

Electrogastrographic characteristics of interdigestive migrating complex in humans

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GELDOLF, H., E. J. VAN DER SCHEE, AND J. L. GRASHUIS. *Electrogastrographic characteristics of interdigestive migrating complex in humans*. *Am. J. Physiol.* 250 (Gastrointest. Liver Physiol. 13): G165-G171, 1986.—Interdigestive myoelectric activity and mechanical activity were studied simultaneously by means of cutaneous electrodes (electrogastrography) and intraluminal pressure recording, respectively, in 10 healthy male volunteers. The aims of the present study were 1) to describe the characteristics of the electrogram during the different phases of the interdigestive migrating complex (IMC) in healthy subjects and 2) to determine to what extent these characteristics can be used to identify the different phases of the IMC. The electrograms were analyzed visually and by running-spectrum analysis. It was concluded that in humans the gastric frequency present in the electrogram appears to be less stable during motor activity than during motor quiescence, in particular during phase III, but far more stable than its canine counterpart. A small but consistent drop in gastric frequency was observed in the changeover from motor quiescence to phase II motor activity. The power of the gastric frequency increased with increasing motor activity, except during phase III. A characteristic frequency and power behavior during phase III could only be recognized in a minority of the IMCs. In general, electrography cannot, given the present state of the art, be used to precisely identify the different phases of the IMC.

antral motor activity; electrography; gastric myoelectric activity; running-spectrum analysis

THE ACTIVITY FRONT of the interdigestive migrating complex (IMC) is an important marker of several physiological events in the gastrointestinal tract (9, 16, 30). Non-invasive detection of the different phases of the IMC, according to the classification of Code and Marlett (6), would be a welcome aid in the study of interdigestive motor and secretory activity. As the control mechanism of intestinal motility is of an electrical nature, electrography (EGG), the recording of gastric myoelectric activity by means of cutaneous electrodes, might make this possible.

The stomach has an inherent rhythmic myoelectric activity with a repetition frequency of about 0.05 Hz (3 cycles/min), which is referred to as "electrical control activity" (ECA) (14, 22). When motor activity is present, the ECA (also known as "basic electric rhythm" or "slow waves") is accompanied by a second component, with or without superimposed fast oscillating potential changes,

called "spike potentials," which in this study is referred to as "electrical response activity" (ERA) (22).

The electrographic signal can be considered as a summation of time-shifted waveforms generated by the ECA and, if present, the contraction-related ERA traveling along the stomach (25). It has been well established that the fundamental frequency of the electrogram in both dogs and humans is of gastric origin and equals the repetition frequency of the ECA (1, 5, 13, 25). Motor activity generally manifests itself in the electrogram by an increase in amplitude of the gastric frequency (25, 31). This phenomenon has been observed most consistently in the postprandial state (12, 13, 26).

Van der Schee and Grashuis (28) recently demonstrated that interdigestive contractile activity in the dog could be recognized in the running spectrum representations of electrograms (based on fast-Fourier transformation) by the appearance of high-power, low-frequency components, with frequencies between 0.085 Hz (the normal gastric frequency in dogs) and ~0.01 Hz. The gastric myoelectric characteristics of the fasting contractile activity in humans have never been described. Manometric studies, however, indicate that the interdigestive motor pattern in humans is different from that found in dogs. Whereas during phase III in dogs groups of strong contractions alternate with short periods (0.5–1 min) of motor quiescence or very weak contractions (10, 15, 21), gastric phase III activity (lasting for ~4–6 min) in humans seems to be more regular and phase IV is very short or missing altogether (8, 17). Moreover, not all activity fronts appear to originate in the stomach. Instead, the duodenum is found to be the point of origin (11, 20).

The objectives of the present study were twofold: 1) to describe the electrographic characteristics during the different phases of the IMC in humans and 2) to determine to what extent these characteristics can be used to identify the phases of the IMC.

MATERIALS AND METHODS

Subjects

Ten healthy male volunteers (median age 25 yr, range 19–40) were studied. After an overnight fast, both intraluminal pressure and electrographic recordings were made during a period of ~3 h.

Recording of Motor Activity in Stomach and Duodenum

In four subjects intraluminal pressure recordings were made using three semiconductor strain-gauge pressure transducers mounted 5 cm apart in a commercially available pressure probe (model 31, Kulite Semiconductor Products, Ridgefield, NJ). In six subjects the pressure activity was recorded by a low-compliance perfusion system originally described by Arndorfer et al. (3). The distances between the three recording sites were 5 cm (proximally) and 7 cm (distally). The tubes were perfused with distilled water via a pneumohydraulic pump (perfusion rate, 0.6 ml/min). Intraluminal pressure changes were recorded continuously using strain-gauge transducers attached to each tube.

Both probes contained radiopaque markers at each recording site, enabling careful positioning under fluoroscopic control. Two recording sites were positioned in the antrum and one in the duodenum. All signals were recorded on a paper chart (Van Gogh EP-8b) and simultaneously stored on magnetic tape (Racal store 14). The motor activity of phase II was quantified by summing the amplitude force (kPa) of the recorded pressure waves during a 10-min period preceding phase III.

Recording of Gastric Myoelectric Activity

In most subjects the EGG bipolarly recorded from two electrodes placed along the antral axis is of good quality (13, 19). However, standard electrode positions cannot be defined precisely because of interindividual anatomic variations (12, 26). Therefore, several leads were used and the lead with the best signal-to-noise ratio was then selected for further analysis. The positions of the six recessed-type electrodes (Red Dot 2256, 3M Co.) are shown in Fig. 1. A strain-gauge respiration transducer was attached to the thoracic wall. The four monopolar signals, the six bipolar signals, and the respiration signal were recorded on a paper chart (Van Gogh EP-8b) and simultaneously stored on magnetic tape (Racal store 14). The high- and low-pass filters (6 dB/octave) were set at 0.012 and 0.46 Hz, respectively.

Signal Analysis

The electrogastragram contains frequency, amplitude, and waveform information. Tracings were analyzed by visual inspection and by running-spectrum analysis, a computerized frequency, or spectral analysis. We limited visual inspection of the EGG in this study to amplitude changes. In running-spectrum analysis, using a fast-Fourier transform, power spectra of short overlapping stretches of a time signal (in this study the EGG) were computed and displayed as a function of time, thus yielding frequency and amplitude information over the course of time (27). No waveform analysis was performed.

A fast-Fourier transform algorithm implemented on a NOVA 2 digital computer was used to obtain the power spectra of the time signals. These signals, replayed from tape 16 times faster than real time, were preprocessed by band-pass filtering using a Butterworth filter (24 dB/

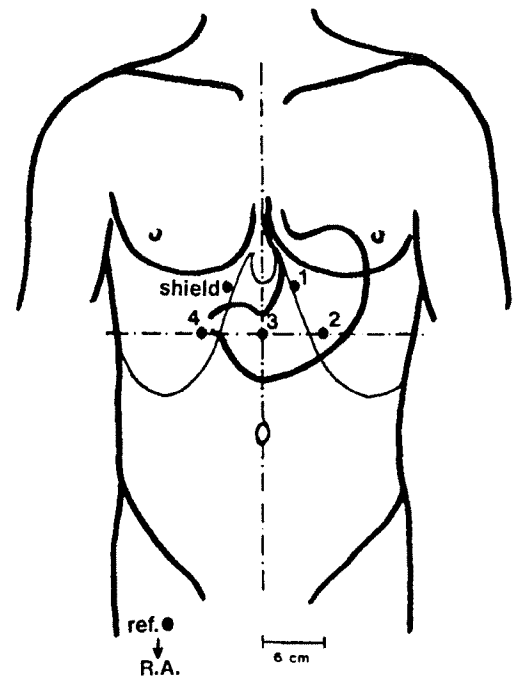


FIG. 1. Electrode positions used in this study. Electrodes 2, 3, and 4 are situated on a transverse line halfway between lower end of sternum and umbilicus. Electrode 3 is placed at intersection of this line and median plane. Distance between all abdominal electrodes is 6 cm. Reference electrode is placed on right ankle. Shield electrode is used to reduce possible interference from 50-Hz mains voltage at input stage of preamplifiers.

octave) with (real-time) cutoff frequencies set at 0.01 and 0.5 Hz in order to remove possible DC components and to avoid aliasing. They were then digitized (real-time sampling frequency 1 Hz) and fed into the computer. Spectra were obtained as follows: every 64 s a power spectrum was computed from the preceding 256 s of the EGG time signal, to which a Hamming window was applied to reduce leakage (4). These time values have been shown to be satisfactory for the extraction of relevant information from the EGG, giving 129 points per spectrum and a frequency spacing of 0.0039 Hz (27). This procedure generates series of spectra that overlap in time, called running spectra, which we plotted in two different ways: pseudo-three-dimensional and gray-scale plots. The gray-scale plot enables the easy recognition of frequency changes in course of time. Power and thus amplitude changes (the amplitude is the square root of the power) can be recognized more precisely in the pseudo-three-dimensional plot. Plots were made on a Versatec 1100 A printer plotter. During processing each computed spectrum was drawn, together with its spectrum number, on a Tektronix 4010 display terminal with hard-copy facilities. Where there were problems of interpretation after completion of the processing each spectrum could be analyzed in detail. The mean gastric frequency (Hz), with standard deviation (SD), and its power content were computed for the several phases of the IMC in the stomach as they were identified by pressure recordings. The SD was used as a measure for the stability of the gastric frequency. The larger the SD, the more unstable was the gastric frequency in the period analyzed. When the activity front did not originate in the stomach, the

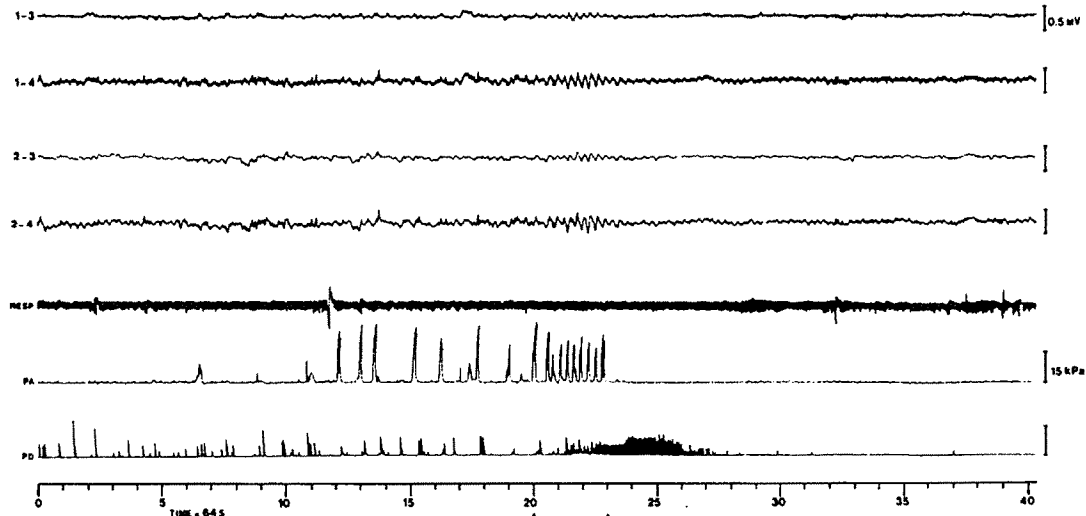


FIG. 2. Four bipolar time signals, respiration signal, mechanical activity in antrum (PA), duodenum (PD), and time scale. During phase III (arrow) an amplitude increase can be recognized followed by a decrease at changeover to motor quiescence.

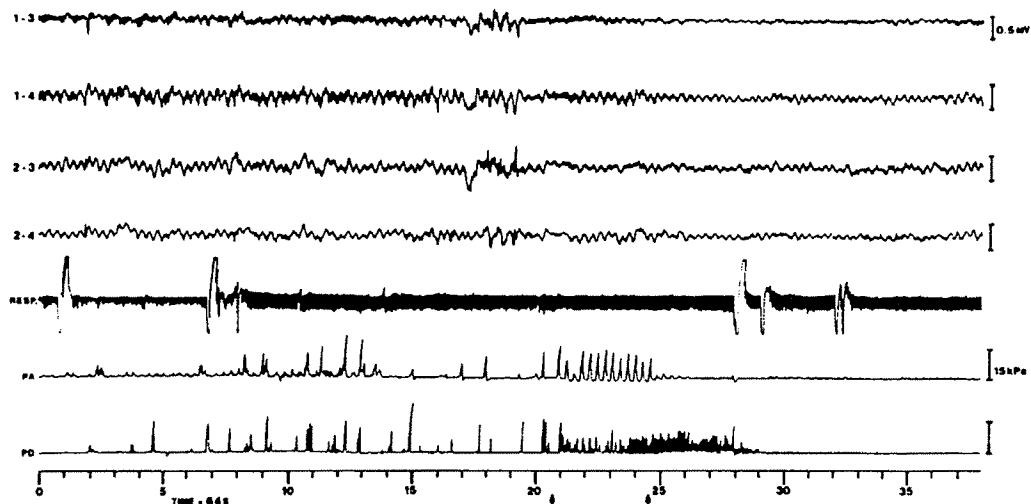


FIG. 3. Four bipolar time signals, respiration signal, mechanical activity in antrum (PA), duodenum (PD), and time scale. Phase III (arrow) cannot be recognized in electrogastrogram. Leaving part of electrogastrogram during phase III out of consideration, an amplitude difference can be seen during phases II and I.

duodenal IMC phases were used to determine which signal stretches had to be analyzed.

Since the absolute value of the amplitude (mV) of a recorded cutaneous signal (and thus its power content) is influenced by a number of factors (e.g., electrode-skin resistance, tissue conductivity, and electrode distance to the stomach wall), it is impossible to make a comparison of interindividual power data. Therefore, only power changes within each separate recording session were used for statistical analysis.

The study was approved by the Medical Ethics Committee of Erasmus University, Rotterdam, on June 4, 1982, and carried out with the written informed consent of the subjects.

Statistical analysis

The Wilcoxon signed-rank test was used to evaluate whether a significant difference existed between the different phases of the IMC in mean gastric frequency, SD,

and its power content (2, 23). To calculate the coefficient of correlation (r) between the gastric motor activity and the power of the gastric frequency, the Spearman rank-correlation test was used (23). Probability (P) values were derived from two-tailed tests. The level of significance used in this study was 0.05.

RESULTS

From the 21 IMC activity fronts recorded with intraluminal pressure recordings in the 10 volunteers, 16 originated in the stomach and the other 5 originated in the duodenum. The median duration of gastric phase III was 4 min (range 3–6 min).

Characteristics of IMC Originating in Stomach

Visual inspection. Motor quiescence (phase I) was characterized by a constant low-amplitude EGG. At the

changeover from motor quiescence to motor activity (phase II), a gradual increase in amplitude could be distinguished in 10 IMC. In three IMC this amplitude increase occurred some time (5–10 min) before motor activity was recorded. At the changeover to phase III an obvious amplitude increase was seen in 6 IMC as illustrated in Fig. 2, while in the remaining 6 IMC phase III appeared to be indistinguishable from phase II (see Fig. 3). At the changeover from motor activity to motor quiescence (phase I), an amplitude decrease could only be recognized with certainty in 12 IMC (Figs. 2 and 3). No amplitude changes could be recognized in 4 IMC predominantly because of the respiration artifact present in the electrogastrogram.

TABLE 1. Comparison of findings during different phases of IMC originating in stomach and duodenum

IMC	Phase I	Phase II	Phase III
<i>Stomach (n = 16)</i>			
Gastric frequency	0.049	0.047	0.048
SD	0.043–0.052	0.041–0.052	0.041–0.056
Power increase	0.0019	0.0029	0.0042
	0.0014–0.0023	0.0021–0.0043	0.0024–0.0060
		2.61*	0.76†
		2.06–5.20	0.05–3.95
<i>Duodenum (n = 5)</i>			
Gastric frequency	0.050	0.050	0.050
SD	0.049–0.051	0.048–0.051	0.049–0.053
Power increase	0.0022	0.0024	0.0023
	0.0018–0.0026	0.0020–0.0029	0.0020–0.0026
		1.17*	0.81†
		1.02–2.18	0.46–1.04

Values represent medians and ranges; n, no. * Power increase at the changeover from phases I to II. † Power increase at the changeover from phases II to III.

Running-Spectrum Analysis

Mean gastric frequency, its standard SD, and power changes in the different IMC phases, expressed as median and range, are summarized in Table 1. Phase I was characterized by a very stable gastric frequency as is shown by the low value of the frequency SD. The initial power of the gastric frequency in phase I was relatively low. In six IMC the power started to increase 5–10 min before phase II motor activity was evident in the pressure recordings. In the other 10 IMC the power increase was synchronous with the start of phase II motor activity. Because of this early power increase, only the first 10 min of the EGG corresponding to phase I following the motor activity front were used for computing the mean gastric frequency, SD, and power of this phase.

In all 16 IMC the gastric frequency during phase II appeared to be less stable ($P < 0.01$) and lower ($P < 0.01$) than during phase I. The power of the gastric frequency in phase II was, at least a factor 2, larger than in the first 10 min of motor quiescence following phase III ($P < 0.01$). This increase in power was positively correlated with the motor activity recorded during a 10-min period of phase II preceding phase III ($r = 0.96$; $P < 0.0001$).

The characteristics of phase III varied considerably both with respect to the frequency and the power behavior. A clear, identical frequency and power behavior were found in only seven IMC, which could easily be recognized in the pseudo-three-dimensional and gray-scale plot as illustrated in Figs. 4 and 5. During phase III of these seven IMC a power increase and a relatively stable, somewhat increased gastric frequency were observed, followed by a decrease in frequency and power. In the other nine IMC, no specific frequency and power behavior could be discerned. The gastric frequency during phase

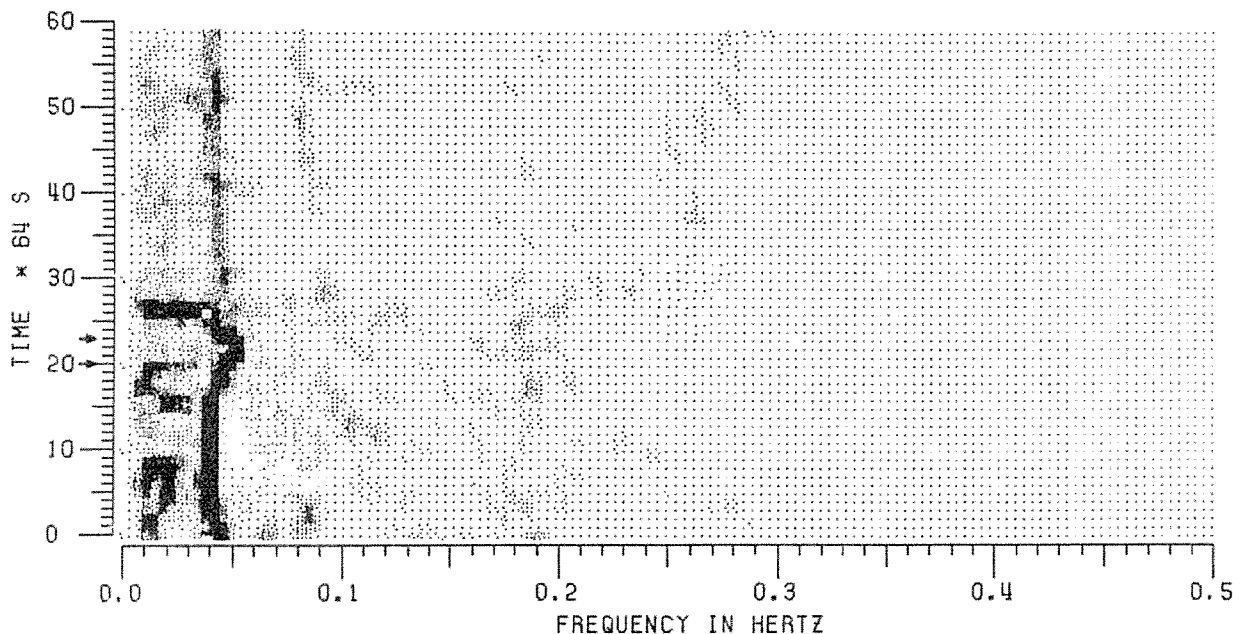


FIG. 4. Gray-scale plot of electrogastrogram shown in Fig. 2 (leads 2–4). Note characteristic frequency behavior during phase III of this IMC (arrow). Low-frequency components at ~0.01–0.03 Hz can be seen throughout analyzed period, although they tend to be less powerful during motor quiescence.

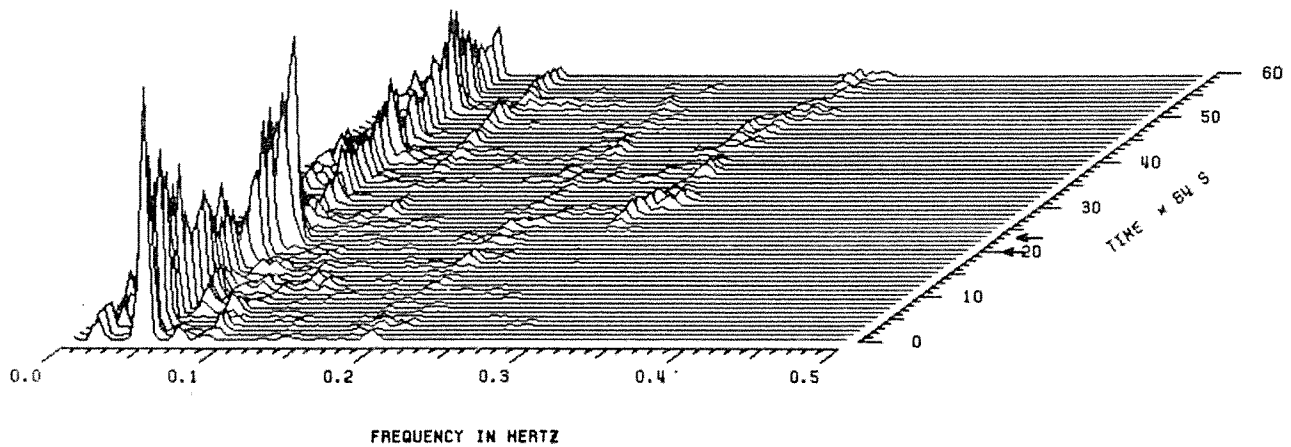


FIG. 5. Pseudo-three-dimensional display of electrogastragram shown in Fig. 2 (leads 2-4). Power changes at changeover from phases II to III and subsequently to motor quiescence can be easily recognized. Frequency at ~ 0.1 Hz is second harmonic. Frequency at $\sim 0.2-0.3$ Hz is of respiratory origin. Phase III marked with arrow.

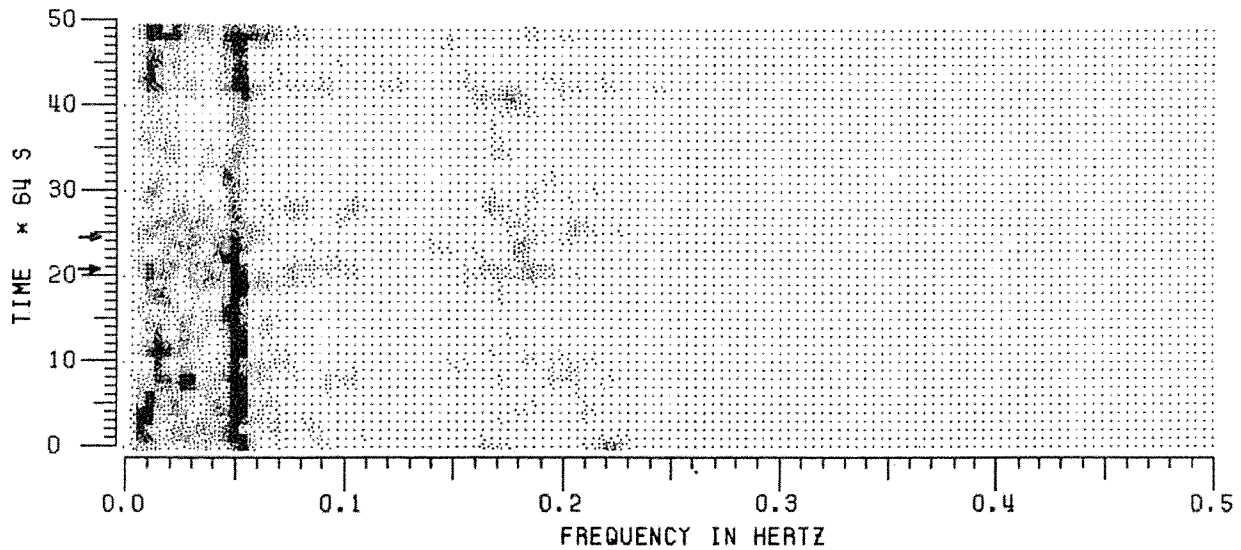


FIG. 6. Gray-scale plot of electrogastragram shown in Fig. 3 (leads 2-4). During phase III (arrow), no frequency changes can be seen. Only power decrease at changeover from motor activity to motor quiescence (phase I) can be recognized. At changeover from phases II to III, a small power decrease (0.90) was present, which cannot be recognized in gray-scale plot. Low-frequency components at $\sim 0.01-0.03$ Hz can be seen throughout analyzed period. Power increase at line 42 coincides with start of phase II motor activity.

III in the majority of the IMC was found to be relatively unstable ($P < 0.01$) as shown by the large frequency SD. The power behavior also varied, and a power increase, no power change, or even a power decrease was observed with respect to the power level of phase II (Fig. 6).

Low-frequency components (0.01-0.03) were observed in all subjects (Figs. 4 and 6), but no correlation between these low-frequency components and motor activity existed.

Characteristics of IMC Originating in Duodenum

Visual inspection. The EGG showed an amplitude decrease following a marked phase II-like motor activity in the stomach in only one IMC cycle. In the other four IMC no activity or weak motor activity was observed in the stomach with intraluminal pressure recording. The

EGG recorded during these four IMC showed no recognizable amplitude alterations.

Running-spectrum analysis. The results of the running-spectrum analysis are summarized in Table 1. No changes in the gastric frequency were observed. With the changeover from motor quiescence to motor activity, a power increase (factor 2.18) was found in one IMC coinciding with the phase II-like motor activity in the stomach. The power changes observed in the remaining IMC originating in the duodenum were smaller, corresponding to the less marked phase II-like motor activity or absent motor activity in the stomach.

DISCUSSION

Our findings with regard to the characteristics of the IMC as measured with intraluminal pressure recording techniques are in agreement with those reported in the literature (7, 11, 18, 20, 29).

Considering the closely related physiological functions of the gastrointestinal tract, the detection of the different phases of the IMC using a noninvasive method would in theory be an interesting application of EGG. Our study has shown that visual inspection of the EGG cannot be reliably used to identify IMC phases. Amplitude changes can only be interpreted as such from good quality EGG, i.e., those devoid of respiration artifacts.

Running-spectrum analysis lends itself to a better and quantitative approach. The characteristic frequency (and power) behavior during phase III as shown in Figs. 4 and 5 can be considered indicative of this phase but was only observed in a minority (44%) of the IMC. During phase II the power was at least a factor 2 larger than during the initial 10 min of phase I. This difference in power, observed in all 16 IMCs, can be easily seen in gray-scale plots or pseudo-three-dimensional plots and can be used in combination with the very stable gastric frequency in the initial period of phase I in order to estimate the end of motor activity and the beginning of phase I. However, the variable power of the gastric frequency during phase III prevents an exact timing of this changeover. In addition, the changeover from phases I to II cannot be exactly determined with an EGG. Whatever the cause of the gradual power increase at the changeover from phase I to II, before motor activity is recorded, this phenomenon prevents the identification of the exact boundary between phases I and II.

With regard to the low-frequency components, it is worthwhile comparing the EGG characteristics of the IMC in humans with those in dogs as described by van der Schee and Grashuis (28). These authors showed that in fasting dogs the presence in the EGG of high-power, low-frequency components and absence of the normal gastric frequency (0.085 Hz in dogs) were indicative of phase III motor activity. They also showed that the mechanism through which this is brought about involves highly variable, prolonged ECA interval durations associated with phase III contractions (24). In humans this type of low-frequency component was not observed. Instead, a relatively stable gastric frequency was found in all human IMC. These observations suggest that in humans during phase III such variability in ECA interval duration does not occur. We conclude therefore that in humans the gastric ECA frequency during the motor activity front of the IMC is far more stable than its canine counterpart.

In general, the power of the gastric frequency in the EGG increases when motor activity is present (13, 25, 31). This is in agreement with the finding that the power of the gastric frequency during periods of phase II motor activity was higher than during periods of motor quiescence. However, two questions of considerable interest arise. 1) Why did the power start to increase in phase I before motor activity was seen in the pressure recordings? Does the technique of pressure recording fail to record weak motor activity? Intraluminal pressure recording in the stomach could be unsatisfactory due to the nontubular anatomy of the stomach (32). 2) Why was an increase in power during phase III not observed in all IMCs? This unexpected behavior, which is in

contrast with phase II, where a significant positive correlation was present between power increase and motor activity, cannot be explained with our present state of knowledge.

Referring back to the objectives of our study we can now summarize. 1) The gastric frequency appeared to be less stable during motor activity, in particular during phase III, than during motor quiescence but far more stable than its canine counterpart. 2) A small but consistent drop in gastric frequency could be observed at the changeover from motor quiescence to phase II motor activity. 3) The power of the gastric frequency increased with increasing motor activity, except during phase III. 4) A characteristic frequency and power behavior during phase III could only be recognized in a minority of the IMC.

We conclude that, given the present state of the art, neither visual inspection nor running-spectrum analysis can be used to exactly identify the different phases of the IMC.

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