

Effect of prolonged exercise on the passage of a solid meal through the stomach and small intestine

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SUMMARY The effect of intermittent moderate exercise on the passage of a solid meal, labelled with radioactive Technetium sulphur colloid, through the stomach and small intestine was investigated by paired studies on seven healthy volunteers. Measurements of gastric radioactivity and breath hydrogen excretion were recorded every 10 minutes while subjects exercised in a controlled manner while seated on a bicycle ergometer. These were compared with values obtained during a separate experiment while the same subjects sat upright in a chair. Exercise significantly accelerated gastric emptying (control $t_{\frac{1}{2}}=1.5\pm 0.1$ h; exercise $t_{\frac{1}{2}}=1.2\pm 0.1$ h; $p<0.02$) but had no significant effect on small bowel transit time.

Comparatively little is known about the effects of exercise on the function of the gastrointestinal tract. Gastric secretion is inhibited during moderate or severe exercise;¹ gastric emptying of liquids has been variously reported as being accelerated,^{1,2} delayed,^{1,2} or unchanged,³ depending in part on the severity of the exercise and whether it preceded or succeeded the ingestion of fluid. Despite dramatic decreases in intestinal blood flow, absorption of fluid, electrolytes, and glucose in man is unaffected by exercise.³ Although exercise is often prescribed for people with constipation, no studies have been carried out to investigate the effect of exercise on the passage of food through the gastrointestinal tract in man.

In this study we have investigated the effect of prolonged moderate exercise on the gastric emptying and small bowel transit time of a solid meal in seven young healthy volunteers.

Methods

SUBJECTS

Studies were carried out on one male and six female healthy volunteers aged between 19 and 21 years. Each subject gave his or her informed consent for the study to be performed and the experimental

protocol was approved by the Ethical Subcommittee of the Sheffield Area Health Authority (Teaching). Female subjects were studied only if they included in their consent a statement to the effect that there was no risk of them being or becoming pregnant during the period of study.

PROCEDURE

The half time for gastric emptying and the small bowel transit time were determined in all seven subjects, while each exercised in a controlled manner seated on a bicycle ergometer. These were compared with values obtained during a control experiment, during which the same subjects sat upright in a chair. The order of the two studies was randomised.

After an overnight fast, each subject ate a meal consisting of three small Frankfurter sausages (60 g), 120 g baked beans, 150 g mashed potatoes, and a dessert containing homogenised pineapple, sweetened with sucrose and thickened with custard powder (75 g). 1.85 MBq (50 μ Ci) 99m Technetium were incorporated in the water which reconstituted the mashed potato. This was complexed to sulphur colloid so that it was not absorbed from the gastrointestinal tract and thus served as a marker for gastric emptying. The total weight of the meal was 405 g and the total calorie intake was 630 Kcal. Subjects were allowed to drink 50 ml water with the meal.

The time taken for the subject to eat the meal was measured. The methods used to estimate gastric

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emptying and small bowel transit time were identical with those described in our previous publication.⁴ Briefly, gastric emptying was determined by monitoring the radioactive counts over the surface of the stomach by means of single crystal scintillation detector.^{4,5} Immediately after ingestion of the meal the point of maximum gastric radioactivity was found with the subject lying recumbent on a couch and this position was marked on the surface of the abdomen. Thereafter the gastric radioactivity was determined by counting over this point for one minute out of every 10 minutes while the subject lay supine. Small bowel transit time was also determined every 10 minutes by measuring the concentration of hydrogen in serial samples of end expired air^{4,6,7} using a metallised membrane electrode.⁸ The small bowel transit time of the head of the meal was defined as the time from starting to eat the meal to the first sustained rise in breath hydrogen concentration. The latter corresponded to an increase in breath hydrogen concentration of at least 2 parts per million (ppm) above basal values, continuing to rise for at least three successive 10 minute samples.

The exercise consisted of pedalling at a constant rate of 33 pedal revolutions per minute for five out of every 10 minutes, for a total period of six hours (excluding the first 10 minutes after starting to eat the meal). The load on the ergometer was the lowest at which a pulse rate of over 120 beats per minute was recorded. This varied from 1.0 to 1.5 kiloponds according to the size and fitness of each subject, and was determined by carrying out exercise tolerance tests several days before the bowel transit measurements. After each five minute exercise period, the subject sat upright in a chair for about four minutes and then lay down during the final minute so that gastric radioactivity could be measured. In the control experiments, the subject sat on a firm upright chair for nine minutes and then lay down for one minute for measurement of gastric radioactivity.

Pulse rate and blood pressure were recorded at least twice during the 10 minutes before each experiment started and thereafter at regular intervals throughout each experiment, while blood pressure was recorded once towards the end of each period of exercise. In the control experiments pulse and blood pressure were monitored every 10 minutes.

REPRODUCIBILITY STUDIES

Measurements of the half time for gastric emptying and the small bowel transit time, after ingestion of the test meal described above, were carried out in an identical manner on two separate occasions on 11 subjects (seven male; four female; aged 20 to 29

years), while they lay supine on a couch. The methods used were the same as those described above.

Results

PULSE RATE AND BLOOD PRESSURE

Exercise caused significant changes in pulse rate and systolic blood pressure (Table), which were sustained throughout the exercise period (Fig. 1).

TRANSIT MEASUREMENTS

The time taken to eat the meal never exceeded seven minutes in any subject.

The stomach appeared to empty in an exponential manner in all experiments. The half time for gastric emptying was shorter in six out of seven subjects during exercise. This difference was statistically significant (Table).

Prolonged exercise was not associated with any significant difference in the small bowel transit time (Table). Five people showed an earlier rise in breath hydrogen concentration when they exercised, whereas in two it was delayed. The average profile of breath hydrogen excretion during exercise was very similar to that obtained during the control study (Fig. 2).

REPRODUCIBILITY OF TRANSIT MEASUREMENTS

Duplicate values for gastric emptying and small bowel transit time are shown in Fig. 3. Repeat measurements of the half time for gastric emptying in the same individuals never varied by more than 17 minutes (mean difference = 9 ± 2 minutes (SEM)). The average difference in duplicate values for small bowel transit time was 20 ± 7 minutes.

Table Average measurements of pulse rate, blood pressure, gastric emptying, and small bowel transit time in seven healthy volunteers during exercise and control experiments

| | Control | Exercise | p |
|-------------------------------|---------|----------|--------|
| Pulse rate (beats per minute) | 72±1 | 117±1 | <0.001 |
| Blood pressure (mm Hg) | | | |
| Systolic | 109±1 | 119±1 | <0.001 |
| Diastolic | 73±1 | 71±1 | <0.001 |
| Gastric emptying t½ (h) | 1.5±0.1 | 1.2±0.1 | <0.02 |
| Small bowel transit time (h) | 5.1±0.7 | 4.6±0.2 | >0.5 |

Results are expressed as mean ± SEM.

Mean pulse and blood pressure were obtained by averaging the values recorded every 10 minutes (towards the end of the exercise period) to obtain a mean value for each experiment in each subject. The mean and standard error of these values in all seven subjects was then calculated.

The degree of significance between paired results (p value) was determined using Student's paired *t* test.

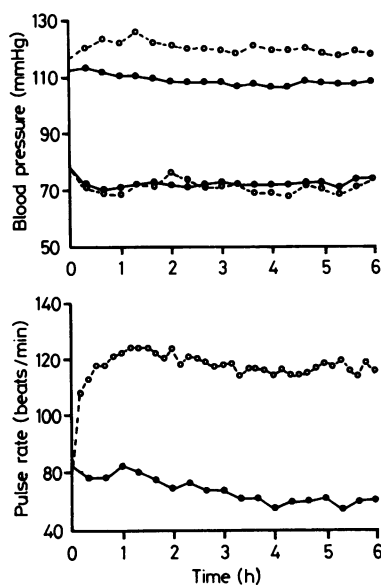


Fig. 1 Effect of exercise on the average systolic and diastolic blood pressure (top) and on the average pulse rate (bottom) in seven normal subjects. \circ Measurements recorded during exercise. \bullet Measurements recorded at rest. Time is measured from the moment the subject started to eat the meal.

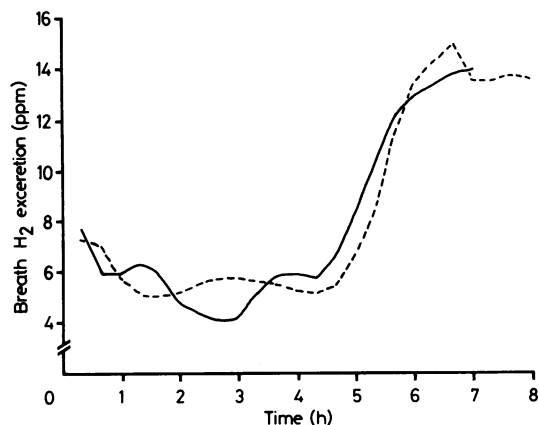


Fig. 2 Comparison of average breath hydrogen excretion profiles during exercise (----) and at rest (—) in seven normal subjects, obtained by averaging the concentration of hydrogen in the breath in all seven subjects at 10 minute intervals throughout the study. Time is measured from the moment the subject started to eat the meal.

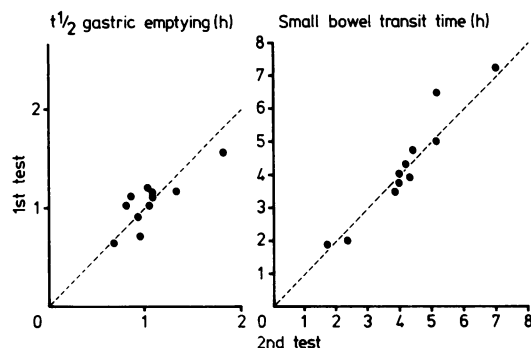


Fig. 3 Reproducibility of duplicate measurements of half time for gastric emptying (left) and small bowel transit time (right) in 11 normal volunteers (seven male, four female, aged 20 to 29 years). The diagonal lines indicate relationships that would exist if duplicate measurements were identical. Time is measured from the moment the subject started to eat the meal.

Discussion

In this project we investigated the effect of prolonged intermittent moderate exercise, equivalent to cycling 35 miles (56 km) up a steady incline, on the passage of a solid meal through the stomach and small intestine. The degree of exercise was normalised according to the subject's physiological response and none of our subjects became physically exhausted even though the exercise continued to six hours.

We considered it important to use non-invasive techniques to determine the transit of a meal through the stomach and small intestine, because the presence of a gastrointestinal tube and regular aspiration of gastric contents might have proved intolerable to subjects undergoing six hours of controlled exercise, and because we have recently shown that the presence of a gastrointestinal tube delays gastric emptying and accelerates small bowel transit.

Gastric emptying was monitored by serial estimations of gastric radioactivity using a single crystal scintillation detector. This method can provide as accurate and reproducible an index of gastric emptying as the gamma camera⁵ while using only a tenth of the dose of radiation. We calculated the radiation dosages from standard tables¹⁰ and found that the total dose to the ovaries generated by a 1.8 MBq (50 μ Ci) source with a 6.03 h half life moving through the stomach, small intestine, and

colon over the course of three days is less than 5 mrad. This is equivalent to the dose received during a standard radiograph of the chest and much less than that received during a radiograph of the abdomen (500 mrad) or a barium meal (150 mrad).

Although the radioactive marker was injected into the liquid which reconstituted the mashed potato, we have previously shown gastric emptying to be unchanged when the same marker is incorporated into the solid phase of the same meal.⁴ Moreover Hinder and Kelly¹¹ have shown that the rates of emptying of solids and liquids are similar in meals of relatively homogeneous consistencies, and differ only in meals consisting of discrete solid and liquid components.¹²

The identification of a sustained rise in the concentration of hydrogen gas excreted in the breath provides an accurate index of the transit time of the head of the meal to the caecum.⁴ As the head of the meal leaves the stomach almost as soon as it is ingested, there is no need to correct this value for the rate of gastric emptying.

The observations on gastric emptying have confirmed the early studies of Hellebrandt² and Campbell,¹ who used barium impregnated meals² or aspiration of gastric contents¹ to show that gastric emptying was accelerated by moderate exercise carried out just after ingestion, but delayed by severe exhaustive exercise. To our knowledge there have been no previous studies in which the effect of exercise on the transit of a meal through the small intestine has been investigated. The lack of any significant effect on small bowel transit time observed in this study cannot be explained by the variability or poor reproducibility of these measurements, as Fig. 3 shows that values for small bowel transit time in normal subjects using this method are highly reproducible. Moreover, we have previously observed significant changes in small bowel transit time in normal subjects in response to psychological stress¹³ and alterations in the composition of the test meal¹⁴ (submitted for publication) and significant differences in small bowel transit time in patients with the irritable bowel syndrome compared with normal subjects.¹⁵

Many of the physiological effects of exercise are thought to be mediated by the release of catecholamines.¹⁶⁻¹⁷ Our results, however, cannot be explained by the classical actions of catecholamines because these would delay gastric emptying and prolong small bowel transit time.¹⁸⁻²⁰ There is evidence that psychological stress increases parasympathetic²¹⁻²⁵ as well as sympathetic tone, and it has been suggested that the variable physiological responses to psychological stress depend on the relative dominance of parasympathetic and

sympathetic tone.²³ If this is true, then it is likely that response to physical stress such as exercise will also vary according to whether the sympathetic or parasympathetic tone is dominant. Thus the reduction in the half time for gastric emptying, induced by moderate exercise, may be explained by a relative dominance in parasympathetic tone, while the delay in gastric emptying, observed by earlier workers in response to severe or exhaustive exercise,^{1,2} may be explained by a dominance of sympathetic tone. However, exercise is known to cause the release of a variety of hormones and transmitter substances,²⁶ other than acetylcholine and catecholamines, and it is possible that it is the effect of autonomic arousal, modulated by these substances, that is responsible for the response observed in a given individual. In particular, exercise is thought to release endogenous opiate-like agents into the peripheral blood^{27,28} and these may interact with opiate receptors in the gut²⁹ to influence gastrointestinal motility. In general, opiates tend to delay gastric emptying³⁰ and small bowel transit, but under certain circumstances they may enhance antral contractions and speed up small bowel motility.³¹

An alternative explanation for the acceleration in gastric emptying observed in this study is that a concomitant reduction in acid secretion, known to occur during exercise,¹ removes the inhibition of gastric emptying caused by duodenal acidity.³²

In conclusion, our studies would offer no support to the belief that moderate exercise in a healthy person immediately after a meal may impair the passage of food through the stomach or small intestine.

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