

Efficiency and Efficacy of the Electrogastragram

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The efficiency and efficacy of the electrogastragram (EGG) involve a few practical factors, including recording length, sample size, and the characteristics of subjects. The aim of this study was to investigate the effect of these factors on the accuracy of EGG analysis. Gastric myoelectrical activity was recorded using electrogastrography in 24 subjects (ages 22–91 years) for 1 hr in the fasting state and 2 hr after a test meal. Computerized spectral analysis was performed to compute EGG parameters, including dominant frequency, dominant power, and the percentage of 2–4 cycles per minute (cpm) slow waves. A parameter called misinterpretation was defined to investigate the effect of recording length. The results were as follows: (1) Using the recording length of 1 hr in each state as a gold standard, the misinterpretation for the recording length of 30 min was 27% for the dominant frequency and 17% for the dominant power. When the recording length was reduced to 15 min, the misinterpretation increased to 61% for the dominant frequency and 38% for the dominant power. (2) With a sample size of 10 subjects and a recording length of 60 min, a statistically significant postprandial increase was observed in the dominant frequency and power, and a trend in the postprandial increase of the regularity of the EGG was noted. When the sample size increased to 24 subjects, a significant postprandial increase was found in all these parameters. (3) None of the EGG parameters exhibited any significant difference between the younger and older subjects or between men and women. In conclusion, a recording length of 30–60 min seems to be appropriate and produces reliable and predictable results. Age and gender do not affect any of the EGG parameters.

KEY WORDS: electrogastrography; gastrointestinal motility; gastric emptying; stomach.

As electrogastrography develops from an experimental method to a clinically applicable tool, some practical issues may arise concerning efficiency and efficacy of the measurement. Unlike the electrocardiogram, which reflects an ultrashort repetitive cycle activity, the electrogastragram (EGG) involves the representation of two completely different patterns (1). Those include the fasting motor activity, which is further classified into three distinct phases, and the fed state (2). A short recording may miss

some information or outweigh a brief sequence that normally contributes little to the final result. On the other hand, a longer one may “slide” into the succeeding pattern, so that an overlap of states can be erroneously interpreted as one (a prolonged recording of the fed state may include the interdigestive activity once the stomach is emptied). Thus, duration and timing of the EGG are extremely important for reliable results and their clinical implications.

Additional considerations should be taken into account concerning other practical aspects. As a diagnostic tool, EGG should be performed with optimal efficiency and accuracy. A recording in the symptomatic patient has to be as short as possible and yet not omit the relevant information. Due to its nature, the

Manuscript received June 18, 1997; revised manuscript received September 26, 1997; accepted January 20, 1998.

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EGG has to be performed with an emphasis on minimizing movements (3); however, the probability of motion artifacts, even in the most cooperative patient, increases with time. So far, different investigators have been using different EGG duration measurements for both pre- and postprandial recordings. These measurements range from a few minutes to several hours (4–6). Another noteworthy aspect concerns sample size adequacy. Small samples may sometimes fail to produce statistically significant results, although a clear pattern or trend is shown, while large samples may be unnecessary and too time consuming. In reviewing other papers, we find a great variety among sample sizes as well (7–9).

Finally, the effect of the sample characteristics (age and gender) cannot be ignored. Although extensively investigated in the past by several groups (10–12), we used this study to repeat measurements using a more advanced spectral analysis method. Therefore, the aim of this study was to investigate the efficiency and efficacy of an “optimal length” EGG measurement as well as sample size impact and gender and age influence.

MATERIALS AND METHODS

Subjects. Twenty-four healthy volunteers (9 men, 15 women) were assessed. None had any gastrointestinal symptomatology, disease, or surgery. The average age was 49 ± 4.7 years, and ranged from 22 to 91. All women (who were not menopausal) were studied in their follicular phase of menses to eliminate the possibility of major hormonal changes. No subject was taking medication during the study period with the exception of two females who used contraceptive drugs.

The subjects were further evaluated considering age influence and were divided into two groups: the average age in the younger group was 30.7 ± 1.8 years (range: 22–41, 7 men, 7 women); and the average age in the older group was 74.7 ± 2.6 years (range: 60–91, 2 men, 8 women).

The protocol was approved by the Institutional Review Board, and a consent form was signed by each subject prior to the study.

Each subject was presented with a standard meal (475 kcal, 21% protein, 17% fat, 61% carbohydrate, and 2 g fiber) (13) in a single session after a fast of at least 6 hr before the recording. The EGG was recorded for 1 hr before and for 2 hr after the test meal. The subjects were placed in a quiet room where they could watch television in a supine position. They were requested to minimize their movements, and talking or reading was not permitted.

EGG Measurement. Gastric myoelectrical activity was recorded noninvasively from electrodes placed on the abdominal skin. The EGG reflects a weighted summation of gastric myoelectrical activity depicted from distinct areas of the stomach. According to numerous studies, the EGG is an accurate measurement of the gastric slow wave and represents gastric motility changes (14–16).

The frequency of the normal slow wave is 3 (range: 2–4) cycles per minute (cpm), and abnormal data may deviate from 1 to 9 cpm. To capture this broad range, a portable ambulatory device with a recording frequency range of 1–18 cpm was used (Digitrapper EGG, Synectics Medical, Inc., Shoreview, Minnesota). The device had been used in our laboratory for four years in numerous studies, and no malfunctions were noted. All EGG recordings were conducted after skin preparation and placement of three electrodes on the abdominal skin. The placement of the electrodes was done according to data acquired from previous studies in which the stomach was localized sonographically (17). The first electrode was positioned above the antrum (located 1–3 cm to the right and midway between the xiphoid process and the umbilicus), the second electrode 45 degrees to the left and 5 cm above the first, and the reference electrode on the left flank under the rib cage. Previous studies have shown that placing the electrodes in this way results in continuous and reliable data regarding the frequency and percentage of the gastric slow wave as well as the relative power of the EGG. More accurate measurement of the stomach and placement of the electrodes are required if the absolute amplitude of the EGG and/or the propagation of the slow wave is to be considered.

EGG Analysis. Because of its low signal-to-noise ratio, the EGG data were processed by computer. As previously mentioned, the normal gastric frequency ranges between 2 and 4 cpm. Other organs in the body produce electrical signals that have different frequency ranges. They could be distinguished from the gastric frequency in the power spectrum. As motion artifacts or profound breathing movements impede the accurate analysis of the EGG, we tried to eliminate them during the study and deleted them by visual inspection of the recording before computerized spectral analysis (18).

In evaluation of the EGG recordings, the following parameters were considered: (1) The dominant frequency—this reflects the frequency of the gastric slow waves; normal range is 2–4 cpm. (2) The dominant power—the amplitude and the regularity of the EGG (contractile activity is associated with its relative changes). Only relative changes of the dominant power were used since its absolute value is associated with many factors that could not be controlled, such as thickness of abdominal wall, accurate location of the stomach, etc. (3) Percentage of 2–4 cpm waves—this represents the percentage of time occupied by the regular 2–4 cpm gastric slow waves. (4) Percentage of dysrhythmias—this specifies the percentage of time associated with irregular gastric slow wave activity. Subclassification includes bradygastria (dominant peak in the 0.5 to 2.0-cpm range), tachygastria (dominant peak in the 4.0 to 9.0-cpm range), and arrhythmias (no dominant peak observed in the 0.5 to 9.0-cpm range). (5) Instability coefficient of the dominant frequency—this reflects the minute-by-minute variation of the dominant frequency of the EGG (1).

Misinterpretation of Effect of Intervention. An EGG study is often designed to investigate the effect of an intervention, such as a test meal or an injection of a pharmacological or hormonal agent. The change due to the intervention in any of the EGG parameters provides important information on the response of gastric myoelectrical activity to the intervention. It is known, however, that gastric mo-

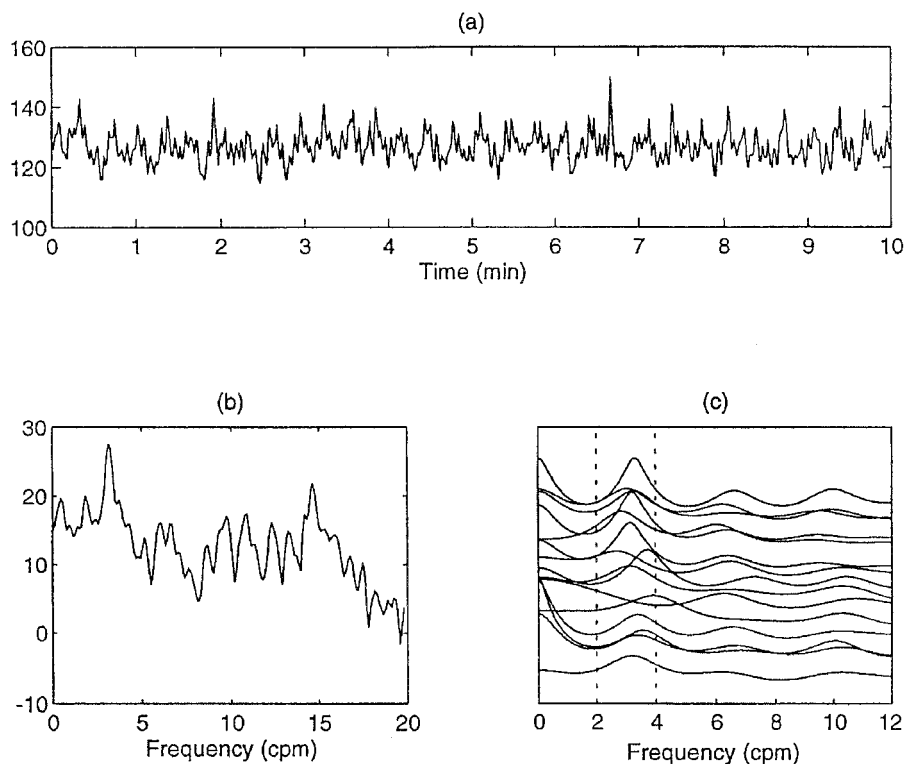


Fig 1. Characteristic electrogastrographic baseline recording in a subject, obtained in the fasting state: (a) a 10-min EGG recording; (b) its averaged power spectrum; (c) running power spectra computed according to the adaptive spectral analysis method. Each line represents the power spectrum of a 2-min segment of EGG data.

tility has three different phases in the fasting state—the so-called migrating motor complex (MMC). The stomach does not contract during phase I of the MMC, contracts randomly in both strength and frequency during phase II, and contracts forcefully and regularly during phase III. Previous studies have indicated that EGG parameters are different during different phases of the MMC. For example, the amplitude of the EGG is higher during phase III than that during phase I. That is, there is an intrastate difference in EGG parameters in the fasting state. If the study is not appropriately designed, this intrastate difference may be comparable or even larger than the change due to the intervention. When fasting EGG is performed without knowing the actual phase of the MMC (which is usually the case), the intrastate difference may lead to a misinterpretation on the effect of the intervention. It is apparent that this intrastate difference may be minimized by increasing the recording length. To investigate the effect of recording length on the accuracy of EGG interpretation, a parameter called misinterpretation (M) is defined as follows:

$$M = \frac{(\text{maximum} - \text{minimum}) \text{ in baseline}}{\text{change due to intervention}} \times 100\%$$

The misinterpretation was calculated for both dominant frequency and power of the EGG. The intervention used in this study was the test meal.

Statistical Analysis. All data were expressed as mean \pm

SEM and $P < 0.05$ was considered statistically significant. Student's t test was performed to evaluate effects of the meal, age, gender, sample size, and the recording length.

RESULTS

Regular slow waves were recorded in the EGG. A typical recording obtained in the fasting state, its averaged (or smoothed) power spectrum, and running power spectra are presented in Figure 1.

Effect of Recording Length

As no significant difference was found in the results related to age and gender (as discussed later), EGG data from both groups (younger and older) were combined and divided into time intervals of different duration to assess the possible effects of recording lengths on the analysis of the EGG.

Recording Length of 60 Minutes. A 60-min recording length carries an established pre- to postprandial statistically significant relationship and is widely used in EGG studies (19–21). Therefore, it was designed to be our standard reference recording length. Interstate measurements in the dominant frequency in-

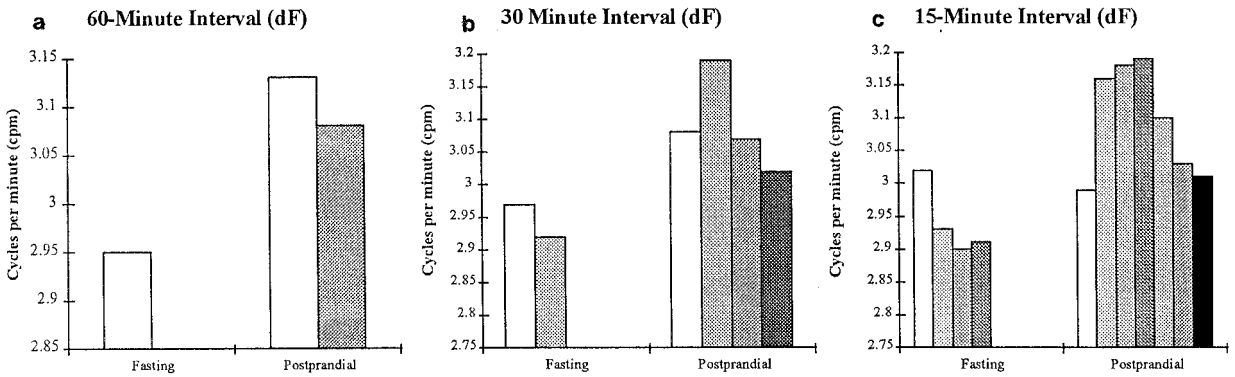


Fig 2. The dominant frequency in the fasting and postprandial states with a recording length of: (a) 60 mins; (b) 30 mins; and (c) 15 mins.

cluded: the average frequency for the fasting state, 2.95 cpm; that of the fed state (in the first hour) was 3.13 cpm. Thus, the interstate difference was 0.18 cpm (Figure 2a). Corresponding results in the dominant power were 30.1 dB in the fasting state and 32.9 dB in the fed state, with an interstate difference of 2.8 dB (Figure 3a).

Recording Length of 30 Minutes. Intrastate measurements of the 30-min recording in the fasting state included two values: the first 30-min value was 2.92 cpm, and the next 30-min value was 2.97 cpm. The misinterpretation for the dominant frequency was 27%. The dominant power achieved in the two 30-min recordings was 29.8 and 30.3 dB, respectively; thus, the misinterpretation was 17% (Figures 2b, 3b).

Recording Length of 15 Minutes. Intrastate measurements for the 15-min recording in the dominant frequency were 3.02, 2.93, 2.92, and 2.91 cpm for every consecutive recording (Figure 2c). The misinterpretation was 61%. The dominant power values in the same recording length were 29.3, 29.7, 29.8, and 30.8 dB with a misinterpretation of 38% (Figure 3c). In the postprandial state, a gradual increase in the

dominant frequency reached a peak and plateaued in the second to fourth 15-min interval (2.99 to 3.19 cpm), with a stepped decrease (down to 3.03 cpm). The postprandial dominant power showed the highest value in the first 15-min interval (33.6 dB, a difference of more than 3.5 dB from the fasting state), with an unsteady decrease afterwards.

Effect of Sample Size

After analyzing all 24 patients, we randomly chose 10 subjects and reanalyzed statistically the major EGG parameters: the dominant frequency, dominant power, the percentage of normal slow waves, and the instability coefficient. Figures 4a and 4b show the fasting and fed dominant frequency in both samples, with a statistically significant postprandial increase of 2.94 ± 0.05 vs 3.24 ± 0.05 cpm ($P < 0.0002$) in the large group ($N = 24$), and 2.85 ± 0.09 vs 3.25 ± 0.06 cpm ($P < 0.007$), in the small group ($N = 10$).

In Figure 5a and 5b, the analogous results in the dominant power are demonstrated with a significant increase in the postprandial state in the large sample, from 29.6 ± 1.06 to 33.5 ± 1.06 dB ($P < 0.02$), and in

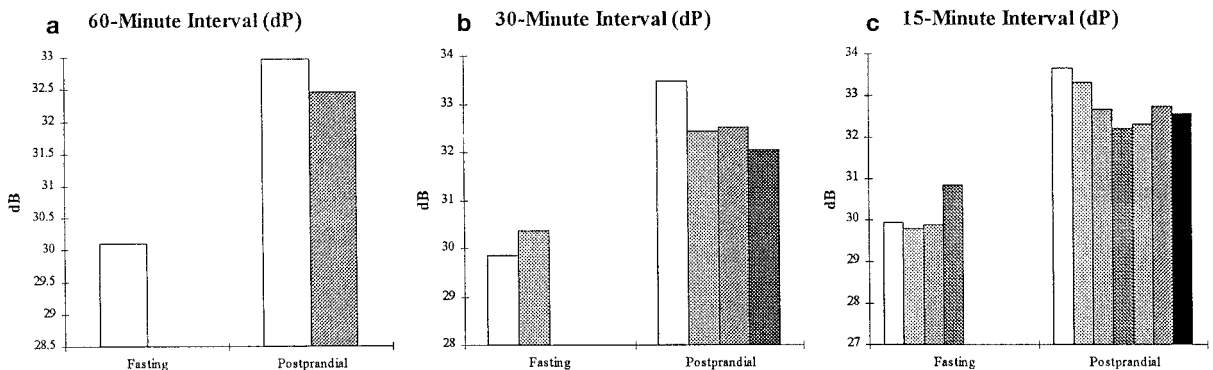


Fig 3. The dominant power in the fasting and postprandial states with a recording length of: (a) 60 mins; (b) 30 mins; and (c) 15 mins.

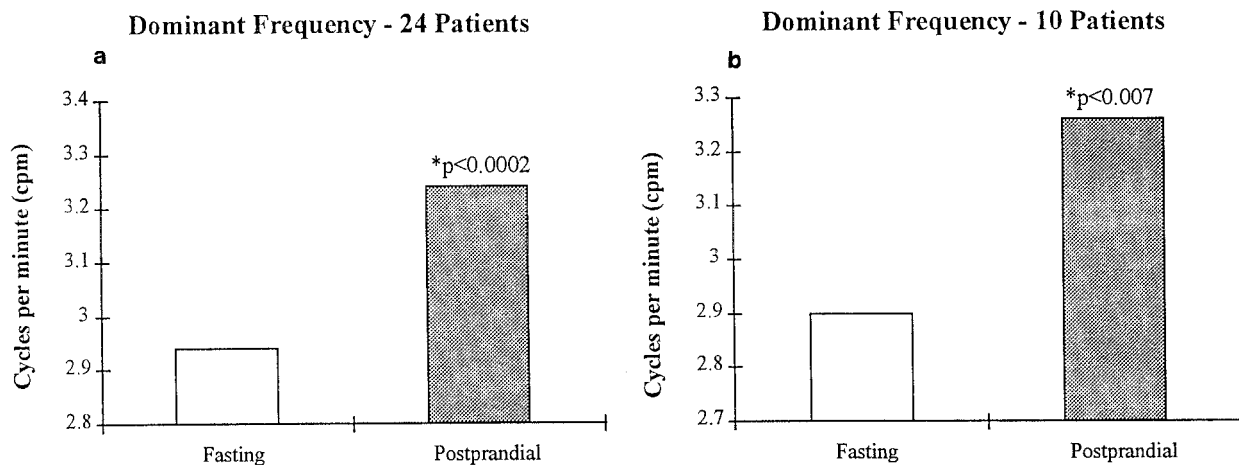


Fig 4. The dominant frequency in the fasting and postprandial states using different sample sizes of: (a) 24 subjects; and (b) 10 subjects. Both samples show a significant increase after food.

the other group 28.1 ± 1.39 vs 30.6 ± 0.83 dB ($P < 0.03$).

Figures 6a and 6b demonstrate a distinct difference between the two samples, showing pre- and postprandial changes in the large sample in the normal wave percentage: 80.5 ± 2.7 vs 87.4 ± 1.8 , ($P < 0.01$). However, in the small sample group, the postprandial change is not statistically significant, although it is noticeable: 76.4 ± 4.6 vs 83.0 ± 2.0 ($P > 0.1$).

Age Effect

No significant differences were noticed in any of the EGG parameters in comparing young to old subjects in the fasting or the fed state. The fasting dominant EGG frequency was 2.92 ± 0.03 in the younger group, and 2.96 ± 0.10 cpm in the older group ($P >$

0.6); the dominant power was 30.05 ± 1.2 in the younger group vs 29.03 ± 0.01 dB ($P > 0.6$) in the older group; the percentage of the 2 to 4-cpm waves was 79.3 ± 3.7 vs 82.2 ± 4.1 ($P > 0.6$); and the instability coefficient of the dominant frequency was 0.28 ± 0.04 vs 0.29 ± 0.04 ($P > 0.9$).

For postprandial results, the dominant EGG frequency was 3.17 ± 0.07 in the younger group and 3.33 ± 0.05 cpm in the older group ($P > 0.1$); the dominant power was 32.5 ± 0.8 in younger group vs 34.66 ± 2.13 dB ($P > 0.3$) in the older group; the percentage of the 2 to 4-cpm waves was 85.7 ± 1.6 vs 89.5 ± 3.5 ($P > 0.3$); and the instability coefficient of the dominant frequency was 0.27 ± 0.02 vs 0.18 ± 0.03 ($P > 0.05$).

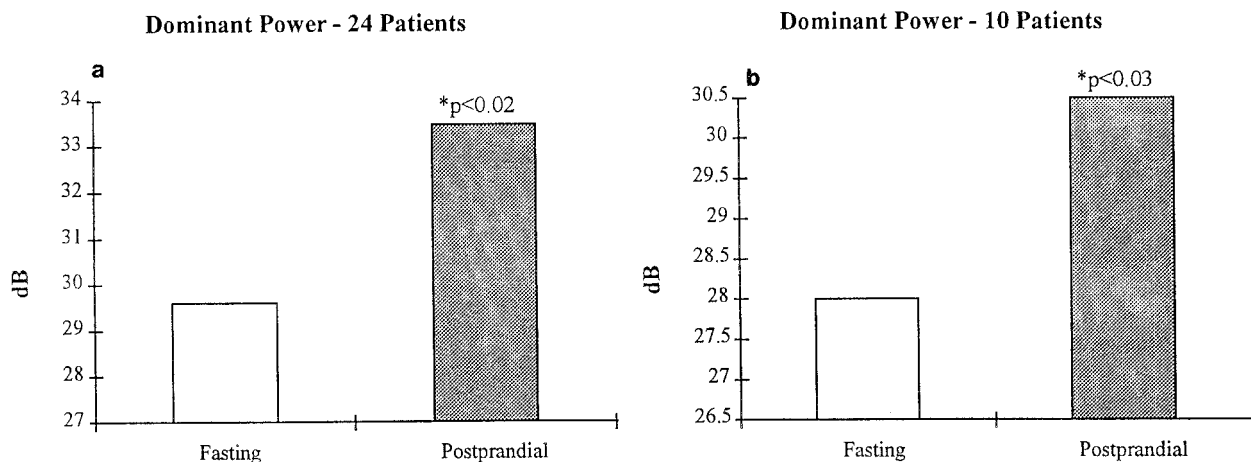


Fig 5. The dominant power in the fasting and postprandial states using different sample sizes of: (a) 24 subjects; and (b) 10 subjects. Both samples show a significant increase after food.

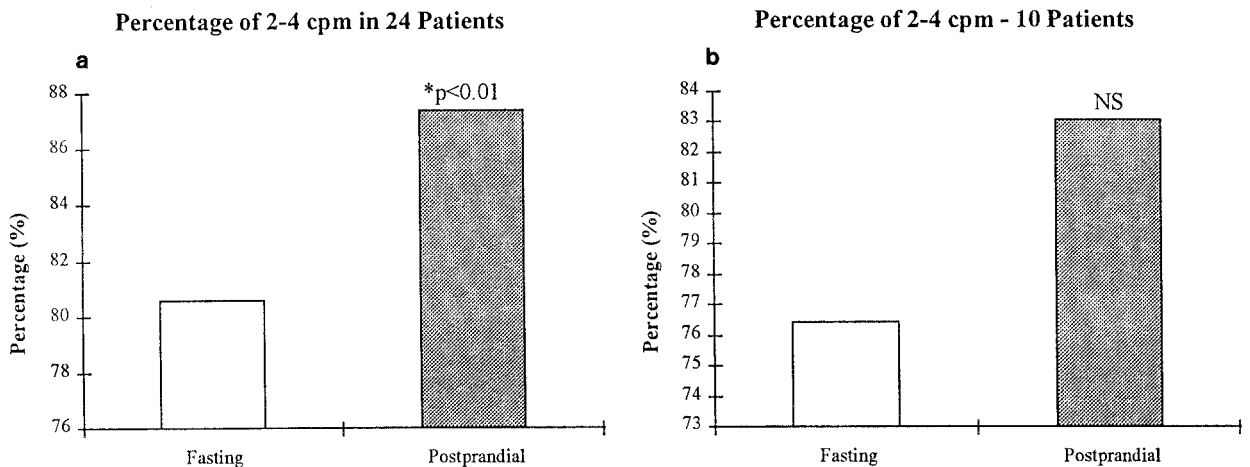


Fig 6. The percentage of the 2- to 4-cpm gastric slow waves in the fasting and postprandial states using different sample sizes: (a) 24 subjects; and (b) 10 subjects. Only the larger sample shows a statistically significant increase, while the other shows only a tendency.

Gender Effect

In comparing male to female subjects, the fasting and postprandial results showed no significant differences in any of the EGG parameters. The fasting dominant EGG frequency in women reached 2.94 ± 0.07 and that in men 2.94 ± 0.03 cpm ($P > 0.9$); the dominant power was 31.05 ± 1.4 in women and 27.23 ± 1.3 dB in men ($P > 0.09$); the percentage of 2 to 4-cpm waves achieved for women was 84.7 ± 3.0 and for men 73.6 ± 5.0 ($P > 0.05$); and the instability coefficient of the dominant frequency was 0.24 ± 0.04 in women vs 0.37 ± 0.05 in men ($P > 0.1$).

The postprandial dominant EGG frequency measured in women was 3.25 ± 0.05 vs 3.22 ± 0.1 cpm in men ($P > 0.7$); the dominant power increased to 34.75 ± 1.4 in women vs 31 ± 1.2 dB ($P > 0.1$) in men; the percentage of the 2 to 4-cpm waves was 87.6 ± 2 vs 86.9 ± 3.0 ($P > 0.8$); and the instability coefficient of the dominant frequency dropped to 0.22 ± 0.03 vs 0.24 ± 0.03 ($P > 0.7$).

DISCUSSION

The efficiency and efficacy of any diagnostic tool are major concerns of investigators and clinicians. In our study, we have reviewed some components in the design of the EGG, including recording length, sample size, and effects of age and gender.

Adequate Recording Length

The recording length of 60 min was set as a standard point of reference in this study. The results obtained with this length of recording were in agreement with previous studies (4, 6). In one of those

studies, a period of more than 6 hr was recorded in the fasting state, but the results were not different from what was expected from a much shorter recording, rendering it unnecessary. As was expected along with measurement lengthening, variation among subjects is further narrowed.

The EGG with a recording length of 30 min was characterized by a rather stable pattern, a relatively small variation, and narrow spectrum of the values of the EGG parameters. In comparison with the recording length of 60 min, the misinterpretation of the postprandial response due to the intrastate difference in EGG parameters was about 20%. This, however, did not lead to any changes in the statistical analysis. Due to relatively small variations between the two recordings of 30 min, the pre- and postprandial change in the EGG was still reliable and predictable.

The recording length of 15 min, however, resulted in a large misinterpretation for the postprandial response. The intrastate difference accounted for more than one third to two thirds of the pre- and postprandial difference. That is, the fasting EGG with a recording length of 15 min is not reproducible. The substantial intrastate difference would mask the pre- and postprandial difference or the change due to an intervention, yielding a misinterpretation of the postprandial response.

In the fasting state, exhibiting very similar final results with the advantage of a shorter recording, a 30-min measurement seems to be enough to produce reliable results, especially concerning the dominant power aspect. The fasting EGG recording aims at capturing the electrical activity during that state. This

activity is represented by the migrating motor complex (MMC), which lasts 84–112 min and is divided to three phases: Phase I comprises 40–60% of the cycle time, and phases II and III comprise 20–30% and 5–10 min, respectively (2). One would assume that for incorporation of these different phases, prolonged recording is necessary; however, the results show that regardless of the duration and timing of measurement, the final outcome is the same (in a 30-min recording). As people are studied randomly without a known correlation with the specific phase in the MMC cycle, we could assume that the short period of phase III, although very different from the others, does not contribute greatly to the final result. Furthermore, analyzing data acquired from a large group probably includes different MMC phases and durations but reflects a collective average.

As for the postprandial state, fragmentation of data into short intervals enabled us to follow the process of transition through the digestive states step by step from the quite steady fasting state to the immediate and late changes following food ingestion. The 15-minute intervals, in particular, provided us with a more precise way of assessing the short-term myoelectrical changes. A rise in the dominant frequency is noted as food is processed, with a stepped increase that reaches a plateau during 30–60 min. The explanation for this phenomenon may be the brief minimal initial postprandial dip that was noted in previous studies. This study further observed, concerning the prediction of gastric emptying (as we did), a gradual increase up to a steady state in the 30-min period; then, a gradual decrease ensues for up to 2 hr postprandially when it reaches fasting state values again. The dominant power reaches a peak during the first postprandial 15 min with a gradual unsteady drop afterwards, which corresponds approximately to information mentioned in the same report (22).

Sample Size

By reviewing previous EGG studies, a spectrum of sample sizes appears from isolated case reports to large groups of several dozen (23–25). In our study, we compared a fraction of our subjects to the whole group. We found that even a small sample size of 10 subjects is sufficient for indicating trends (Figure 6b), although some results may show significance (Figures 4b and 5b). It depends greatly upon the nature and direction of the change.

The larger the variation among the responses, the more patients will be needed for producing an accurate prediction. For practical consideration, 10 sub-

jects may exhibit an obvious typical pattern that sometimes needs enhancement by adding a few more subjects. In EGGs, we expect the major parameters of the dominant frequency and power and the percentage of 2 to 4-cpm slow waves to increase and the instability coefficient to drop after a standard test meal. It seems that, with a sample size of 10, the first two parameters will achieve a statistically significant value, while the last one will only reflect a collective trend. When increasing the sample size, we may expect the 2 to 4-cpm percentage of the slow waves to reach a significant value. As for other parameters (eg, proportion of distinct types of arrhythmia), a much larger sample is required due to the wide variation.

Age and Gender

The influence of age and gender has been discussed in the past by several investigators (10, 11, 21). The application of the advanced spectral analysis method (in contrast to Fourier analysis) allowed us to repeat the measurements and compare them to the existing results. Older adults did not differ from younger ones (up to 70 years of difference) in any of the EGG parameters when healthy volunteers were tested (with the same test meal). Similar results were produced after considering the data according to gender. The fact that women were studied at the beginning of their menses probably helped in stabilizing the results by decreasing the importance of hormonal changes as reported by Parkman et al (11). Our results revalidated most data described in the study of Pfaffenbach et al with a different analysis method (10).

The same guidelines should be applied for healthy adults regardless of age and gender. Efficient EGG length of measurement may last for about 30 min before and 30–60 min after a standard test meal. In a small sample size of healthy subjects, we expect a statistically significant postprandial increase of the dominant frequency and power only. An increase in the percentage of normal slow waves and a decrease in the instability coefficient will achieve statistical significance in a much larger sample. Adjustments should be performed considering the specific characteristics of the population studied (longer measurements for suspected delayed gastric emptying or less cooperative patients; eg, infants) and the objective of the study (a larger sample size for a wide-ranging parameter).

The applicability of the EGG has been addressed in numerous previous studies (3, 6, 7, 15, 19, 20, 24, 25). It may be used to noninvasively diagnose patients with gastric motor disorders, such as delayed gastric

emptying (22, 26), to identify whether gastric dysrhythmia is involved in the pathogenesis of gastrointestinal motor disorders and/or symptoms (15, 20), and to study the response of gastric myoelectrical activity to an intervention, such as test meals and medications.

In conclusion, an EGG recording of 30-min in the fasting state and 30–60 min in the fed state seems to be appropriate, and produces reliable and predictable results. Postprandial increases in the dominant frequency and power are normal responses of the EGG after a solid meal. The regularity of the postprandial slow wave may increase significantly if the sample size is large enough. Age and gender do not affect any of the EGG parameters.

ACKNOWLEDGMENTS

The authors wish to thank Regina Randall for her preparation of the manuscript.

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