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GASTRIC EMPTYING DURING EXERCISE

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Key Points

1. Ingested drinks are retained in the stomach for a variable period of time, and the rate of gastric emptying may limit the replacement of carbohydrate and water during exercise.
2. High intensity exercise will slow or even stop gastric emptying, but exercise at intensities up to about 70-75% of maximal oxygen uptake has little or no effect on the rate of gastric emptying.
3. Increasing energy content will slow gastric emptying, and the pattern during exercise is the same as that observed at rest. Emptying is also slowed by solutions with very high osmolality relative to that of body fluids.
4. There is a large variation among individuals in the rate of gastric emptying.
5. Factors such as weather conditions may influence the choice of drinks.
6. Athletes should experiment during training to establish how much fluid they need and can tolerate.

INTRODUCTION

Fatigue during prolonged exercise is generally a consequence of depletion of the body's limited carbohydrate reserves and/or dehydration and the associated problem of hyperthermia. In most sports situations, both factors probably contribute to fatigue, with their relative contributions depending primarily on the climatic conditions. When temperature and humidity are high, fatigue is likely to occur before the carbohydrate stores are depleted, but at low ambient temperatures, the thermoregulatory system is not stressed and carbohydrate depletion is a primary cause of fatigue. In either situation, fatigue can be delayed and exercise performance improved by ingestion of suitably formulated beverages during exercise.

Most athletes consider that fluids are inside the body as soon as they are swallowed, but in fact, the contents of the gastrointestinal tract are effectively outside the body. The speed at which ingested carbohydrate, electrolytes, and water are available to the body depends on the rate at which they are emptied from the stomach and on the rate of their absorption into the blood from the small intestine. These factors must be taken into account in the formulation of drinks. Of these two processes, it is likely that gastric emptying generally limits the availability of ingested fluids; if the rate of fluid delivery from the stomach exceeds the absorptive capacity of the intestine and large bowel for a significant period of time, diarrhea ensues. Although this condition is by no means unknown during exercise, it does not normally occur in most individuals. There is normally a close coupling between gastric emptying and intestinal absorption. It is the uncoupling of these two processes that can lead to an excessive delivery of water and food energy to the colon and to gastrointestinal complaints.

METHODS OF MEASURING GASTRIC EMPTYING

There are numerous reports in the literature of factors influencing the rate of gastric emptying of liquid and solid meals, and many of these investigations have produced conflicting results. This is due, at least in part, to the different techniques that have been used to measure gastric emptying, so it is important to consider the different techniques involved. Most studies on emptying rates of liquids have relied on gastric aspiration techniques in which the stomach contents are recovered at a fixed time interval after ingestion of the test drink. This method assumes a linear rate of emptying. However, use of scintigraphic techniques, in which the movement of a non-absorbable radioactive tracer added to the drink can be followed by obtaining sequential images of the test drink as it passes through the stomach shows that emptying follows an exponential time course (Leiper & Maughan, 1988); gastric aspiration techniques that rely on repeated sampling provide more direct evidence confirming these observations (Rehrer et al, 1989). Comparison of aspiration and scintigraphic techniques by making simultaneous measurements with both shows that the two methods give similar results (Beckers et al., 1992).

Because the emptying pattern is exponential rather than linear, interpretation of the results is strongly influenced by the time at which measurements are made. When sampling at a single time point has been used, different investigators have chosen different intervals in the range 10-60 min between drink ingestion and sampling, making comparisons between drinks and between studies difficult.

It is obvious that emptying of solid meals cannot be measured using aspiration methods, and there are also problems in ensuring that added tracers empty at the same rate as the bulk of the meal. Other techniques, including electrical impedance and magnetic resonance imaging, offer some prospects, but most of the available information relates to the emptying of liquid meals. There are, in any case, few exercise situtations where solid food is consumed during or immediately before exercise. Such examples include prolonged triathlons and cycling events.

Table 1. Some of the factors known to influence the gastric emptying rate of liquids. There are in addition a large number of factors that may have some minor effect on this process.

Volume	Increasing volume promotes emptying
Energy Content	Increasing energy content slows emptying
Osmolality	Markedly increasing osmolality slows emptying
pH	Marked deviations from neutrality slow emptying
Exercise	Hard (>70-75% VO2 max) exercise slows emptying
Stress	Mental stress and anxiety slow emptying
Dehydration	Slows gastric emptying; increases risk of gastrointestinal distress

CONTROL OF GASTRIC EMPTYING

Some exchange of water does occur in the stomach, but it is not clear whether there is net absorption; no significant absorption of nutrients, other than alcohol to a limited extent, takes place in the stomach (Karel, 1948). The gastric emptying rate regulates the rate at which ingested food and fluids are delivered to the site of absorption in the small intestine and the extent to which they are modified by the gastric secretions. Many factors influence the rate of gastric emptying of liquids, and some of these are listed in Table 1. Most of this information is derived from studies on resting individuals; the effects of exercise will be discussed later.

The exponential nature of the emptying curve indicates the crucial importance of the volume of the stomach contents in controlling the rate of emptying. As fluid is emptied and the stomach volume falls, so the rate of emptying is decreased. Maintaining a large fluid volume in the stomach will promote emptying, and repeated drinking, to replace the fluid that has been emptied, will maximize the rate of fluid and nutrient delivery to the small intestine (Rehrer et al., 1990b; Mitchell & Voss, 1991; Noakes et al., 1991).

The composition of ingested fluids also has a major effect on the rate of emptying, and emptying is slowed if solutions are markedly hypertonic with respect to the osmolality of body fluids (Hunt & Pathak, 1960), by increasing acidity (Hunt & Knox, 1969) and by increasing energy content (Hunt & Stubbs, 1975). It seems well established that the emptying rate of carbohydrate (CHO) solutions is slowed relative to isotonic saline solutions (McHugh & Moran, 1979; Brener et al., 1983), although Barker et al., (1974) found no difference in the emptying rates of isosmotic solutions of glucose and potassium chloride.

The effect of increasing glucose concentrations on the time course of emptying has been extensively investigated; the emptying rate is slowed in proportion to the glucose content and slows as the volume of fluid remaining in the stomach decreases. Some reports have indicated that the rate of gastric emptying is decreased if the CHO content of the drink exceeds 2.5% (Costill & Saltin, 1974; Foster et al., 1980), but other studies have shown that emptying of solutions containing up to 10% glucose or glucose polymer is not delayed relative to water (Owen et al., 1986; Rehrer et al., 1989). At least part of this apparent discrepancy is probably the result of the design of these studies. In most of the early investigations, the volume of fluid remaining in the stomach was measured at a single time point after ingestion of the test drink. If a fixed volume of two different glucose solutions, one dilute and one concentrated, is given, the initial emptying rate for the dilute solution will be more rapid; because gastric volume is a major determinent of the rate of emptying, the emptying rate is reduced as the volume decreases, but this effect will be less marked for the more concentrated solution which empties more slowly in the initial phase. From the results of studies where the whole time course has been investigated, it appears that glucose concentrations in excess of about 4-5% will slightly delay gastric emptying (Vist & Maughan, 1992). It is also apparent that, although increasing the glucose content of the ingested fluid does slow the rate at which fluid leaves the stomach, it results in a faster delivery of glucose (Hunt et al., 1985).

Several studies have used isotopic tracers to study the fate of ingested solutions during exercise. Most of these investigations have used concentrated (25-30%) solutions of glucose, usually without added electrolytes. Although it might be expected that these solutions would empty from the stomach only extremely slowly and would not be well tolerated, it appears that the ingested glucose is readily available for oxidation during exercise at intensities up to 60-70% of maximal oxygen uptake. These studies have been reviewed by Maughan (1991).

Substitution of maltodextrins (short chain glucose polymers) for free glucose may help to promote the emptying of glucose-electrolyte solutions from the stomach by reducing the osmolality of the solution while maintaining the total glucose content, although the studies reported in the literature are by no means in agreement. In an early report, Hunt (1960) found no major differences in the emptying rates of solutions containing isoenergetic amounts of monomeric glucose or starch. Foster et al., (1980), however, reported that substituting glucose oligomers 3-4 units in length for free glucose (5% solution) increased the rate of emptying by approximately one third, but no differences existed in emptying rates between free glucose and polymers for 10, 20, and 40% solutions. These results are in marked contrast to those reported recently by Sole and Noakes (1989); they found that a 15% glucose polymer solution emptied faster than a 15% solution of free glucose, although 5% and 10% solutions of free glucose and polymer appeared to be emptied at the same rates. The disparate results may be due to the fact that total gastric volume, including the volume of gastric secretions, was measured in the study of Foster et al., (1990) and the volume of the gastric secretions was unknown. Increased beverage osmolality increases the volume of gastric (as well as intestinal) secretions, and it is therefore possible that the total volume of the stomach contents may have been greater when solutions containing glucose rather than polymers were drunk, even though the amount of the ingested drink remaining in the stomach was the same. In another study, Naveri et al., (1989), found similar emptying rates for electrolyte solutions with 3% carbohydrate added in the form of either glucose or a polymer. Owen et al., (1986) found no difference in the rate of emptying of 10% solutions of glucose or glucose polymer, in spite of the higher osmolality of the free glucose solution. Rehrer et al., (1992) also observed similar emptying rates with 17% solutions of glucose polymer (313 mosmol/kg) and free glucose (1223 mosmol/kg); however, a 4.5% glucose solution emptied faster than a 17% polymer solution with the same osmolality. Even dilute polymer solutions are generally emptied more slowly than plain water, but Seiple et al., (1983) did report that a 7% glucose polymer solution with an osmolality of 216 mosmol/kg was emptied as fast as water; however, the first sampling point in this study was at 30 min, by which time at least 90% of total volume had emptied for all the solutions studied. In none of the above studies was the emptying rate of polymer solutions slower than that of free glucose solutions with the same energy content, and the polymer solutions were generally emptied faster even when the differences were not statistically significant.

It now seems likely that several other factors which were formerly thought to be important, such as carbonation and the temperature of ingested drinks, do not have a major influence on the rate of emptying (Maughan, 1991). These factors may, however, be important in affecting the palatability of drinks, which will influence the volume consumed.

In summary, gastric emptying of liquids is regulated by a number of factors of which the most important are the volume and the energy content. Osmolality is of secondary importance and probably has little effect in the range of most commonly consumed sports drinks. Increasing the carbohydrate content of drinks will delay emptying. Substitution of glucose polymers for free glucose may slightly increase the rate of delivery of fluid and substrate to the small intestine, but the evidence is not clear, indicating that any effect is likely to be rather small. The factors regulating gastric emptying have been the subject of extensive reviews (Murray, 1987; Brouns et al., 1987; Maughan, 1991).

EFFECTS OF EXERCISE ON GASTRIC EMPTYING

Compared with the extensive literature on the regulation of gastric emptying at rest, relatively few measurements have been made during exercise. Costill and Saltin (1974) showed that 15 min of cycling exercise had no effect on gastric emptying of a dilute glucose-electrolyte solution until a work intensity of about 70% VO_2 max was reached; at 80-90% VO_2 max, the emptying rate was only about 50% of the resting rate. In a rather poorly controlled study, Ramsbottom and Hunt (1974) found that 20 min of “severe exercise” (100W!) reduced the emptying rate of a 278 mmol/L (5%) glucose solution in 4 of 6 subjects. During intermittent cycling exercise at 74% of VO_2 max , gastrointestinal transit time, estimated by breath hydrogen analysis, was not different from rest, and was not different when concentrated glucose (1000 mmol/L) or flavoured dilute (150 mmol/L) solutions were given (Segal et al., 1985). Mitchell et al., (1989) found that prolonged (105 min) cycling at 70% VO_2 max did not affect the rate of emptying of a 6% carbohydrate solution (4% glucose polymer, 2% sucrose) compared with rest; their subjects drank approximately 620 mL/h, and the calculated emptying rate was close to 600 mL/h. Similar results were obtained during intermittent exercise (Mitchell et al., 1988). Emptying rate in excess of 1 L/h, corresponding to over 90% of the ingested volume, can be achieved during prolonged (3 h) exercise at 60% VO_2 max in the heat (Ryan et al., 1989). Using a double sampling gastric aspiration technique that allowed the time course of emptying to be measured, Rehrer et al., (1989) reported that exercise at 50 or 70% VO_2 max had no significant effect on the emptying rate of sweetened water or CHO-electrolyte solutions, although there was a trend towards a decreased emptying rate of the CHO-electrolyte solutions, but not of water, with increasing exercise intensity. They also showed that gastric emptying and gastric secretion were not different between trained and untrained individuals.

Figure 1

Rate of accumulation in the circulation of a deuterium tracer added to a dilute carbohydrate-electrolyte drink consumed at rest or during exercise at intensities corresponding to 42, 61 and 80% of maximum oxygen uptake.(Reproduced with permission from Maughan et al., 1990).

When a dilute glucose-electrolyte solution labeled with 2H2O is given at rest or during exercise, the rate of accumulation of deuterium in the plasma decreases in proportion to the exercise intensity, and the time to peak plasma deuterium concentration increases with increasing exercise intensities in the range 40 - 80% VO_2 max (Figure 1). These results imply a decreased availability of ingested fluids during exercise: either or both gastric emptying and intestinal absorption may be slowed (Maughan et al., 1990). Although it has been suggested that the use of tracer techniques may not give a valid measure of net water flux in the small intestine when different solutions are compared (Gisolfi et al., 1990), the technique appears to be valid for the comparison of the same solution under different conditions.

The above studies all involved cycling exercise, but earlier, albeit rather poorly controlled, investigations had established that gastric emptying is delayed during running (Campbell et al., 1928). In 1967, Fordtran and Saltin reported that the rate of emptying of a concentrated glucose-electrolyte solution (740 mmol./L (13.3%) glucose; 52 mmol/L NaCl) was not changed during 1 h of treadmill running at 70% VO_2 max compared with rest; emptying of plain water was much faster and was slightly delayed by exercise. Costill et al., (1970) found no differences in the gastric emptying rates of water and a dilute glucose-electrolyte solution during 2 h of treadmill running at 70% VO_2 max in highly trained runners. Owen et al., (1986) found no difference in emptying rates of solutions containing 10% glucose (586 mosmol/kg) or 10% glucose polymer (194 mosmol/kg) compared with sweetened water during 2 h treadmill running in the heat (35 C) at 65% VO_2 max; emptying of the glucose solution, but not of the others, was retarded relative to artifically sweetened water ingested during exercise at a lower (25C) ambient temperature. In contrast to these results, Neufer et al., (1986) found that 15 min of running at 50 or 70% VO_2 max increased the rates of emptying of water and of carbohydrate-containing solutions relative to rest. Later, Neufer et al., (1989a) confirmed these results for walking and running at 28-65%

VO_2 max, but found a decreased emptying rate at 75% VO_2 max compared with rest. The same authors also reported that exercise in the heat (49 C) or after dehydration reduced gastric emptying compared with exercise at a neutral temperature (Neufer et al., 1989b). These results were confirmed by Rehrer et al., (1990a). Sole and Noakes (1989) have reported that gastric emptying of water, but not of a 10% glucose polymer solution, is delayed during 30 min of treadmill running at 75% VO_2 max; this result is the opposite of that obtained by Rehrer et al., (1989) during cycling.

Houmard et al., (1991) have shown that the gastric emptying rate of water was slowed during either cycling or running at 75% of VO_2 max, but that exercise had no effect on the emptying rate of a 7% carbohydrate-electrolyte solution, which was emptied more slowly than water at rest but not during exercise. There was no difference between the two exercise modes. Although this study was generally well controlled, i.e., the same subjects were studied at rest and during the two different exercise modes, it suffers from the limitation that a single measurement of the volume of the gastric residue was made at the end of the 1 h study period. However, Rehrer et al., (1990b) also found no difference in gastric emptying between cycling and running at the same relative intensities with repeated drinking when serial measurements were made throughout exercise.

As with the resting studies described above, some of the variability between these exercise studies is probably an effect of differences in sampling times. In some of the exercise studies, the experimental protocol required the subjects to ingest several different test beverages sequentially during a single session. The effects of the presence of previous drinks in the small intestine cannot be excluded as a source of error (Rehrer et al., 1989a).

The mechanisms by which exercise might influence the function of the gastrointestinal tract are thought to be related to the increased circulating catecholamine level and reduced perfusion of the splanchnic vascular bed during strenuous exercise; these effects have been reviewed by Murray (1987).

Practical Applications

The common assumption that frequent small sips is the best pattern of fluid ingestion for maximizing fluid and carbohydrate replacement during exercise is not supported by the fact that increasing the ingested fluid volume results in an increased rate of gastric emptying. Starting with a large bolus and repeatedly ingesting additional amounts so as to maintain a high volume of liquid in the stomach will lead to a greater rate of water and carbohydrate delivery to the small intestine. The presence of large volumes in the stomach is better tolerated by some individuals than by others, but there may be a training effect that allows larger volumes to be consumed without problems. Ingestion of increased volumes of drinks immediately prior to and during exercise should therefore be practiced during training before a major competition.

Depending on beverage availability and individual tolerance, it is generally best to begin an endurance event with a partially filled stomach. If possible, the composition of drinks should be adjusted to meet the anticipated energy (carbohydrate) and fluid demands. During a short-duration (less than 1 hour) competition or training session held on a hot humid day, fluid replacement will take priority over carbohydrate provision, and relatively dilute carbohydrate-electrolyte drinks are best. This probably means a drink that is isotonic or hypotonic, with a carbohydrate content of less than about 5%-6%. At the other extreme, during a slow cross-country ski tour in cold weather, sweat losses will be small, and fluid replacement will be secondary to carbohydrate supply. In this case, the carbohydrate content of the drink may be as high as 10-15%, to enhance energy delivery. These are extreme examples, and most individuals will do best in most situations by taking a drink that is about 5-8% carbohydrate: this will provide the best compromise between rehydration and carbohydrate delivery. Glucose, fructose, sucrose and glucose polymers are all commonly used in sports drinks, and mixtures of sugars may have benefits in terms of efficacy and palatability. Drinks containing only fructose are usually best avoided as the rate of absorption in the small intestine is slower and this may cause gastrointestinal distress. The temperature of ingested fluids is of little importance in terms of gastrointestinal function, but chilled beverages are generally more palatable. Exercise at intensities that can be sustained long enough for fluid replacement to be necessary does not significantly affect gastrointestinal function, and there is no indication that drinking patterns should be altered to take account of exercise of different intensities.

The aim should always be to replace as much of the sweat loss as is possible, in order to maintain cardiovascular and thermoregulatory function. An example of the minimum fluid ingestion pattern that would be recommended for distance runners is outlined below:

Before competition - (5-10 min before the start) - 8 mL/kg body weight (400-600mL)

During competition - every 15-20 min (every 5 km) - 3 mL/kg body weight (150-250mL)

During prolonged exercise in hot weather, when sweat loss can exceed 1 L/h, these recommendations should be considered minimums. In cycling and other sports where drinks are continuously available and are easily ingested, greater volumes may be consumed, and the frequency of drinking can be increased.

SUMMARY

Exercise has little effect on gastric emptying at intensities of less than 70% of VO_2 max: even at higher exercise intensities, there is little evidence to suggest that the decrease is sufficient reason to avoid fluid ingestion during exercise. The type of exercise is of little importance, and similar rates of gastric emptying are observed in cycling and running when the exercise intensity is the same.

Increasing the volume of fluid present in the stomach at any time will stimulate gastric emptying. The rate at which fluids are available for absorption in the small intestine is therefore maximized by the frequent ingestion of large volumes so as to maintain a substantial residual volume.

The energy content of drinks is an important regulator of the rate of gastric emptying; for sports drinks, the energy content is primarily in the form of carbohydrate. Addition of carbohydrate, especially in the form of glucose, is important to stimulate water absorption in the small intestine as well as to supply a source of energy for the working muscles. Increasing the carbohydrate content of drinks will reduce their emptying rate, decreasing the rate of fluid delivery, but, within a broad concentration range (perhaps about 2-10%) this effect is offset by the stimulation of intestinal water uptake. An increasing carbohydrate content, however, increases the rate of energy delivery. Increased osmolality also slows gastric emptying, but this effect is generally secondary to the effects of volume and of energy content. Increasing osmolality does affect the rate of gastric secretion, but this has little effect on net fluid balance. Beverage temperature and carbonation affect palatability but have little effect on the rate at which fluids are emptied. Indirect effects of palatability on the volume of fluid that is voluntarily ingested should not, however, be underestimated.

Hypohydration and hyperthermia decrease the rate of gastric emptying, and efficient fluid replenishment requires the ingestion of sufficient volumes of an appropriate replacement fluid in anticipation of losses. Delaying replacement until a fluid deficit has been incurred is likely to cause serious problems for the athlete.

Individual differences in gastric emptying rates are large and will influence the volume that can be consumed. Some degree of adaptation to fluid ingestion during exercise may occur and it is essential that each athlete establish an optimal individualized regimen. Experimentation with different drinking patterns is best done in training rather than in competition.

References

Barker G.R., G.M. Cochrane, G.A. Corbett, J.N. Hunt, S.K. Roberts (1974). Actions of glucose and potassium chloride on osmoreceptors slowing gastric emptying. J. Physiol. 237: 183-186.

Beckers E.J., J.B. Leiper and J Davidson (1992). Comparison of aspiration and scintigraphic techniques for the measurement of gastric emptying rates in man. Gut. 33: 115-117.

Brener W., T.R. Hendrix, P.R. McHugh (1983). Regulation of the gastric emptying of glucose. Gastroenterology 85: 76-82.

Costill D.L., B. Saltin (1974). Factors limiting gastric emptying during rest and exercise. J. Appl. Physiol. 37: 679-683.

Fordtran J. and B. Saltin (1967). Gastric emptying and intestinal absorption during prolonged severe exercise. J. Appl. Physiol. 23: 331-335.

Foster C., D.L. Costill, W.J. Fink (1980). Gastric emptying characteristics of glucose and glucose polymers. Res Quart 51: 299-305.

Hunt J.N., M.T. Knox (1969). The slowing of gastric emptying by nine acids. J. Physiol. 201: 161-179.

Hunt J.N., J.D. Pathak (1960). The osmotic effect of some simple molecules and ions on gastric emptying. J Physiol. 154: 254-269.

Hunt J.N., D.F. Stubbs (1975). The volume and energy content of meals as determinants of gastric emptying. J. Physiol. 245: 209-225.

Hunt J.N., J.L. Smith, C.L. Jiang (1985). Effect of meal volume and energy density on the gastric emptying rate of carbohydrates. Gastroenterology 89: 1326-1330.

Karel L. (1948). Gastric Absorption. Physiol. Rev. 28: 433-450.

Leiper J.B., R.J. Maughan (1988). Experimental models for the investigation of water and solute transport in man: implications for oral rehydration solutions. Drugs 36 Suppl. 4: 65-79.

McHugh P.R., T.H. Moran (1979). Calories and gastric emptying: a regulatory capacity with implications for feeding. Am. J. Physiol. 236: R254-260.

Maughan R.J. (1991). Effects of CHO-electrolyte solution on prolonged exercise. In: Lamb D.R., M.H. Williams (Eds). Perspectives in Exercise Science and Sports Medicine. Benchmark Press, Carmel. 1991 pp 35-89

Maughan R.J., Leiper J.B. and McGaw B.A. (1990). Effects of exercise intensity on absorption of ingested fluids in man. Exp. Physiol. 75: 419-421.

Mitchell J.B., K.W. Voss (1990). The influence of volume on gastric emptying and fluid balance during prolonged exercise. Med. Sci. Sports Ex. 23 314-319.

Noakes T.D., N.J. Rehrer, R.J. Maughan (1990). The importance of volume in regulating gastric emptying. Med. Sci. Sports Ex. 23, 307-313.

Owen M.D., K.C. Kregel, P.T. Wall, C.V. Gisolfi (1986). Effects of ingesting carbohydrate beverages during exercise in the heat. Med. Sci. Sports Ex. 18: 568-575.

Rehrer N.J., E. Beckers, F. Brouns, F. Ten Hoor, W.H.M. Saris (1989). Exercise and training effects on gastric emptying of carbohydrate beverages. Med. Sci. Sports Ex. 21: 540-549.

Rehrer N.J., E. Beckers, F. Brouns, F. Ten Hoor, W.H.M. Saris (1990a). Effects of dehydration on gastric emptying and gastrointestinal distress while running. Med. Sci. Sports Ex. 22: 790-795.

Rehrer N.J., F. Brouns, E. Beckers, F. Ten Hoor, W.H.M. Saris (1990b). Gastric emptying with repeated drinking during running and bicycling. Int. J. Sports Med. 11:238-243

Rehrer N.J., A.J.M. Wagenmakers, E.J. Beckers et al (1992). Gastric emptying, intestinal absorption and carbohydrate oxidation during prolonged exercise. J. Appl. Physiol. 72: 468-475

Vist G.E., R.J. Maughan. Gastric emptying of dilute glucose solutions in man. Med. Sci. Sports Ex. 1992: 24; S70.

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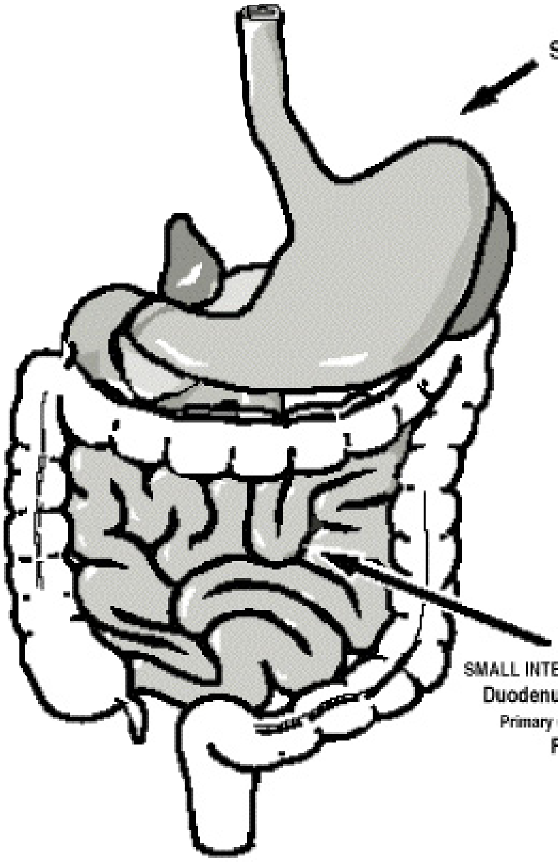
FACTORS AFFECTING GASTRIC EMPTYING AND ABSORPTION



STOMACH

Major factors that influence the gastric emptying rate of fluids:

Volume	(Increased volume leads to increased emptying rate)
Energy Content	(Increased energy content leads to decreased emptying rate)
Osmolality	(Increased osmolality leads to decreased emptying rate)
pH	(Marked deviations from neutrality leads to decreased emptying rate)
Exercise	(>70-75% VO max exercise leads to decreased emptying rate)
Stress (Psychological stress and anxiety leads to decreased emptying rate)	
Dehydration	(decreased gastric emptying) (increased risk of gastrointestinal distress)

SMALL INTESTINE

Duodenum (~1 foot), Jejunum (~8 feet), Ileum(~11 feet)

Primary site of fluid absorption (60% of absorption occurs here)

Factors affecting intestinal fluid absorption:

Osmoality	Water absorption is maximal from hypotonic or isotonic solutions containing glucose and sodium
Carbohydrate	An optimal concentration of carbohydrate, especially in the form of glucose, in conjunction with sodium will stimulate fluid absorption
Sodium	Increases fluid absorption in the proximal small intestine (duodenum)
Amino Acids	May enhance fluid absorption
Anions	Chloride is the perfect anion to maximize fluid absorption