On the site of absorption of fat from the human small intestine

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EDITORIAL SYNOPSIS The results of previous studies of the site of absorption of fat in the human small intestine using a test meal with a water-soluble reference substance have been criticized because of observations which have indicated that fat separates from the water-soluble marker in the stomach. It is now shown that the separation of fat and marker follows a sufficiently well-defined pattern to allow correction of the results obtained. The separation of fat and marker does not invalidate the authors' previous conclusions that the site of absorption of most of the fat fed to man has been the proximal jejunum.

The site of absorption of fat from the human small intestine has been reported from studies in which the intestinal content during digestion was collected by intubation (Borgström, Dahlqvist, Lundh, and Sjövall, 1957). The meal fed contained a water-soluble, non-absorbable reference substance and emulsified fat. The percentage of absorption was calculated from the ratio of fat to reference substance in the collected samples to that of the fed mixture. The results indicated that most of the fat fed, as well as the glucose and protein, had been absorbed by the proximal jejunum.

These results have recently been criticized because of observations which indicated that the fat separates from the water-soluble reference substance in the stomach. It was suggested that 'the interpretation of the results as to the site and extent of absorption of fat are of little value until it has been conclusively shown that dissociation of fat and marker, except that caused by absorption of fat, has not taken place' (Wiggins and Dawson, 1961). We have been aware of this source of error, which probably is unavoidable in this type of study. Its magnitude depends on the stability of the emulsion in the stomach. In the present study we have tried to quantitate the error involved in our experiments by studying the ratio of fat to marker and glucose to marker in samples collected in the duodenum, *i.e.*, before any appreciable absorption has taken place. The results show, as was apparent from the studies of Wiggins and Dawson, an appreciable separation of fat from marker. This, however, seems to follow a fairly well-defined pattern, and we have therefore

corrected the absorption curve accordingly. It is concluded that the separation of fat and marker does not invalidate our previous general conclusion as to the site of absorption of fat from the small intestine in man.

METHODS AND RESULTS

The procedures of intubation and sampling and the composition of the test meal were the same as described earlier (Lundh, 1958) but the experiments differed from those of Borgström *et al.* (1957) in that only 300 ml. was fed. From 20 intubations in which the collections were performed in the duodenum, the concentrations of reference substance (polyethylene-glycol), glucose, and fat were obtained. Total fat, glucose, and polyethylene-glycol were determined as previously described (Borgström *et al.*, 1957). The ratio glucose/polyethylene-glycol and fat/polyethylene-glycol were calculated as a percentage of those of the test meal. The results obtained are shown in Figure 1. It is apparent from this figure that the ratio glucose/polyethylene-glycol stays fairly constant during the whole collection period with a low percentage of the glucose being absorbed in the duodenum.

The ratio fat/polyethylene-glycol follows that of glucose/polyethylene-glycol only during the first 20 minutes of sampling. It then drops to between 40 and 50% of that of the test meal but increases during the last half-hour of collection to a figure well above that of the test meal. These results,

FIG. 1. Ratio of glucose and fat to marker (P.E.G.) and fat to glucose in samples collected from the duodenum of humans after the feeding of a test meal. The ratios are given as percentages of those of the test meal. (Mean values of 20 experiments; for the fat/P.E.G. ratio, the standard error of the mean is also included.)

which were also observed by Wiggins and Dawson, indicate a separation of fat and polyethylene-glycol in the stomach leading to the emptying during the main part of the digestion period of a gastric content with only about half the amount of fat in relation to marker. During the last part of the digestion period a gastric content is delivered with a higher ratio for fat/polyethylene-glycol than the test meal. The characteristic course of the curve makes possible a correction of the results obtained from other experiments from lower levels of the intestine. In this way an approximately correct absorption curve can be calculated.

Figure 2 shows an absorption curve for fat over the length of the human small intestine calculated directly from the values determined for fat and polyethylene-glycol in samples from 10 additional intubations, and a curve in which these absorption figures have been corrected using the values in Figure 1 to account for the separation of fat and polyethylene-glycol at different time intervals. In these calculations the amount of fat remaining in each sample has been calculated from the total fat content per millilitre and the figure for polyethylene-glycol (P.E.G.), i.e., mg. fat/ml. divided by P.E.G. (%). The amount absorbed has then been obtained by subtracting the value from the amount of fat in the fed fluid meal. In the corrected figures the fat content of the meal in these calculations, due to the separation of fat from polyethylene-glycol in the stomach, has been corrected according to the results in Figure 1. The fed mixture contained as an average 56 mg. fat per ml.; the corrected fat content at the different time intervals using glucose as marker is: 53.5, 51.7, 29.3, 27.8, 25.7, 35.6, 37.2, and 95.0 mg. per ml.

The time interval between the feeding of the meal and the beginning of an ample flow of intestinal content is dependent on the level sampled. In the corrections described the time intervals for the different levels have been counted from the moment the intestinal content started to flow. When sampling from the distal part of the small intestine the flow rate is usually rather low and therefore half-hourly or hourly samples have been collected. For these figures mean values for the fat content of the corrected meal over the sampling period have been used.

FIG. 2. Absorption figures for fat obtained from samples collected from different levels of the human small intestine during digestion of a test meal. In the corrected curve the separation of fat from marker has been taken into consideration in the calculations as described in the text.

DISCUSSION

The separation of emulsified fat from the water-soluble marker found by Wiggins and Dawson to take place in the stomach is also apparent in intestinal content collected in the duodenum. Calculation of the glucose to marker ratio in duodenal samples shows a low absorption of glucose (less than 10% generally) and the glucose can therefore also be used as reference substance for the lipids. The curve for the ratio of fat to glucose in the duodenal contents shows a decrease to about 0.5 during the middle part of the digestion period and increases to figures about unity during the latter part of the period.

It is apparent from Fig. 2 that the general course of the absorption curves are not much different, and the conclusions drawn earlier as to the site of absorption of fat are therefore valid (Borgström *et al.*, 1957). The amount of fat present in the intestinal content from the jejunum in most cases is so low that the absorption figures calculated from the corrected and uncorrected data are fairly close. Moreover, the samples collected during the end of the digestion period, which usually contain more lipid, show higher absorption figures in the corrected than the uncorrected series.

The present results thus show that there are no significant differences in the general curves obtained for data calculated directly and those corrected for separation of fat and marker in the stomach. In the individual samples, however, considerable deviation from the mean is frequent, and therefore a more ideal fat/marker relationship would be of great value. This could probably be done by increasing the stability of the emulsion, as fairly stable emulsions can be obtained using synthetic detergents. Such stabilizing agents might, however, influence the digestion and absorption process. The other alternative is to use a lipid-soluble marker. The inter-

preting of such experiments would probably also be difficult. After the lipids had been absorbed the marker might be suspended badly in the intestinal content. If it adsorbed to the mucosa valid sampling would be unlikely.

In fact a lipid-soluble marker has been used to some extent in human experiments in which C^{14} -cholesterol was fed in a triglyceride-containing formula. Due to the low absorbability of cholesterol in comparison to the glyceride the former accumulated in the lipid phase during absorption. This separation between cholesterol and glycerides was found to start in the proximal jejunum, again indicating an extensive absorption of glycerides in that site (Borgström, 1960).

SUMMARY

The site of absorption of fat in the human small intestine has previously been defined using a test meal with a water-soluble reference substance. The results of these studies have recently been criticized because of observations which indicated that fat separates from the water-soluble marker in the stomach. In the present study it has been shown that the separation of fat and marker follows a well-defined pattern which allows of corrections of the results obtained. It is concluded that the separation of fat and marker does not invalidate our previous general conclusion as to the site of absorption of fat from the human small intestine.

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