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Use of radionuclide imaging to determine gastric emptying of carbohydrate solutions during exercise

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Abstract

***Objective*—To investigate the repeatability of continual assessment of the gastric emptying rates of carbohydrate solutions in exercising subjects using ^{99m}technetium labelling.**

***Methods*—Gastric emptying of a 5% glucose solution and an iso-osmotic maltodextrin solution was measured using 3 MBq of ^{99m}technetium labelled diethylene triamine penta-acetic acid (DTPA) and continuous gamma camera imaging in five male subjects. The subjects performed four 1 h trials at 70% $\dot{V}O_2$ peak on a cycle ergometer. After 15 min, 200 ml of a radiolabelled solution of glucose or maltodextrin were ingested in a blind crossover protocol. The two solutions were each ingested on separate occasions (trial 1 and trial 2) to establish repeatability.**

***Results*—Statistical analysis showed no differences between trial 1 and trial 2 for both solutions. There were no significant differences for the emptying rates between the two test solutions.**

***Conclusions*—Posterior imaging using a computer linked gamma camera following the ingestion of ^{99m}technetium labelled DTPA mixed with carbohydrate solutions provides a repeatable method of assessing gastric emptying characteristics in exercising subjects. This technique showed no significant differences between the emptying rates of a single dose of iso-osmotic glucose or maltodextrin solution.**

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Keywords: radiolabelling; gamma camera imaging; gastric emptying; carbohydrate; exercise.

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The availability of carbohydrate as a substrate for the exercising muscle is known to be a limiting factor in sustaining endurance exercise.[1 2] The onset of fatigue in endurance exercise has been closely correlated with the point at which muscle glycogen depletion is almost complete.[3] Liver glycogen depletion may be accompanied by a fall in the amount of blood glucose, as a significant proportion of carbohydrate oxidised during exercise is supplied by plasma glucose.[4] Endurance performance may also be impaired by dehydration, and during prolonged physical activity in the heat, 1 to 3 litres·h^{-1} of fluid may be lost as sweat.[5] The provision of carbohydrate-electrolyte solutions during exercise has been seen to extend performance through maintenance of plasma glucose levels and through provision of water.[2] The efficiency of fluid replacement and carbohydrate provision has been reported as being largely dependent on the rate of gastric emptying,[6] which in turn may be affected by energy content, osmolarity, volume, temperature, and pH of the ingested fluid, as well as by diurnal variation, the metabolic state of the individual, and the ambient temperature.[6]

A method to allow repeatable monitoring of the gastric emptying of carbohydrate solutions is necessary in the development of an optimum carbohydrate beverage for the athlete. The method most commonly used is an intubation and aspiration technique.[6] However, the development of non-invasive techniques to monitor gastric emptying has been recommended, as some findings have indicated that the presence of a nasogastric tube may itself delay gastric emptying.[7] Non-invasive techniques include applied potential tomography, in which a computerised image of stomach contents is generated from measures of electrical resistivity,[6] and *x* ray observations of radio-opaque meals.[6] Both have been used to assess gastric emptying under resting conditions but their effectiveness in exercising conditions is uncertain.

A further non-invasive technique used clinically is scintigraphy, which involves the tagging of gastric contents with a radioactive label and subsequent monitoring of the activity within the stomach. Studies have recently been performed using this technique in exercising subjects who have ingested solid meals.[8 9] Results are normally presented as the percentage of radioactivity retained in the stomach, and have been shown to be repeatable. A study by Carrio *et al*[10] evaluated radionuclide labelling for monitoring gastric emptying during physical exercise and concluded that the use of a large radiolabelled test meal is well suited to studying the influence of exercise on gastric motility. However, in exercise situations the ingestion of fluids is a more practical consideration. Comparison of the traditional aspiration techniques with scintigraphic analysis before and after exercise has shown good agreement between the two techniques.[11] The advantage of scintigraphy is that a picture of the emptying curve can be obtained continuously and there is no need for intubation.

Fig 1 The experimental set-up.

No studies have yet reported the use of the single field continual scintigraphic monitoring of gastric emptying during exercise.

The aim of this study was to investigate the repeatability of using a low specific activity (3 MBq) of ^{99m}technetium radiolabelled diethylene triamine penta-acetic acid (DTPA) and a large field of view gamma camera placed posteriorly to monitor the gastric emptying rates of iso-osmotic carbohydrate solutions continually in exercising subjects.

Methods

Five male subjects aged 25 (SD 2·5) years gave informed written consent to undertake the study. All were endurance trained athletes – two cyclists and three runners. The study was approved by the ethics committee of the Liverpool John Moores University. The permission of the Administration of Radioactive Substances Advisory Committee (ARSAC) was also obtained to give the radiolabelled solutions.

An initial assessment of peak oxygen consumption ($\dot{V}O_2$ peak) was performed by each subject riding to volitional exhaustion on an electrically braked cycle ergometer using a 3 min incremental protocol. Oxygen uptake was monitored throughout using a computerised gas analysis system (Cardiokinetics). The subjects refrained from exercise during the 24 h before the studies and regulated their food intake. All subjects consumed a similar pretest lunch (between 1200–1300 h) consisting of an easily digested sandwich and a non-alcoholic drink. Time of testing was kept constant, with all testing sessions starting between 1600 and 1700 hours. A single-blind counterbalanced design was employed. The subjects attended the laboratory on four separate occasions with studies being separated by at least one week.

To investigate the repeatability of the method used, each subject ingested the test solution on two separate occasions [trial 1 (T1) and trial 2 (T2)]. The ingested solutions were either 200 ml of a 5% glucose solution or 200 ml of an iso-osmotic maltodextrin solution. Before ingestion, the solutions were mixed with 3 MBq of ^{99m}technetium labelled DTPA. On arrival at the laboratory the subject was positioned on the cycle ergometer to enable the gamma camera to record a posterior view of the subject's stomach (fig 1). To ensure the region being monitored remained constant, the subject was asked to maintain an upright position with as little lateral movement as possible throughout the duration of the trial. Once positioned, the subjects began exercising at a work intensity corresponding to 70% of their predetermined $\dot{V}O_2$ peak, maintaining a pedal rate of 60 rpm. After 15 min of exercise the subject consumed 200 ml of the radiolabelled solution through a straw over a period of 30 s while continuing to exercise. Images were acquired posteriorly on a large field of view gamma camera (Siemans 7500) at a rate of one frame·min^{-1} for 45 min and stored on a digital computer (Nuclear Diagnostics PCS 512).

On a composite image of the first few frames, regions of interest (ROI) were drawn over the stomach and background and a gastric emptying curve and background curve were obtained. After correction for background radioactivity and radioactive decay, curve data were expressed as a percentage of the maximum count recorded in an initial image of the study. This initial maximum count was assumed to correspond to 100% of the ingested material. Due to intersubject variability in the patterns of emptying (figs 2 and 3), the data were not easily represented by simple mathematical function, that is a single exponential, and so calculations of areas under the curve (AUC) were made. Continuous monitoring helps to see emptying patterns, although the AUC is not particularly sensitive for slow emptiers

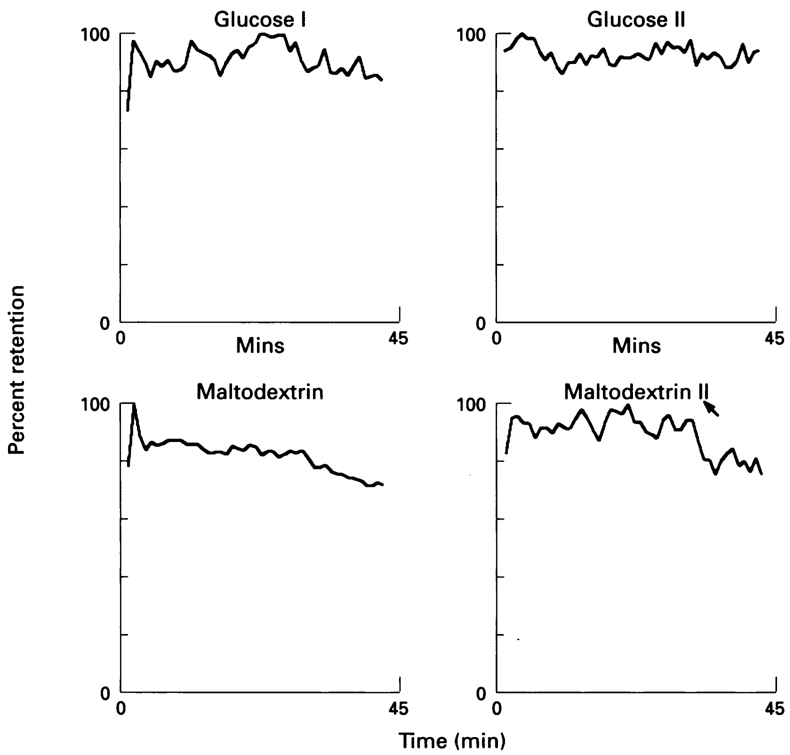

Fig 2 Per cent retention v *time for the four trials using a subject who emptied slowly.*

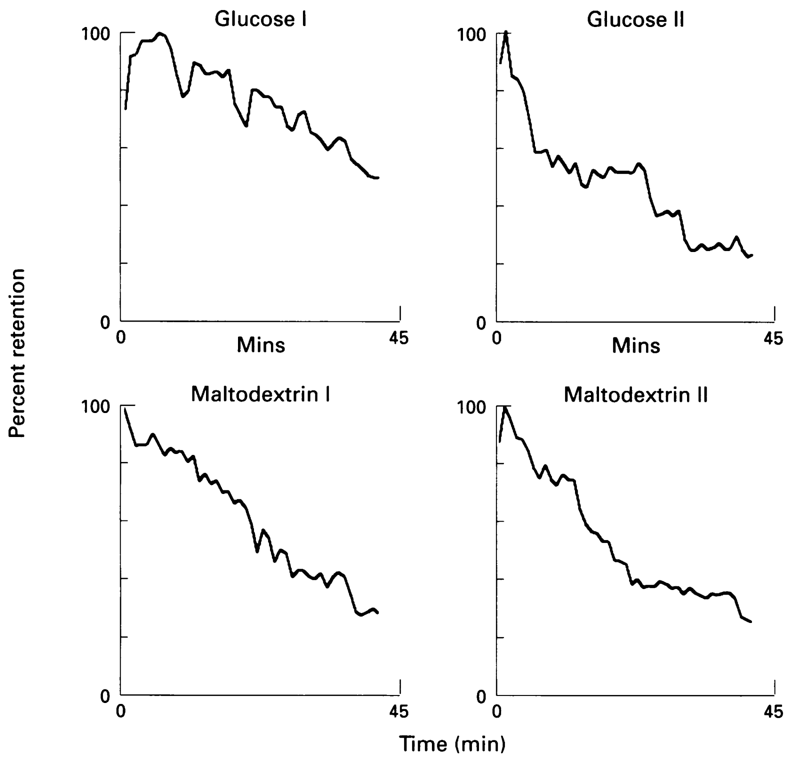

Fig 3 Per cent retention v *time for the four trials using a subject with rapid gastric emptying.*

(fig 2). The higher the value for the AUC the slower the gastric emptying.

Paired *t* tests were performed between T1 and T2 for each trial for the AUC, and likewise for the mean AUC between the glucose and maltodextrin trials.

Results

A summary of the values of the areas under the curves for each subject can be seen in the table. Paired *t* tests performed between T1 and T2 for each solution showed no significant differences between trials ($t = 1{\cdot}13$ for GL; $t = 0{\cdot}87$ for Md). No significant differences were observed between the mean AUC for the glucose and maltodextrin solutions ($t = 0{\cdot}12$).

Discussion

The results from the statistical analyses show no significant differences in the individual gastric emptying patterns from one trial to another irrespective of the type of carbohydrate ingested. This suggests that the technique is a repeatable process for monitoring gastric emptying during exercise.

Areas under the curves for each subject during the four trials.

		Area under curve	
		Glucose	*Maltodextrin*
Subject 1	Trial 1	3089	2490
	Trial 2	2555	2544
Subject 2	Trial 1	4120	3619
	Trial 2	4084	3988
Subject 3	Trial 1	3128	3949
	Trial 2	4024	4136
Subject 4	Trial 1	3655	3351
	Trial 2	2095	3421
Subject 5	Trial 1	3351	2570
	Trial 2	2127	2330

A comparison of the emptying patterns of the 5% glucose solution and the iso-osmotic maltodextrin solution showed no significant differences. Similar gastric emptying rates were found with both solutions. After 45 min, on average, 43·1% of the maltodextrin solution had emptied from the stomach compared with 49·5% of the glucose solution. Since both solutions emptied at similar rates, it may be assumed that the greater carbohydrate content of the maltodextrin solution would make it a more plentiful source of exogenous carbohydrate than the glucose solution. The amount of maltodextrin delivered to the small intestine would have averaged approximately 16·6 g in the 45 min, compared with approximately 5 g for glucose.

Previous investigations using the intubation technique during exercise at 70% $\dot{V}O_2$ max have shown that gastric emptying rates for 6% glucose solutions (9·9 $ml{\cdot}min^{-1}$) and 7·5% glucose polymer (12·1 $ml{\cdot}min^{-1}$) to be higher than in this study.[12 13] These values, however, were over a 120 min period in which repeated drinks were given every 15 min. This suggests that a maintained volume of fluid in the stomach may lead to greater emptying rates. It must be pointed out that the process of intestinal absorption can also influence the rate of delivery of glucose into the blood.[14]

Evident in this study were the marked individual differences in gastric emptying rates. Some subjects were seen to empty rapidly (fig 3), while others showed slow rates of emptying (fig 2). The data highlight the fact that the individual differences were the same for each trial, that is, subjects who empty quickly do so regardless of the drink given. This suggests that studies investigating gastric emptying characteristics during exercise must consider the individual differences which will occur from one athlete to another. Similarly, athletes used to drinking during exercise may show different characteristics from those unused to drinking during exercise. Because of the different nature of body movement and positioning, gastric emptying during running may show different characteristics than during cycling.

In conclusion, it appears from this study that the use of ^{99m}technetium labelled DTPA in carbohydrate solutions, together with external imaging with a large field of view, computer linked gamma camera, provides a repeatable process for monitoring gastric emptying continually during exercise. Also, there are no significant differences in the rates of gastric emptying of iso-osmotic solutions of glucose and maltodextrin when given as a single drink during exercise.

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