/100 ml)</th>
<th>Serum aspartate transaminase‡ (i.u./litre)</th>
<th>Serum total globulin (g/100 ml)</th>
<th>Splenomegaly</th>
<th>Oesophageal varices</th>
<th>PSE†</th>
<th>Body weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>34</td>
<td>M</td>
<td>Cirrhosis of unknown aetiology</td>
<td>2.4</td>
<td>25</td>
<td>3.1</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>61</td>
<td>M</td>
<td>Active macronodular cirrhosis*</td>
<td>3.0</td>
<td>120</td>
<td>4.4</td>
<td>+</td>
<td>0</td>
<td>+</td>
<td>66</td>
</tr>
<tr>
<td>3</td>
<td>50</td>
<td>M</td>
<td>Active chronic hepatitis with cirrhosis*</td>
<td>1.5</td>
<td>25</td>
<td>3.8</td>
<td>0</td>
<td>+</td>
<td>+</td>
<td>72</td>
</tr>
<tr>
<td>4</td>
<td>47</td>
<td>F</td>
<td>Cirrhosis of unknown aetiology*</td>
<td>1.0</td>
<td>6</td>
<td>3.2</td>
<td>0</td>
<td>+</td>
<td>+</td>
<td>54</td>
</tr>
<tr>
<td>5</td>
<td>18</td>
<td>M</td>
<td>Cirrhosis of unknown aetiology*; surgical porta-caval anastomosis</td>
<td>8.0</td>
<td>40</td>
<td>5.9</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>47</td>
</tr>
<tr>
<td>6</td>
<td>51</td>
<td>F</td>
<td>Primary biliary cirrhosis*; surgical porta-caval anastomosis</td>
<td>6.0</td>
<td>65</td>
<td>3.1</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>59</td>
</tr>
</tbody>
</table>

* Confirmed by liver biopsy.
† Portal-systemic encephalopathy.
‡ Normal upper limit 17 i.u./litre.
containing 555 m-mole/l (10.0 g/100 ml) fructose, after a 10–12 hr overnight fast. Two fasting blood samples (capillary and venous) were taken at a 10 min interval, and also at 60, 120, 150 and 180 min after the start of the infusions from the opposite arm. With all intrajejunal and intravenous infusions the rate was 6.0 ml kg⁻¹ hr⁻¹.

All biochemical methods were as previously described (Cook, 1969). Capillary fructose and glucose, venous pyruvate, lactate and triglyceride-glycerol were all estimated by specific enzyme methods. All estimations were carried out in duplicate.

All sucrose and fructose infusion solutions were tested for glucose by the glucose oxidase method used for blood glucose estimations. The sucrose solutions contained less than 30 mg/100 ml and the fructose solutions less than 10 mg/100 ml glucose.

RESULTS

Table 3 gives the fasting concentrations of blood glucose, insulin, pyruvate, lactate and triglyceride-glycerol in the three groups of patients. One patient (No. 3) had mild abdominal colic towards the end of the sucrose infusion and passed a loose stool soon after the completion

---

**Table 2. Details of the patients with normal liver function studied**

<table>
<thead>
<tr>
<th>Group</th>
<th>No.</th>
<th>Age (years)</th>
<th>Sex</th>
<th>Diagnosis</th>
<th>Body weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(mean and range)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B*</td>
<td>4</td>
<td>33</td>
<td>2</td>
<td>Recovered lobar pneumonia</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(22–48)</td>
<td></td>
<td>Urinary infection</td>
<td>(53–68)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Uterine fibroids</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>No abnormality</td>
<td></td>
</tr>
<tr>
<td>C†</td>
<td>4</td>
<td>36</td>
<td>1</td>
<td>Hydatid cyst of liver</td>
<td>64</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(18–56)</td>
<td></td>
<td>Recovered lobar pneumonia</td>
<td>(59–72)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Recovered infective hepatitis</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>No abnormality</td>
<td></td>
</tr>
</tbody>
</table>

* Fructose and glucose, and fructose infusions given on consecutive days.
† Fructose and glucose, and glucose infusions given on consecutive days.

---

**Table 3. Fasting concentrations (mean and range) of biochemical indices in the patients studied**

<table>
<thead>
<tr>
<th>Group</th>
<th>Capillary glucose (mg/100 ml)</th>
<th>Venous insulin (μι/μι)</th>
<th>Venous pyruvate (mg/100 ml)</th>
<th>Venous lactate (mg/100 ml)</th>
<th>Venous triglyceride-glycerol (mg/100 ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>68*</td>
<td>38</td>
<td>0.8</td>
<td>11.1</td>
<td>11.3</td>
</tr>
<tr>
<td></td>
<td>(54–87)</td>
<td>(22–50)</td>
<td>(0.4–1.1)</td>
<td>(7.5–17.9)</td>
<td>(6.0–22.8)</td>
</tr>
<tr>
<td>B</td>
<td>61</td>
<td>20</td>
<td>0.8</td>
<td>8.7</td>
<td>16.8</td>
</tr>
<tr>
<td></td>
<td>(51–68)</td>
<td>(14–24)</td>
<td>(0.7–0.9)</td>
<td>(7.1–12.1)</td>
<td>(11.5–20.3)</td>
</tr>
<tr>
<td>C</td>
<td>65</td>
<td>23</td>
<td>0.8</td>
<td>8.3</td>
<td>10.9</td>
</tr>
<tr>
<td></td>
<td>(58–79)</td>
<td>(17–31)</td>
<td>(0.5–1.1)</td>
<td>(6.1–10.7)</td>
<td>(7.4–18.4)</td>
</tr>
</tbody>
</table>

* Excludes patient 4 whose mean fasting glucose was 148 mg/100 ml.
Absorption and metabolism of sucrose

of the study; no other patient had any symptoms during or after the intrajejunal or intravenous infusions, although each was carefully questioned.

Intrajejunal infusions

Fig. 1 summarizes the biochemical changes during the intrajejunal infusions (group A). There is a close relation between all of the biochemical indices during the sucrose and the fructose-glucose infusions. Fig. 2 compares the areas under the curves during the two infusions in the individual patients. Fructose areas were slightly lower after fructose and glucose than after sucrose in all except patient 3; in Nos. 2 and 5 the difference was less than 5%. Glucose areas were also slightly lower after the fructose and glucose than sucrose infusions except in patients 3 and 6. Insulin areas followed the blood glucose areas fairly closely; patient 4 had a very low insulin rise during both infusions and in that patient and patients 2 and 3 the rise was greater after fructose and glucose than after sucrose. The rise in blood-pyruvate and lactate concentrations corresponded closely and showed a significant correlation with each other (P<0.01; n = 35). The ratio between the mean rise in lactate and that of pyruvate was 2.4. Pyruvate and lactate areas followed the fructose and glucose areas fairly closely; in patient 4, however, the area for lactate during the fructose and glucose infusion was 63% higher than that for sucrose. Serum triglyceride-glycerol concentrations fell slightly during the infusions; the mean changes were similar during both infusions.

Intravenous infusions

Figs. 3 and 4 summarize results of the biochemical changes during the intravenous infusions (groups B and C). Blood fructose concentrations during the fructose and glucose and the fructose infusions were very similar in all of the patients studied. Blood glucose concentrations during the fructose and glucose and the fructose infusions were also similar; there was a very small blood glucose rise during the fructose infusions (Cook, 1969). Blood insulin levels showed a slower rise than blood glucose and were similar during the glucose and fructose and the glucose infusions; there was only a very small rise in insulin during the fructose infusions (Cook, 1969). The rise in blood-pyruvate and lactate concentrations corresponded closely and showed a significant correlation (for group B, P<0.001 (n = 31), and group C, P<0.001 (n = 30)). In both groups B and C, the ratio of the mean rise in lactate to that of pyruvate was 2.1. The mean areas under the pyruvate and lactate curves during the glucose infusions are approximately equal to the differences between those during the fructose and glucose, and the fructose infusions. During the fructose infusions lactate concentrations were relatively low in all four patients studied, and corresponded to the group of subjects who produce relatively small amounts of lactate after intravenous fructose as described by Cook & Jacobson (unpublished observation). Serum triglyceride-glycerol concentrations tended to fall in the early part and rise towards the end of the infusions; the greatest decrease was after fructose.

DISCUSSION

The results of the intravenous infusions confirm that in man the monosaccharides of sucrose are metabolized by different metabolic paths; the presence of one monosaccharide in high blood concentration does not influence metabolism of the other.

During the intrajejunal infusions, the rates of absorption and metabolism of sucrose and
Fig. 1. Results of *intrajejunal* infusions of sucrose (292 m-mole/l), and of fructose (277 m-mole/l) and glucose (277 m-mole/l), in six cirrhotic patients with portal-systemic collateral vessels or anastomoses (group A). The mean±1 SEM for the rise in blood fructose, glucose, insulin, pyruvate, lactate and triglyceride-glycerol at each time interval during the infusions are shown. (●, sucrose; ○, fructose and glucose).
Fig. 2. Summary of the results of the rise in blood fructose, glucose, insulin and lactate during the two intrajejunal infusions in the six individual patients (group A). The area under the curve, above the mean fasting level, is shown for each. The black columns represent the sucrose and the white columns the fructose and glucose infusions. The figures on the columns represent the percentage difference of the areas under the fructose and glucose compared with the sucrose curves.
FIG. 3.

FIG. 4.
Absorption and metabolism of sucrose

695

its monosaccharides were similar; this is clearly shown by the blood fructose and lactate concentrations respectively. In only one patient were symptoms present during the sucrose infusion and in him the blood concentrations of fructose and lactate were slightly lower than after the monosaccharides. In an additional two patients a solution containing 584 m-mole/l sucrose and one containing 555 m-mole fructose and 555 m-mole glucose/l were given intrajejunally at the same rate as that used in the present study on consecutive days, and they had abdominal colic and diarrhoea after all of the infusions. Although not statistically significant, there was a tendency for the blood concentration of fructose in the present study to be slightly higher during the sucrose infusions; this is presumably largely due to the fact that the equivalent of approximately 5% more monosaccharide was infused when sucrose was given compared with the monosaccharide solution. In two patients the differences between the areas under the fructose curves were less than 5%. In the other three who did not have symptoms, the difference was between 10 and 15%; the reason for this is not clear. It seems unlikely that osmotic factors are relevant as solutions introduced into the jejunum are very rapidly diluted. A slightly higher rate of absorption for sucrose compared with its monosaccharides cannot definitely be excluded by the present study, but it seems unlikely that more precise data than this can be obtained from intact unanaesthetized man. The possibility that a sucrase deficiency in our patients has led to an abnormally low blood-fructose after sucrose must be considered, but if that was the case some symptoms after sucrose would have been expected. Sucrose hydrolysis in fact occurs at a very high rate (Gray & Santiago, 1966). MacDonald & Turner (1968) using oral sugar solutions showed that much higher blood fructose concentrations, between 30 and 40%, were obtained after sucrose than fructose and glucose, and they considered that that represented a difference in absorption rates between the two solutions, even though the blood glucose concentrations did not show a significant difference. The reason for their results was presumably due either to a difference in the gastric emptying rate for the two solutions or to problems in the estimation of low blood concentrations of fructose. The former of these explanations seems unlikely as the effect of sucrose and its monosaccharides on the gastric emptying rate has been shown to be similar (Elias et al., 1968). It seems most unlikely that the abnormal liver-cell function in the patients in the present study is important in the interpretation of the results. Dahlqvist & Thomson (1963) using a modified Cori technique, have shown in the intact rat, that the rate of sugar disappearance from the lumen of the small intestine after intragastric sucrose, and fructose and glucose is similar. Gray & Ingelfinger (1966) have shown in man using a double-lumen perfusion technique that the hydrolysis of sucrose is not a rate-limiting step in its absorption; fructose and glucose regulate the rate, and glucose seems to be absorbed more rapidly than fructose. In that study the concentration of the solutions was lower than those used in th

Fig. 3. Results of intravenous infusions of fructose (555 m-mole/l) and glucose (555 m-mole/l), and of fructose (555 m-mole/l), in four patients with normal liver function (group B). The mean ±1 SEM for the rise in blood fructose, glucose, insulin, lactate and triglyceride-glycerol at each time interval during the infusions are shown (○, fructose and glucose; △, fructose).

Fig. 4. Results of intravenous infusions of fructose (555 m-mole/l) and glucose (555 m-mole/l), and of glucose (555 m-mole/l), in four patients with normal liver function (group C). The mean ±1 SEM for the rise in blood fructose, glucose, insulin, lactate and triglyceride-glycerol at each time interval during the infusions are shown (○, fructose and glucose; ■, glucose).
present study, although the infusion rate was more than twice as high. The results of the present study are in line with those observations.

The close similarity of absorption rates from the two infusion solutions in the present study is emphasized by the very similar concentrations of blood pyruvate and lactate, which result from fructose metabolism in the liver and adipose tissue (Froesch, 1966). The reason for the much higher pyruvate and lactate concentrations in patient 4 after fructose and glucose is not clear; it seems unlikely that this could be associated with her diabetes mellitus. The blood concentrations of these metabolites during a constant infusion, after a plateau has been reached, bear a close relationship to the rate of entry of fructose into the circulation (Cook & Jacobson, unpublished observation). The rate of pyruvate and lactate production during a constant intravenous fructose infusion, however, differs widely in different individuals and this may have a genetic basis (Cook & Jacobson, unpublished observation). There is no evidence from the present study that the presence of a high glucose concentration during sucrose ingestion influences the rate of pyruvate and lactate production from fructose.

Glucose and insulin concentrations were similar during the two infusions, but the areas under the curves tended to be slightly lower after fructose and glucose than after sucrose. The very high insulin levels in patients 1–3 are due presumably to the peripheral insulin resistance previously demonstrated in cirrhotic patients (Megyesi, Samols & Marks, 1967).

There is no evidence from the present investigation that fructose stimulates insulin release, or that there is hyper-insulinism associated with fructose or sucrose ingestion in these acute experiments (Stout & Vallance-Owen, 1969). If a metabolite of fructose stimulates insulin secretion or release (Aitken & Dunnigan, 1969) it is to a very minimal degree. The inability of fructose to stimulate insulin release is not influenced by the presence of high glucose concentrations.

MacDonald (1968) has shown that the serum triglyceride concentration rises in some individuals after prolonged fructose and sucrose ingestion. There is no evidence from this study that fructose given orally or intravenously over a 3 hr period produces a significant rise in triglyceride-glycerol in the dose used.

The shape of the curves for all indices were very similar after the two intrajejunal infusions in all of the patients studied, and this confirms the value of this experimental model in comparative studies of carbohydrate absorption in man.

This investigation emphasizes the very high blood lactate concentrations reached after fructose or sucrose administration especially in cirrhotic patients in whom a plateau is not always reached during a 3 hr infusion period. It seems advisable that oral or intravenous fructose should not be given in high concentrations to cirrhotic patients owing to the risk of lactic acidosis (Huckabee, 1961; Tranquada, Grant & Peterson, 1966).

ACKNOWLEDGMENTS

I thank Professor Sheila Sherlock and Dr I. A. D. Bouchier for permission to study patients under their care. I am most grateful to Miss Janice Jacobson for valuable technical assistance, to Dr Joyce Bell for the triglyceride-glycerol estimations, and to Professor D. N. Baron for the biochemical tests of liver function. Dr P. J. Scheuer interpreted the liver biopsy histology. The Ingram Trust provided financial support.
Absorption and metabolism of sucrose

REFERENCES


MacDonald, I. & Turner, L.J. (1968) Serum-fructose levels after sucrose or its constituent monosaccharides. Lancet, i, 841-843.


