Effects of oral glucose intake on gastric myoelectrical activity and gastric emptying

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Abstracts

To investigate the effect of oral glucose intake on gastric motility, we measured gastric myoelectrical activity and gastric emptying on two test conditions: 1) glucose intake and 2) water intake in the same 10 healthy male volunteers (20 to 29 years old). Gastric motility was evaluated with cutaneous-recorded electrogastrography (EGG) for 30 min both on fasting and after glucose or water intake, while gastric emptying was measured using acetaminophen-absorption method. There were no significant changes in EGG dominant frequency after water intake, but the frequency increased significantly after glucose intake. A postprandial dip (*i.e.*, a transient decrease in frequency immediately after the food intake) was observed in 3 subjects after water intake and in 8 subjects following glucose intake. The EGG power ratio was significantly larger after glucose than water intake, with delayed gastric emptying in the former case. These results suggest that glucose is one of the components responsible for postprandial gastric motility.

Key words: gastric motility, electrogastrography, gastric emptying, glucose, water

Introduction

Various factors contribute to the onset of postprandial gastric motility patterns. Some studies in normal subjects (Stacher *et al.*, 1990; Cunningham *et al.*, 1991; Cunningham *et al.*, 1991; Harris *et al.*, 1991) have shown that the intake of a caloric high- meal or -fat meal causes physiological changes including delayed gastric emptying and modulation of gastrointestinal motility. It is not clear whether there are differences in the gastric motility patterns after meals between low- and high-caloric intakes. Furthermore, the role of ingested nutrients such as glucose or fat in postprandial gastric motility is poorly understood.

This study investigated the effect of glucose on gastric motility by comparing gastric

myoelectrical activity and gastric emptying after oral liquid intake between an equal volume of water and glucose-containing solution.

Materials and Methods

Subjects

Studies were performed in 10 healthy male volunteers (20–29 years old). All subjects understood the purpose of this study and provided written informed consent. No subjects had metabolic or gastrointestinal disorders, and none had been taking any medications. The glucose and water intake tests were conducted on each subject. The temperature of both glucose solution and water is set at 10°C. The two independent tests were randomly performed on different days.

Experimental procedure

Gastric motility was assessed with cutaneous-recorded electrogastrography (EGG) and by measurements of gastric emptying using the acetaminophen-absorption method. After fasting for at least 4 hours, the EGG was recorded for 30 min in the supine position. The subjects then stood up and ingested 20 mg/kg of acetaminophen powder mixed with either 225 ml of water or 75 g/225 ml of glucose (TRELAN G75, Shimizu Pharmaceutical, Shimizu, Japan). Immediately following the intake, the subjects returned to the supine position and the EGG record was repeated for a further 30 min. The EGG was measured using bipolar Ag-AgCl electrodes placed on the right and left midclavicular lines along the long axis of the stomach over the surface of the upper abdomen. The EGG signals were low-pass filtered with a cut-off frequency of 0.1 Hz, and recorded on an FM data recorder (MR-30, TEAC, Tokyo, Japan). The obtained data were sampled at 1 kHz using an analog/digital converter (ADX-98E, Canopus Electronics, Kobe, Japan). The power spectral density in the EGG was computed with a program using an autoregressive model. The following parameters were obtained from the EGG using autoregressive power spectral analyses and evaluated for each subject.

1. EGG dominant frequency: the frequency at which the power was highest within the range of 0.02–0.107 Hz (1.2–6.4 cpm) of an entire EGG recording. It has been suggested that the dominant frequency of the EGG reflects the frequency of the gastric slow waves (Familoni *et al.*, 1991; Chen *et al.*, 1994).
2. Percentage of normogastria: defined as the percentage of time during which normal 0.04–0.06 Hz (2.4–3.6 cpm) slow waves were present over the entire observation period. This parameter reflects the regularity of the gastric myoelectrical activity. An EGG frequency higher than 0.06 Hz (3.6 cpm) was defined as tachygastria and one slower than 0.04 Hz (2.4 cpm) was defined as bradygastria.
3. Power ratio: defined as the ratio of after to before water or glucose intake EGG dominant power values (*i.e.*, postload power/preload power), where the dominant power refers to the power at the EGG dominant frequency. It is suggested that changes in the EGG dominant power reflect gastric contractility (Smout *et al.*, 1980; Hamilton *et al.*, 1986; Chen *et al.*, 1994).
4. Postprandial dip (PD): a transient frequency decrease that is usually seen in the EGG in

Table 1 Changes in EGG parameters and gastric emptying induced by an equal volume of fluid intake of water and glucose solution

		water intake			glucose intake		
		before	<i>P</i>	after	before	<i>P</i>	after
EGG parameters							
Frequency	D.F. (cpm)	3.1 ± 0.2	NS	3.1 ± 0.3	3.0 ± 0.2	0.05	3.4 ± 0.2
	Normogastria (%)	79.5 ± 11.2	NS	72.4 ± 15.3	80.1 ± 9.7	NS	78.3 ± 11.9
	Tachygastria (%)	14.1 ± 7.6	NS	16.3 ± 8.2	12.6 ± 7.1	NS	15.5 ± 7.4
	Bradygastria (%)	6.4 ± 3.9	NS	11.3 ± 6.8	7.3 ± 5.0	NS	6.2 ± 3.0
Power ratio				1.4 ± 0.3			2.2 ± 0.6*
Postprandial dip (person)				3			8**
Gastric emptying							
Serum acetaminophen (mg/ml)				12.2 ± 2.3			8.8 ± 1.9***

Values are mean ± SD. EGG: electrogastrography, cpm: cycle per minute, D.F.: dominant frequency.

P*<0.05 vs. water intake, *P*<0.05 vs. water intake by chi-square test, ****P*<0.01 vs. water intake.

normal subjects immediately after food intake (Geldof *et al.*, 1986; Geldof *et al.*, 1989; Kaneko *et al.*, 1995). In this study it was determined by visual inspection.

Venous blood (~10 ml) was collected at identical time points for subsequent measurement of plasma glucose and serum insulin and acetaminophen. The serum acetaminophen concentration was determined by fluorescence polarization immunoassay (TDX system, DAINABOT Co, Ltd, Tokyo, Japan). The degree of gastric emptying was expressed as the serum acetaminophen concentration 45 min after glucose or water intake.

Statistical analysis

Values of EGG parameters and serum acetaminophen concentration are expressed as mean ± SD. The changes in the EGG dominant frequency and the percentage of normogastria as well as the comparisons of the EGG power ratio and serum acetaminophen concentration were analyzed using the paired *t*-test. The significances in difference in occurrence of a PD and normogastria were assessed using Yates chi-square test. A probability of less than 0.05% (*P*<0.05) was considered statistically significant.

Results

Electrogastrography

During the preload period, the EGG spectra in all 10 subjects contained a dominant frequency in the normal range of 0.04–0.06 Hz (2.4–3.6 cpm) in all tests. No significant changes in EGG dominant frequency and the percentage of normogastria were seen between before and after water intake. In contrast, a significant increase in EGG dominant frequency was observed after glucose intake (Table 1). All 10 subjects showed a higher value of EGG power ratio after glucose intake compared with that after water intake (Fig. 1). EGG power ratios associated with glucose intake were significantly higher than those with water intake. PD was observed in 3 subjects in the case of water intake, and in 8 subjects after glucose intake (Table 1).

Fig. 1. The power ratio of EGG in each individual with water or glucose intake.

Fig. 2. Gastric emptying expressed as the serum acetaminophen concentration 45 minutes after water or glucose intake.

Gastric emptying

Nine subjects showed a lower value of serum acetaminophen concentration after glucose intake compared with that after water intake (Fig. 2). There was a significant decrease in serum acetaminophen concentration after glucose intake compared with that after water intake, indicating that gastric emptying was delayed after glucose intake (Table 1). There was a significant inverse correlation between the change in serum acetaminophen concentration and the change in EGG power ratio from oral intake of water to that of glucose (Fig. 3). Plasma glucose and serum insulin showed maximal values at 30 min after glucose intake.

Fig. 3. Relationship between the change in gastric emptying and the change in EGG power ratio. Δ Serum acetaminophen and Δ EGG power ratio were calculated by subtraction of values in glucose intake from values in water intake of each subject.

Discussion

The present study showed that there was a difference in the effects on gastric myoelectrical activity and gastric emptying between oral glucose and water intakes. After glucose intake, a slight increase in the dominant frequency in the EGG and a delay in gastric emptying were observed. These results suggest that glucose is one of components responsible for postprandial gastric motility.

In this study, we used the EGG and assessed gastric emptying by the acetaminophen-absorption method to qualify gastric motility. EGG involves recording of gastric myoelectrical activity from abdominal surface electrodes (Geldof *et al.*, 1986; Alvarez, 1992; Chen *et al.*, 1993), and has recently been attracting attention as a simple, non-invasive method for investigating gastric motility in both fasting and postprandial states. The stomach itself has a myogenic mechanism for essential determining movement. It has been suggested that the EGG accurately reflects gastric slow waves (Familoni *et al.*, 1991; Chen *et al.*, 1994) and that an increase in the power of the EGG reflects contraction-related spike potentials (Smout *et al.*, 1980; Hamilton *et al.*, 1986). The acetaminophen-absorption method is a reliable and simple test for evaluating gastric emptying. Heading *et al.* (1973, 1976) reported a significantly negative correlation between the half-time of gastric emptying measured with the scintiscanning technique and the serum acetaminophen concentrations at 30 min and 60 min. Harasawa *et al.* (1979) reported an inverse correlation between the half-time of gastric emptying and the acetaminophen concentration at 45 min. That study assessed the clinical applications of this method by measuring gastric emptying in patients with peptic ulcers (Harasawa *et al.*, 1979; Kamiya *et al.*, 1998), gastritis and gastric cancer (Tatsuta *et al.*, 1990).

From the present study, it appears that oral glucose intake caused a change in the gastric

pace-maker that generates slow waves. A slight but significant increase in the EGG dominant frequency was observed following glucose intake, whereas this was not seen after oral water intake. In some studies (Geldof *et al.*, 1986; Koch *et al.*, 1987; Geldof *et al.*, 1989; Chen *et al.*, 1991; Kobayashi *et al.*, 1997), a slight but significant increase in EGG dominant frequency was observed after food intake in healthy subjects. The changes in EGG dominant frequency after glucose intake are similar to the responses to food intake. Whereas some studies (Verhamgen *et al.*, 1998; Macintosh *et al.*, 2001) have shown that the EGG frequency remained unchanged after intraduodenal glucose infusion in healthy young subjects. The mechanism responsible for the increase in EGG dominant frequency during the postprandial period is not understood.

Moreover, in the present study the EGG power ratio was significantly greater after oral glucose intake than after oral water intake. Postprandial increases in EGG power have been reported (Smout *et al.*, 1980; Stern *et al.*, 1989; Chen *et al.*, 1991; Kaneko *et al.*, 1995; Kobayashi *et al.*, 1998; Riezzo *et al.*, 2000; Chou *et al.*, 2001) previously and Macintosh *et al.* (2001) reported the increase in the EGG power ratio during and after intraduodenal glucose infusion in healthy young and old men.

The increase in the EGG power seems to be mediated by two factors: 1) the postprandial increase in the gastric contraction and 2) the gastric distension bringing the stomach closer to the recording electrodes. Since the volume of liquid ingested was same in both experiments in our study, it can be inferred that while the increase in power (1.4 ± 0.3) after water intake is principally attributable to the physical expansion of the stomach, the power increase following glucose intake (2.2 ± 0.6) be due to the addition of contraction-related spike potentials.

PD, which is a transient decrease in frequency that occurs within a few minutes following ingestion of food (Geldof *et al.*, 1986, 1989; Kaneko *et al.*, 1995), was observed in 3 subjects following water intake and in 8 subjects after glucose intake. PD is usually found in normal subjects, and its onset is probably mediated by the physical distension of stomach due to food intake. From these results, it is suggested that the onset of PD may be mediated by physical stimulation by the entry of food into the stomach and the ensuring of the stomach. However, PD was not observed in 7 normal subjects after water intake and 2 normal subjects following glucose intake. This finding points to the possibility that other factors may mediate such phenomenon. The physiological significance and the cause of the PD still need to be elucidated.

Gastric emptying was delayed significantly after glucose intake compared with that following water intake. The factors that regulate gastric emptying consist of dilation of the fundus, peristalsis of the gastric body, contraction of the antrum and pyloric function. In this study, there was a significant inverse correlation between the reduced gastric emptying and the increased EGG power ratio in oral intake of glucose. It is suggested that stomach does not distend enough and the ingested water flows into the duodenal bulbs immediately after water intake. In contrast, in case of the glucose intake, the contraction of gastric antrum and pyloric part increases and the obstruction of pyloric ring give rise to the delayed gastric emptying. These effects may be mediated by the small intestinal nutrient-feed back mechanism. Previous reports (Hebbard *et al.*, 1996; Rayner *et al.*, 2000) in normal subjects and diabetic patients have indicated that hyperglycemia increases gastric compliance. Others have reported (Verhamgen *et al.*, 1998) an increase in basal pyloric pressure waves after intraduodenal glucose infusion.

Reports in diabetic patients (Schvarcz *et al.*, 1997; Rayner *et al.*, 2001) have shown that hyperglycemia delays gastric emptying. Our data support these previous studies.

Our results suggest that oral glucose intake causes changes in the gastric pacemaker activity, which is one of the factors that regulate the gastric emptying. No data are available to explain whether these changes in gastric motility are due to the action of high blood glucose levels alone, to changes mediated by the nervous system or to the action of humoral factors such as insulin and gastrin. The changes in gastric motility following oral glucose intake in the present study are thought to have been produced by the complex interaction of these humoral and nervous-system factors. Further study including other nutrients such as fat intake is needed to elucidate the effects of these factors.

In conclusion, the changes in gastric myoelectrical activity and gastric emptying after oral glucose intake were similar to the patterns recognized in the postprandial state. It is suggested that glucose is one component responsible for postprandial gastric motility.

References

- Alvarez, W.C. (1922). New methods of studying gastric peristalsis. *Am. J. Physiol.* **201**: 287–291.
- Chen, J. and McCallum, R.W. (1991). Response of the electric activity in the human stomach to water and a solid meal. *Med. Biol. Eng. Comput.* **29**: 351–357.
- Chen, J. and McCallum, R.W. (1993). Clinical application of electrogastrography. *Am. J. Gastroenterol.* **88**: 1324–1336.
- Chen, J., Schirmer, B.D. and McCallum, R.W. (1994). Serosal and cutaneous recording of gastric myoelectrical activity in patients with gastroparesis. *Am. J. Physiol.* **266**: G90–G98.
- Chen, J., Richards, R.D. and McCallum, R.W. (1994). Identification of gastric contractions from the cutaneous electrogastrogram. *Am. J. Gastroenterol.* **89**: 79–85.
- Chou, L.T., Wu, C.Y., Chen, H.P., Chang, C.S., Wong, P.G., Ko, C.W. and Chen, G.H. (2001). The correlation of depression and gastric dysrhythmia in functional dyspepsia. *J. Clin. Gastroenterol.* **33**: 127–131.
- Cunningham, K.M., Horowitz, M. and Read, N.W. (1991). The effect of short-term dietary supplementation with glucose on gastric emptying in humans. *Br. J. Nutrition* **65**: 15–19.
- Cunningham, K.M., Daly, J., Horowitz, M. and Read, N.W. (1991). Gastrointestinal adaptation to diets of differing fat composition in human volunteers. *Gut* **32**: 483–486.
- Familoni, B.O., Bowes, K.L., Kingma, Y.J. and Cote KR. (1991). Can transcutaneous recordings detect gastric electrical abnormalities? *Gut* **32**: 141–146.
- Geldof, H., Schee, E.J.V.D., Blankenstein, M.V. and Grashuis, J.L. (1986). Electrogastrographic study of gastric myoelectrical activity in patients with unexplained nausea and vomitig. *Gut* **27**: 799–808.
- Geldof, H., Schee, E.J.V.D. and Grashuis, J.L. (1986). Electrogastrographic characteristics of interdigestive migrating complex in humans. *Am. J. Physiol.* **250**: G165–G171.
- Geldof, H., Schee, E.J.V.D. and Smout, A.J.P.M. (1989). Myoelectrical activity of the stomach in gastric ulcer patients. *J. Gastrointest. Motil.* **1**: 122–130.
- Hamilton, J.W., Bellhsene, B.E., Reicherlderfer, M., Webster, J.G. and Bas, P. (1986). Human electrogastrograms. Comparison of surface and mucosal recordings. *Dig. Dis. Sci.* **31**: 33–39.
- Harasawa, S., Tani, N., Suzuki, S., Miwa, S., Sakita, R., Nomiyama, T. and Miwa, T. (1979). Gastric emptying in normal subjects and patients with peptic ulcer. *Gastroenterologia Japonica* **14**: 1–10.
- Harris, A., Lindeman, A.K. and Martin, B.J. (1991). Rapid orocecal transit in chronically active persons with high energy intake. *J. Appl. Physiol.* **70**: 1550–1553.

- Heading, R.C., Nimmo, J., Prescott, L.F. and Tothill, P. (1973). The dependence of paracetamol absorption on the rate of gastric emptying. *Br. J. Pharmacol.* **47**: 415–421.
- Heading, R.C., Tothill, P., McLoughlin, G.P. and Shearman, D.J.C. (1976). Gastric emptying rate measurement in man. *Gastroenterol.* **71**: 45–50.
- Hebbard, G.S., Sun, W.M., Dent, J. and Horowitz, M. (1996). Hyperglycemia affects proximal gastric motor and sensory function in normal subjects. *Eur. J. Gastroenterol. Hepatol.* **8**: 211–217.
- Kamiya, T., Nagao, T., Ando, T., Misu, N., Kobayashi, Y., Hirako, M., Hara, M. and Fujinami, T. (1998). Effects of trimebaine maleate on gastric motility in patients with gastric ulcer. *J. Gastroenterol.* **33**: 823–827.
- Kaneko, H., Sakakibara, M., Mitsuma, T. and Morise K. (1995). Possibility of postprandial electrogastrography for evaluating vagal/nonvagal cholinergic activity in humans, through simultaneous analysis of postprandial heart rate variability and serum immunoreactive hormone levels. *Am. J. Gastroenterol.* **90**: 603–609.
- Kobayashi, Y. and Kamiya, T. (1997). Postprandial electrogastrographic changes with or without parasympathetic nerve blockade. *J. Smooth Muscle Res.* **33**: 203–210.
- Koch, K.L., Stewart, W.R. and Stern, R. (1987). Effect of barium meals on gastric electromechanical activity in man. *Dig. Dis. Sci.* **32**: 1217–1222.
- Macintosh, C.G., Horowitz, M., Verhagen, M.A.M.T., Smout, A.J.P.M., Wishart, J., Morris, H., Goble, E., Morley, J.E. and Chapman, I.M. (2001). Effect of small intestinal nutrient infusion on appetite, gastrointestinal hormone release, and gastric myoelectrical activity in young and older men. *Am. J. Gastroenterol.* **96**: 997–1007.
- Rayner, C.K., Verhagen, M.A.M.T., Hebbard, G.S., Dimatteo, A.C., Doran, S.M. and Horowitz, M. (2000). Proximal gastric compliance and perception of distension in type 1 diabetes mellitus: effects of hyperglycemia. *Am. J. Gastroenterol.* **95**: 1175–1183.
- Rayner, C.K., Samsom, M., Jonens, K.L. and Horowitz, M. (2001). Relationships of upper gastrointestinal motor and sensory function with glycemic control. *Diabetes Care* **24**: 371–381.
- Riezzo, G., Chiloiro, M., Guerra, V., Borrelli, O., Salvia, G. and Cucchiara, S. (2000). Comparison of gastric electrical activity and gastric emptying in healthy and dyspeptic children. *Dig. Dis. Sci.* **45**: 517–524.
- Schvarcz, E., Palmer, M., Aman, J., Horowitz, M., Stridsberg, M. and Berne, C. (1997). Physiological hyperglycemia slows gastric emptying in normal subjects and patients with insulin-dependent diabetes mellitus. *Gastroenterol.* **113**: 60–66.
- Smout, A.J.P.M., Schee, E.J.V.D. and Grashuis, J.L. (1980). What is measured in electrogastrography? *Dig. Dis. Sci.* **25**: 179–187.
- Stacher, G., Berghann, H., Gaupmann, G., Schneider, C., Kugi, A., Hobart, J., Binder, A. and Mittelbachsteiner, G. (1990). Fat preload delays gastric emptying reversal by cisapride. *Br. J. Clin. Pharmacol.* **30**: 839–845.
- Stern, R.M., Crawford, H.E., Stewart, W.R., Vasey, M.W. and Koch, K.L. (1989). Sham feeding cephalic-vagal influences on gastric myoelectric activity. *Dig. Dis. Sci.* **34**: 521–527.
- Tatsuta, M., Ishii, H. and Okuda S. (1990). Gastric emptying in patients with fundal gastritis and gastric cancer. *Gut* **31**: 767–769.
- Verhamgen, M.A.M.T., Samsom, M. and Smout, A.J.P.M. (1998). Effects of intraduodenal glucose infusion on gastric myoelectrical activity and antropyloroduodenal motility. *Am. J. Physiol.* **274**: G1038–G1044.