Relationship between surface electrogastrography and antropyloric pressures

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Sun, W. M., A. Smout, C. Malbert, M. A. L. Edelbroek, K. Jones, J. Dent, and M. Horowitz. Relationship between surface electrogastrography and antropyloric pressures. *Am. J. Physiol.* 268 (*Gastrointest. Liver Physiol.* 31): G424–G430, 1995.—The cutaneous electrogastrogram (EGG) and intraluminal antropyloroduodenal pressures were recorded in 12 healthy volunteers for 30-min periods during phase II of the interdigestive motor complex, during intraduodenal infusion of 10% triglyceride, and after intravenous erythromycin (3 mg/kg). During phase II, the frequency of the EGG was relatively constant in each individual, with a median frequency of 0.046 Hz [2.8 counts per minute (cpm)]. EGG frequency was greater ($P < 0.05$) than the median rate of antral pressure waves (1.8 cpm). The suppression of antral pressure waves ($P < 0.05$) and stimulation of isolated pyloric pressure waves (IPPWs) ($P < 0.05$) produced by triglyceride infusion were not associated with changes in EGG frequency compared with phase II. The frequency of the EGG and the rate of IPPWs were comparable. After erythromycin, EGG frequency was 0.03 Hz (1.8 cpm), less than during both phase II and triglyceride infusion ($P < 0.05$) and almost identical to the rate of antral pressure waves. Pressure waves were nearly always associated with an EGG signal. In contrast, the temporal relationship between the EGG signal and pressure waves was variable. During triglyceride infusion ($r = 0.83$, $P < 0.001$) and after erythromycin ($r = 0.83$, $P < 0.001$) there was a close (approximately 1:1) relationship between the rate of pressure waves and EGG frequency. However, there was no significant relationship ($r = 0.32$, not significant) between the number of pressure waves and EGG frequency during phase II. These observations indicate that the EGG correlates with antral pressure wave activity during intravenous erythromycin infusion but not during phase II activity and that during intraduodenal triglyceride infusion isolated pyloric pressure waves are in phase with the gastric pacemaker frequency.

erythromycin; triglyceride

SURFACE ELECTROGASTROGRAPHY (EGG) is a potentially useful technique to study normal and disordered gastric motor function in humans, because it is noninvasive and does not involve radiation exposure. Discharge from the gastric pacemaker usually occurs at a frequency of ~0.05 Hz [3 counts per minute (cpm)] and determines the timing and maximum rate of gastric contractions (28). EGG recordings have been shown to have the capacity to demonstrate abnormalities of gastric pacemaker function (1, 5, 22). Such changes have been considered to be associated with abnormal gastric contractile activity (32). However, gastric contractions vary considerably in their mechanical patterns, consistent with the complex mechanical functions of the stomach in mixing, grinding, and emptying food and the variation in mechanical outcomes among individual contraction sequences. Thus the rate of gastric emptying is in large part dependent on the spatial and temporal relationship of phasic gastric contractions. Single contraction sequences show a diversity of spatial/temporal patterns in the proximal stomach, antrum, pylorus, and proximal small intestine (15, 23). Localized pyloric contractions probably play a major role in the regulation of nutrient emptying by acting as a brake (16, 17, 29). There is limited information about the relationship between gastric motor activity of different spatial/temporal patterns and the EGG (6, 24). Furthermore, there have been no studies into the relationship between pyloric motor activity and the EGG. We have investigated these relationships with concurrent recordings of antropyloric pressure and the surface EGG in healthy volunteers during three widely differing patterns of gastric motility.

METHODS

Subjects

Studies were carried out in 12 normal volunteers, 9 males and 3 females, aged 18–30 yr. None had a previous history of gastrointestinal disease or was taking medication. Four of the volunteers had previously participated in research studies involving nasogastric intubation. Smoking was prohibited from the evening before the study. The protocol was approved by the Human Ethics Committee of the Royal Adelaide Hospital in 1992, and each subject gave written informed consent.

Experimental Protocol

Each study commenced at about 10:30 A.M. after an overnight fast. With the subject supine, a sleeve/side-hole manometric catheter was passed through an anesthetized nostril and positioned across the pylorus with the use of dual point transmucosal potential difference (TMPD) measurements (13, 21). A 21-gauge cannula was placed in an antecubital vein for administration of erythromycin. Two disposable silver-silver chloride electrodes (Nikomed, Australia) were attached to the skin midway between the umbilicus and xiphoid to record EGG, and a reference electrode was attached to the skin on the midaxillary line below the costal margin.

After the sleeve sensor was positioned across the pylorus, antropyloroduodenal pressures and EGG were recorded for a minimum of 30 min during gastric phase II interdigestive motor activity. The latter was defined as occurrence of sporadic antropyloric pressure waves at a rate of >1 but <3 waves/min (13). An intraduodenal infusion of a triglyceride emulsion (10% Intralipid, Vitrum, Stockholm, Sweden) was then given at a rate of 1 ml/min for 30 min. Thirty minutes
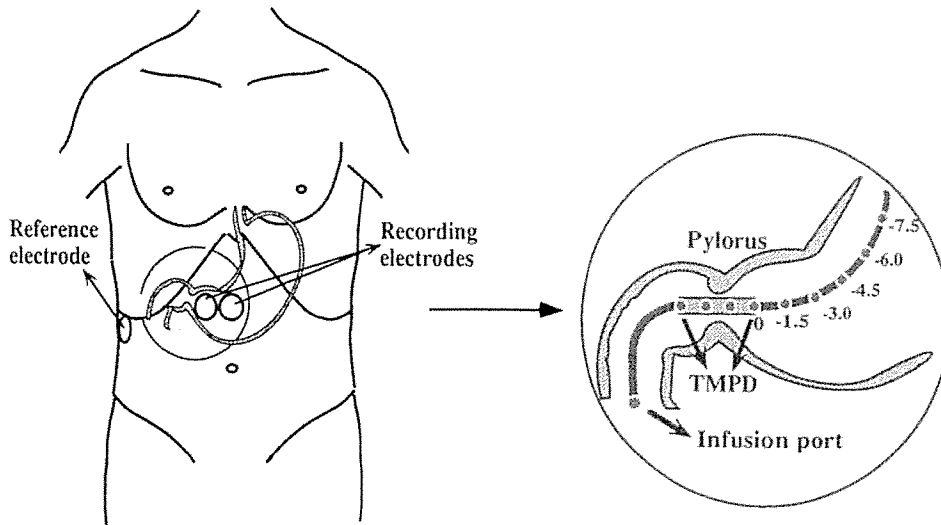
Fig. 1. Diagram showing manometric assembly and position of surface electrodes for electrogastrography (EGG). Arrows pointing to recording electrodes also indicate preamplifiers. Side holes 6 and 9 were used to measure transmucosal potential difference (TMPD) across the pylorus as well as pressure, and side hole 11 was used for intraduodenal triglyceride infusion. A 4.5-cm sleeve sensor was located between side holes 6 and 9, so that patterns of pressures generated by localized pyloric contractions were frequently recorded by the manometric side holes along the sleeve. To define sleeve position, TMPD was monitored with the use of the manometric side holes at either end of the sleeve, the so-called antral and duodenal TMPD side holes.

after completion of this infusion, erythromycin as the lactobionate (Abbott Laboratories, Sydney, Australia) was given intravenously in a dose of 3 mg/kg over 15 min.

Measurements

Antropyloric pressures. The 11-lumen manometric assembly was similar to that used in previous studies (Fig. 1) (14, 21). The nine manometric side holes were at 1.5-cm intervals so that this chain spanned the antrum and pylorus. A sleeve sensor incorporated into the assembly monitored pyloric pressures. A further channel, 10 cm from the distal end of the sleeve, was used for intraduodenal triglyceride infusion. All manometric channels were perfused with degassed distilled water at a rate of 0.3 ml/min, except the TMPD channels, which were perfused with degassed normal saline at the same rate. Manometric signals were amplified by a 16-channel Synectics Polygraf (Synectics, Sweden). The signals were sub-

sequently digitized at 10 Hz using an A-D board (NB-MIO16, National Instruments, TX), then processed and stored on an Apple Macintosh IIci computer, using proprietary software (MAD 16, Synectics; Royal Adelaide Hospital; C. H. Malbert) developed from the LabView package (National Instruments).

Electrogastrography. To ensure optimal electrical contact of the surface electrodes, the abdominal skin was cleaned with ethanol and lightly abraded. The electrical signals were preamplified with a purpose-designed preamplifier (Synectics, Sweden) (Fig. 1). The low and high cutoff frequencies were 0.02 and 0.28 Hz (−3 dB), respectively. The EGG signal was then digitized at 2 Hz and also stored on the Apple Macintosh IIci computer.

Data Analysis

Recordings were only analyzed when the sleeve sensor was positioned correctly according to the following criteria: when
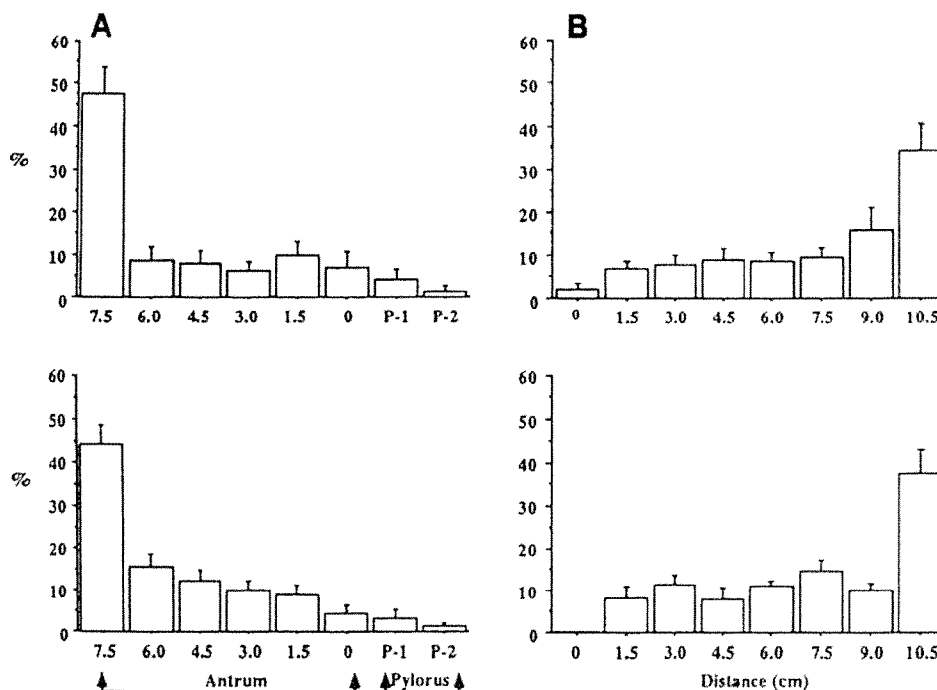

Fig. 2. Temporal relationship of pressure waves. Origin (A) and length (B) of antral pressure waves during phase II (top) and after intravenous erythromycin (bottom). The y-axis shows number of pressure waves as a % of the total number of antral or isolated pyloric pressure waves. P-1 and P-2, side holes located along the sleeve sensor.

Table 1. *Rates of pressure waves and frequency and power ratio of main spectra of EGG signal during phase II and intraduodenal triglyceride infusion and after intravenous erythromycin infusion*

	Phase II	Triglyceride	Erythromycin
Antral wave/min	1.8 (1.8–3.2)	0.0 (0.0–0.0)*	2.0 (1.4–3.2)†
IPPWs/min	0.1 (0.0–0.5)	2.3 (2.0–3.6)*	0.1 (0.0–0.7)†
EGG, cpm	2.8 (1.4–3.3)	2.4 (2.0–3.4)	1.8 (1.2–3.3)*†
Power ratio, %	100	94 (53–150)*	154 (110–280)*†

Results are median values and ranges. Note that frequencies (Hz) have been transformed to number per minute. EGG, electrogastrogram; IPPWs, isolated pyloric pressure waves; cpm, counts per minute. †$P < 0.05$ compared with triglyceride; *$P < 0.05$ compared with phase II.

the antral TMPD was equal to or more negative than -20 mV, the duodenal TMPD was equal to or more positive than -15 mV, and the difference between the two readings was at least 15 mV (18). Comparisons were made between the 30-min recordings of pressure and EGG during fasting (phase II), intraduodenal lipid infusion, and erythromycin administration.

Antropyloric Pressure Waves

The analysis included all pressure waves ≥ 10 mmHg that lasted between 5 and 25 s (14). Pressure waves recorded at two or more antral side holes were considered to be "associated" when the time difference between the onset of waves in adjacent channels was within -5 ± 10 s (11). A group of temporally associated pressure waves was defined as a wave sequence. The occurrence of pressure waves was scored for individual side holes to obtain a picture of the spatial pattern of pressure wave sequences (11).

IPPWs were defined as pressure waves that were detected by the sleeve sensor and by no more than one side hole located along the sleeve sensor, in the absence (± 5 s) of an associated pressure wave of any magnitude that was ascribable to either gastric or duodenal contraction (19). Basal pyloric pressure was defined as the difference between the basal pressure

recorded by the sleeve sensor and the distal antral pressure (antral TMPD) (17, 18, 21) and was measured 2 min before and 15 min after intraduodenal triglyceride.

Electrogastrography. EGG and pressure signals were treated by fast Fourier transformation (FFT) to obtain individual spectra (31). A "flat-top" window for the signal was used, because this method allows optimal definition of amplitude. The running spectral analysis was updated every 1 min from the preceding 4 min with an overlap period of 1 min (27). The antral TMPD channel was used for this FFT analysis. The mean amplitudes of the main spectra of the EGG for 30-min periods during intraduodenal triglyceride infusion and intravenous erythromycin were divided by the mean amplitude of the EGG signal recorded during phase II (30 min) to derive a power ratio, which was expressed as a percentage (26).

Relationship between the EGG signals and pressure waves. The antral TMPD side-hole pressure record was used for evaluation of the relationship between individual antral pressure waves and the EGG, because we have demonstrated that the majority of contractions in the distal (as opposed to the proximal) antrum result in lumen occlusion (12). The onset of each deflection of both the EGG and distal antral pressure waves was determined visually. These judgments were made without reference to the other tracings to give an independent evaluation. To evaluate the relationship between the onsets of the major EGG deflection and pressure waves, the onset of the EGG deflection was defined as *time 0*. The minimum time difference between the two was used. During intraduodenal triglyceride infusion, the time of onset of IPPWs recorded by the sleeve was used to assess the relationship between pressure waves and EGG.

Statistical Analysis

Data are given as median values and ranges. The relationships between EGG frequency and the rate of pressure waves were evaluated with linear regression analysis. The differences between the frequency of the EGG and rate of the pressure waves and the power ratios of the main frequency of the FFT were evaluated with the Friedman method. A P value <0.05 was considered significant in all analyses.
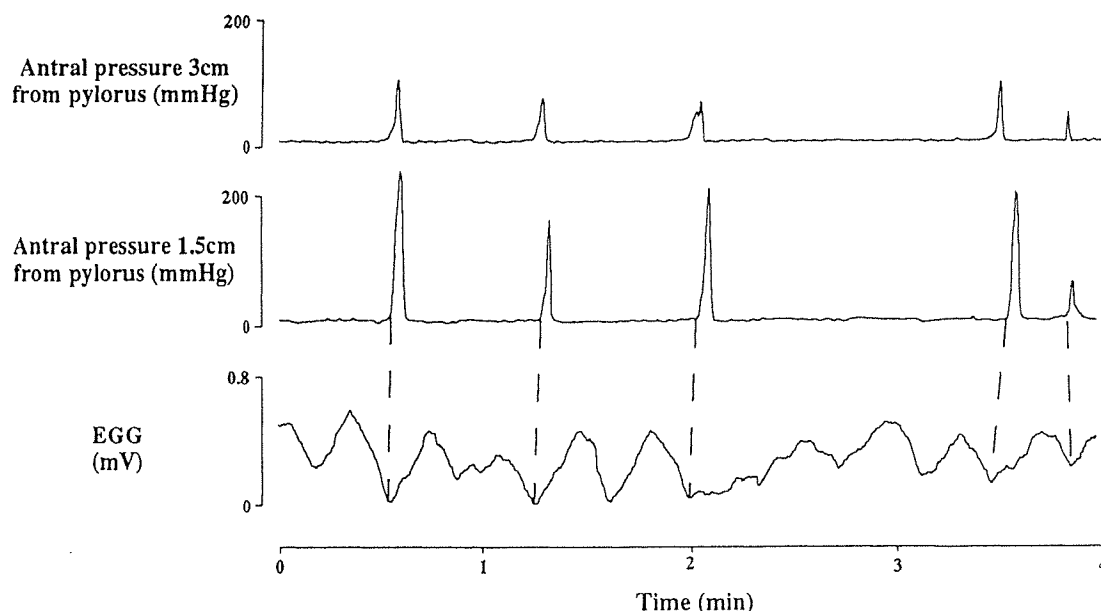

Fig. 3. Recordings of antral pressure waves and electrogastrography (EGG) during phase II. EGG frequency is 3 per minute and the rate of pressure waves 1–2 per minute. Onset of each pressure wave is associated with an EGG signal.
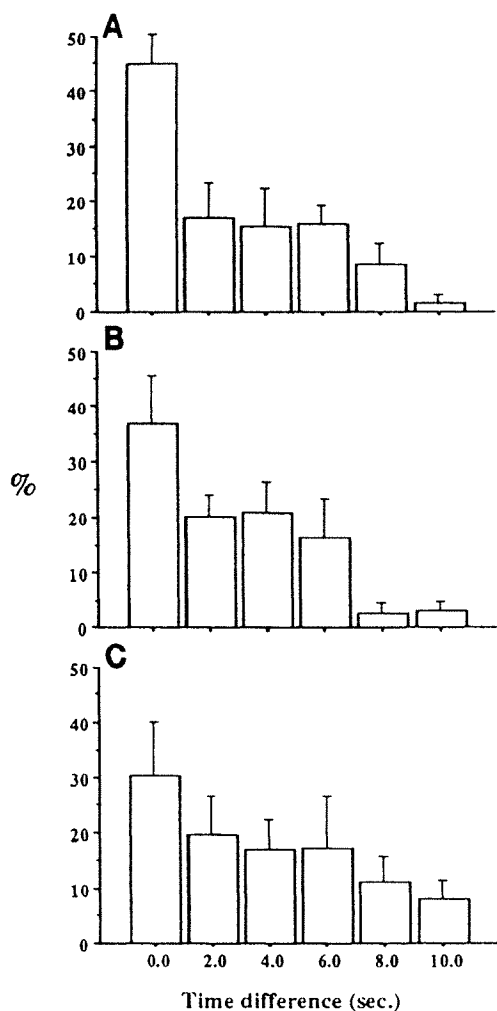
Fig. 4. Temporal relationship between onset of pressure waves and deflection of EGG signal during phase II (A), intraduodenal triglyceride (B), and intravenous erythromycin (C). The y-axis shows number of pressure waves as % of the total number of antral or isolated pyloric pressure waves in each of the 3 experimental conditions. Onset of pressure waves falls within 4 s of EGG deflection in most cases.

RESULTS

The experiments were generally well tolerated by all subjects. Three subjects experienced mild nausea during the erythromycin infusion. The sleeve sensor was positioned correctly > 98% of the time. The oscillation of the EGG signal was sufficiently clear-cut to allow determination of the time of its initial major deflection for 88% of the time during phase II, 79% of the time during triglyceride infusion, and 81% of the time after administration of erythromycin.

Phase II Activity

Figure 2 summarizes the distribution of all antropyloric pressure waves according to recording side holes (Fig. 2). The median rate of distal antral pressure waves (recorded at the antral TMPD side hole) was 1.8 cpm (0.03 Hz) (Table 1). The frequency of the EGG during the same period was 0.046 Hz (2.8 cpm), higher than the rate of antral pressure waves ($P < 0.05$, Table 1 and Fig.

3). Antral pressure waves were usually associated with a deflection of the EGG signal, because 78% of antral pressure waves occurred within 4 s of the onset of the deflection of the EGG (Fig. 3 and Fig. 4). However, the relationship of the EGG signal to pressure waves was not constant, varying from 1:1 to 1:3 (Fig. 3). There was no significant relationship between EGG frequency and the rate of the antral pressure waves ($r = 0.32$, not significant, slope $= 0.24$; Fig. 5).

Intraduodenal Triglyceride Infusion

Figure 6 shows an example of the dominant pattern of pressure and the EGG signal after intraduodenal triglyceride infusion. There were no differences in the EGG compared with phase II (see Fig. 3). By contrast, and in keeping with previous studies (14), intraduodenal triglyceride infusion stimulated basal pyloric pressure [median difference 2.5 (0–13) mmHg, $P < 0.05$] and isolated
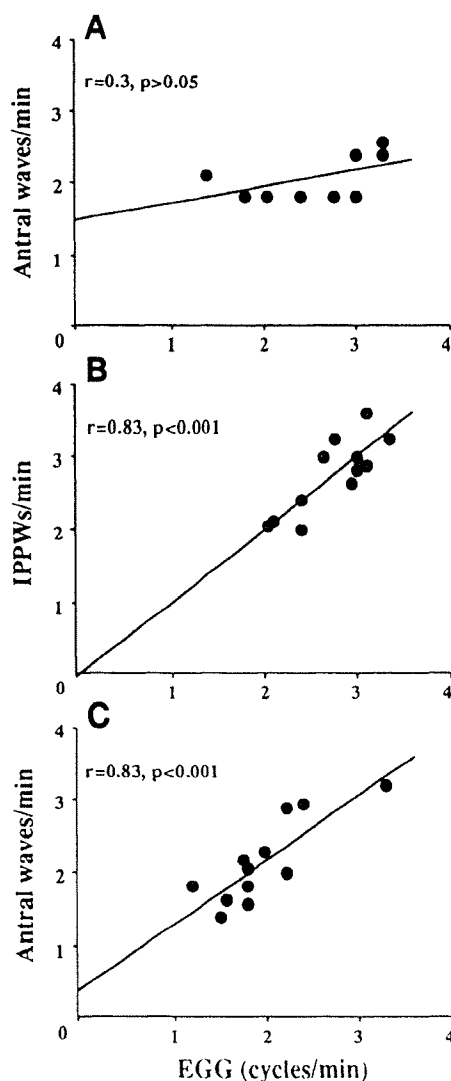

Fig. 5. Relationship between frequency of EGG and 1) number of antral pressure waves during phase II (A), 2) number of isolated pyloric pressure waves (IPPWs) during intraduodenal triglyceride (B), and 3) number of antral pressure waves during intravenous erythromycin (C).
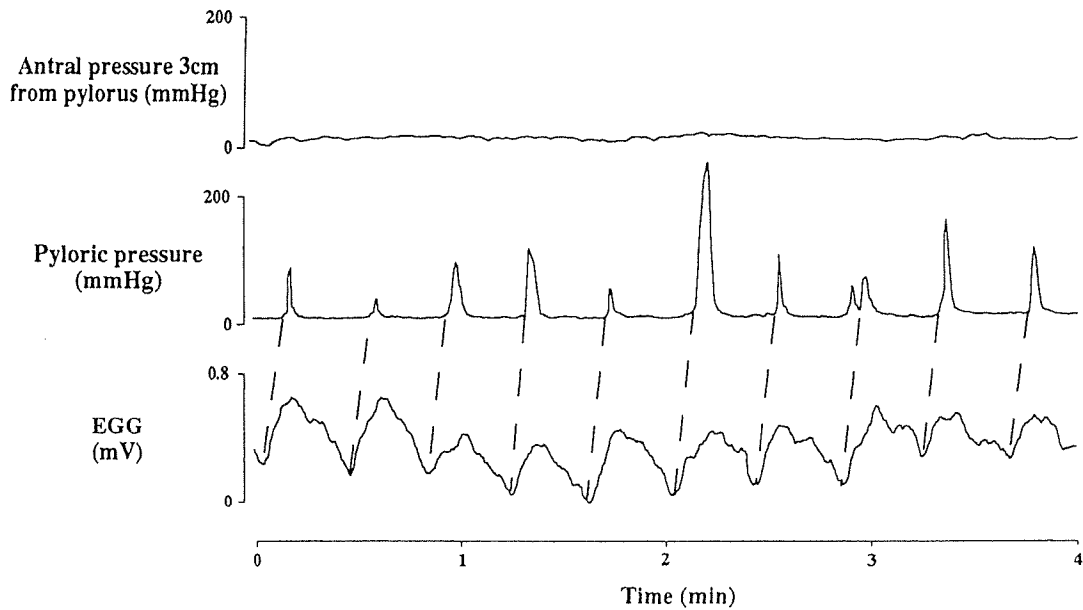
Fig. 6. Recordings of IPPWs and EGG during intraduodenal triglyceride. EGG frequency and rate of IPPWs are both ~3 per minute. Onset of each pressure wave is closely associated with an EGG signal.

pyloric pressure waves (IPPWs) and inhibited antral and duodenal pressure waves (Fig. 6). The rate of IPPWs, 2.3 cpm (0.038 Hz), was not different from the frequency of the EGG (Table 1). The rate of IPPWs during intraduodenal lipid infusion was higher ($P < 0.05$) than the number of antral pressure waves during phase II. However, there was no significant difference in EGG frequency between phase II and triglyceride infusion. The onset of 77% of IPPWs was within 4 s of the onset of the deflection of the EGG signal (Fig. 4). There was a close correlation between the rate of the IPPWs and the frequency of the EGG ($r = 0.83, P < 0.001$; Fig. 5), which was almost 1:1 (slope 1.01). The power ratio of

the EGG was slightly less than during phase II ($P < 0.05$) (Table 1).

Intravenous Erythromycin Infusion

Erythromycin infusion produced the expected high-amplitude and long-duration antral pressure waves (Fig. 7). Figure 2 shows that the distribution of all antropyloric pressure waves according to recording side holes was similar to that seen during phase II (Fig. 2). The rate of antral pressure waves was not significantly different from phase II and was greater ($P < 0.05$) than during intraduodenal lipid (Table 1). There were virtu-
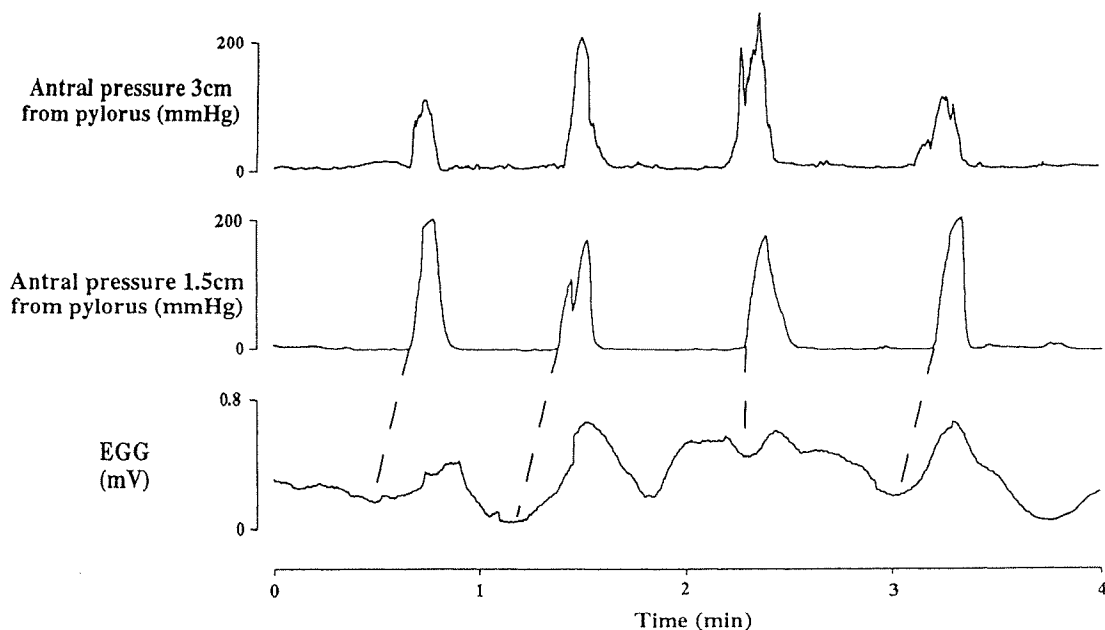

Fig. 7. Recordings of antral pressure waves and EGG during intravenous erythromycin. EGG frequency and rate of antral pressure waves are both ~1 per minute. Onset of each pressure wave is closely associated with an EGG signal.

ally no IPPWs during erythromycin administration. EGG frequency during erythromycin was less ($P < 0.05$) than during both phase II and intraduodenal lipid (Table 1). Sixty-six percent of antral pressure waves occurred within 4 s of the onset of the deflection of the EGG signal (Fig. 4). There was a close correlation between the rate of antral waves and EGG frequency ($r = 0.83, P < 0.001$, Fig. 5), which was about 1:1 (slope 0.9). The power ratio of the EGG was higher ($P < 0.05$) than that during both phase II and intraduodenal lipid (Table 1).

DISCUSSION

Our observations indicate that in normal subjects surface electrogastrography correlates with antral pressure wave activity during intravenous erythromycin infusion but not during phase II activity and that during intraduodenal triglyceride infusion isolated pyloric pressure waves are in phase with the gastric pacemaker frequency.

During phase II, intraduodenal triglyceride infusion, and intravenous erythromycin administration, virtually all pressure waves were apparently associated with an EGG signal. This concept is supported further by the observed effect of erythromycin infusion. The amplitude and duration of antropyloric pressure waves were markedly increased after erythromycin, yet, despite these changes, there was a 1:1 relationship between the EGG signal and the number of antral pressure waves. In the doses used, intraduodenal triglyceride stimulated localized pyloric pressure waves (19) and intravenous erythromycin stimulated antral pressure waves (14) at a maximum rate. In these circumstances the significant interindividual differences in the rate of pressure waves was reflected closely by the EGG frequency, so that almost all of the variance in the rate of antral and localized pyloric pressure waves was accounted for by changes in the EGG. This implies that the EGG can predict the rate of antral or localized pyloric pressure waves in normal individuals after these stimuli. It needs to be recognized that the EGG cannot discriminate antral from pyloric pressure waves. It remains to be determined whether the use of intravenous erythromycin will have diagnostic value in patients with abnormal gastric motility, to evaluate gastric pacemaker function.

Previous studies have produced conflicting data as to whether the pylorus possesses its own pacemaker or whether pyloric motility is controlled by the gastric or duodenal pacemaker (3, 25). The observed 1:1 relationship between the EGG signal and IPPWs suggests that the pylorus is probably controlled by the gastric pacemaker during intraduodenal triglyceride infusion. A study in which the gastric pacemaker frequency was modified while localized pyloric waves were stimulated would be required to prove this definitively. Although electromyographic studies have suggested that neither gastric nor duodenal electrical activity could be recorded from the pylorus, leading to the conclusion that the pylorus was "insulated" (3), these studies suffered from significant methodological limitations. In particular, recordings were not made from the inner pyloric muscle

ring. More recent observations support the concept that the pylorus is controlled by the gastric pacemaker (9, 25). Slow waves recorded in the antrum are propagated to the pylorus by elements within the circular muscle layer (25) in the dog and in the rabbit (9). In humans there is evidence that gastric pacemaker discharge is transmitted to the first part of the duodenum (10). We have reported previously that an IPPW frequency of 12 waves per minute can be recorded occasionally during intraduodenal lipid infusion in humans, a frequency that is apparently incompatible with antral contractile activity (17), but we have recognized subsequently that in such instances 3 waves per minute pressure wave activity is still identifiable (J. Dent, M. Horowitz, and W. M. Sun, unpublished observations).

The EGG power ratio increased after erythromycin administration, which stimulated high-amplitude antral pressure waves. Previous studies have reported a postprandial increase in the EGG power ratio (4, 7, 26, 27) which has been attributed both to the stomach being closer to the abdominal surface and increased gastric contractions (4, 7). Our data support the latter but not the former concept, in that our observations were made during fasting. The increase in power ratio almost certainly reflects the effects of erythromycin on gastric myoelectrical activity (8, 20). It is interesting to note that the stimulant effect of erythromycin on individual contraction sequencing and emptying (2, 14, 30) is associated with a reduction in pacemaker frequency, suggesting that the temporal and spatial organization within a pressure wave sequence may be a more important determinant of its mechanical consequences than the frequency of contractions (2, 14).

In conclusion, our observations suggest that the pylorus is in phase with the gastric pacemaker activity during intraduodenal triglyceride infusion and that the EGG correlates with antral contractile activity during intravenous erythromycin infusion, but that conventional analysis of the EGG does not give information on spatial patterns of gastric (antral or pyloric) pressure waves. It remains to be determined whether more sophisticated analysis of the vectors of the EGG signal recorded from multiple points would yield useful information about the control of gastric motility.

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