

Original contributions

Gastric Myoelectrical Activity in Patients With Gastric Outlet Obstruction and Idiopathic Gastroparesis

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Objective: The cause of gastroparesis may be uncertain in some patients. Mechanical obstruction of the stomach or duodenum should be excluded in patients with idiopathic gastroparesis. The objective of this study was to compare gastric myoelectrical activity in patients with idiopathic gastroparesis with that of patients with gastroparesis due to mechanical obstruction of the stomach or duodenum. **Methods:** Electrogastrography techniques were used to record gastric myoelectrical activity in 20 patients with idiopathic gastroparesis and in nine patients with gastroparesis secondary to gastric outlet obstruction. Four of these nine patients initially were thought to have idiopathic gastroparesis. Electrogastrograms (EGGs) were recorded from 29 healthy subjects who served as controls. EGGs were recorded for 20–30 min 2 h after a standard 200-Kcal meal and were analyzed visually and by computer. **Results:** Patients with gastroparesis due to outlet obstruction had high-amplitude and excessively regular 3–cycles-per-minute (cpm) EGG patterns, whereas patients with idiopathic gastroparesis had primarily 1- to 2-cpm patterns and little 3-cpm EGG activity. The percentage of total EGG power in the 3-cpm range was approximately 50% in patients with gastric outlet obstruction compared with 20% in patients with idiopathic gastroparesis ($p < 0.001$). The percentage of EGG power in the normal 3-cpm range was greater in the obstructed patients (50%) than in the healthy controls (35%; $p < 0.052$). **Conclusions:** Gastric myoelectrical patterns recorded in the EGG distinguish mechanical and idiopathic causes of gastroparesis and may be useful in evaluating patients with nausea, vomiting, and gastroparesis of unknown cause. (*Am J Gastroenterol* 1998;93:1803–1809. © 1998 by Am. Coll. of Gastroenterology)

INTRODUCTION

Emptying of food from the stomach is dependent upon normal gastric contractile and electrical activities, pyloric and duodenal resistance, and the caloric density and physical characteristics of the food. Gastric slow waves are the electrical events that determine the direction, frequency, and velocity of gastric contractions. Slow wave potentials originate near the junction of the fundus and the body along the greater curvature of the stomach. This area is known as the gastric pacemaker region. The normal frequency of slow waves originating from the pacemaker region is 3 cycles per minute (cpm) in humans (1). The propagation of slow waves in an aboral direction, from gastric body to pylorus, coordinates gastric peristaltic contractions, which triturate and empty solids from the stomach into the duodenum (2).

Deviations from the normal 3-cpm myoelectrical activity (normal range, 2.4–3.6 cpm) are referred to as gastric dysrhythmias (3). Dysrhythmias may be further classified as bradygastrias, 1–2.4-cpm waves, which include flatline or arrhythmic patterns, and tachygastrias, which are abnormally fast, 3.6–9.9-cpm myoelectrical signals. Gastric dysrhythmias have been recorded in patients with gastroparesis due to diabetes mellitus, and in those with postsurgical arterectomy, chronic mesenteric artery ischemia, and idiopathic gastroparesis (1, 4–7). Gastric myoelectrical activity in patients with mechanical obstructions has not been studied. Mechanical obstruction of the stomach due to pyloric or duodenal lesions must always be considered in the evaluation of gastroparesis, but the presence of an obstruction may sometimes evade detection.

In the course of evaluating patients with nausea and vomiting due to idiopathic gastroparesis, we recorded remarkably regular, high-amplitude, 3-cpm electrogastrogram (EGG) waves. These high-amplitude 3-cpm EGG waves suggested that myoelectrical function of the stomach was normal because the normal slow wave rhythm was present, but the finding of gastroparesis in these patients was surprising, leading to further tests and the discovery of previ-

ously undetected mechanical obstruction of the stomach or small bowel.

The aim of this study is to describe the gastric myoelectrical activity in patients with gastroparesis due to mechanical obstructions and to compare these results with EGG recordings both from patients with idiopathic gastroparesis and from healthy controls subjects.

MATERIALS AND METHODS

Subjects

Nine patients (five men and four women; ages, 20–75 yr; mean, 47 yr) with mechanical obstructions of the gastrointestinal tract, nausea, and vomiting were studied. Five patients had obstructions of the pyloric channel secondary to chronic peptic ulcer disease or Crohn's disease. The obstruction in these patients was identified before the EGG studies were obtained. In the other four patients, the patients' diagnosis was idiopathic gastroparesis and mechanical obstruction was not suspected at the time of initial EGG studies. Three patients were eventually found to have pyloric obstruction and one had a fibrous stricture distal to the duodenal bulb. Twenty patients with idiopathic gastroparesis who had presented with nausea and vomiting were studied. These 20 subjects (six men and 14 women; ages, 20–74 yr; mean, 44.6 yr) underwent electrogastrographic studies and gastric emptying studies after barium and endoscopic examinations had excluded mechanical obstructions of the stomach and duodenum. Twenty-nine healthy volunteers (17 men and 12 women; ages, 21–28 yr; mean, 28.5 yr) with no history of gastrointestinal disease and no gastrointestinal symptoms also underwent EGG recordings.

Electrogastrographic methods

Four silver-chloride electrodes were positioned on the abdomen to record the EGG, as previously described (3, 8). Three electrodes were placed in the left upper quadrant and epigastric regions. The first electrode was positioned below the left rib margin in the midclavicular line. The third electrode was placed equidistant between the xiphoid process and the umbilicus, and the second electrode was positioned along a line between the first and third electrodes. The fourth electrode served as a reference electrode and was positioned in the right upper quadrant along the line formed by the other three electrodes. The skin beneath the electrodes was slightly abraded before attaching each electrode. The electrodes were connected to a rectilinear recorder (SensorMedics, Anaheim, CA) through direct nystagmus couplers (Model 9859). The high-frequency cutoff was 0.30 Hz and the low-frequency cutoff was 0.016 Hz. A custom software program for EGG data analysis was used, as described later.

All patients and control subjects were fasted overnight. In the morning, 2 h after a 200-KCal meal consisting of two slices of toast and apple juice, the EGG recordings were obtained. The EGG recordings in the patients were 30 min

in duration; patients did not receive a water load. The EGG recordings in the healthy subjects included a baseline 20-min recording, after which the subjects ingested 240 ml of water. However, the EGG data presented here from the healthy subjects are from the 20-min baseline fasted period only.

Analysis of EGG signals

The recording channel with the clearest electrogastrographic signal was chosen for visual and computer analysis. Frequencies of interest recorded in the EGG are 1.0–2.4 cpm (1–2 cpm = bradygastrias), 2.4–3.6 cpm (3 cpm = normal range), 3.6–9.9 cpm (4–9 cpm = tachygastrias), and 10–15 cpm (duodenal or respiratory frequencies). Visual inspection of the EGG recording was used to determine the predominant gastric rhythm. Computer analysis representing approximately 20 min of electrogastrographic signals recorded from each subject during fasting was compared with the visual interpretation of the electrogastrographic signal, to confirm the visual EGG pattern and to ascertain shifts in electrogastrographic frequency that were not appreciated by visual inspection.

Computer analysis of EGG signals. The EGG signal was channeled to the A/D conversion board in the laboratory computer, where it was digitized at 4.267. The digitized signal was zero-centered and filtered to remove high-frequency (> 15 cpm) and very low-frequency (< 1 cpm) components, which may alter the 1–15 cpm of interest in the raw EGG signal (8). The filters used were fourth-order elliptical filters with a 200-milli-dB passband ripple. The low-pass filter had a high-frequency band edge at 0.15 Hz with required attenuation of –90 dB in the stopband.

After digital filtering, the time series was Fourier transformed and spectral density estimates were calculated. The spectral analysis describes the signal frequencies. The spectral analysis utilized a Hanning window and yielded spectra with frequency bin widths of 0.002084 Hz. The EGG spectra calculated from a discrete time period, *i.e.*, a Fourier transformation, were graphed in a pseudo-three-dimensional plot or running spectral analysis. Running spectral analyses (RSA) were constructed by performing spectral analysis on successive segments of the digitized EGG signal, each of which overlapped preceding segments. Each line in the running spectral analysis represented approximately 4 min of EGG signal, with a 75% overlap. Thus, each line represents 60 s of new data added to the previous 180 s of EGG data, for a total of 4 min of EGG data per line.

Percentage distribution of power. Power distributions were calculated by summing the powers within one of the four major frequency bands listed above during a specified period of time and dividing that number by the total power in all four bands. For example, the power at 2.4–3.6 cpm was divided by the power in the 1- to 15-cpm range and multiplied by 100 to give the percentage of power in the normal 3-cpm range.

Solid-phase gastric emptying time

Patients were fasted for at least 8 h before the baseline solid-phase gastric emptying study. The standard meal consisted of two eggs scrambled with 500 uCi of technetium-99 sulfur colloid and then cooked until done. The eggs were ingested in 3–5 min, after which the subject was given 30 ml of water to drink. Details of the gastric emptying test have been published (4).

A large field-of-view camera with a parallel hole collimator was used in these studies. The energy range for 99 mTc was preset with a 20% window, and the preset stop was set for 60 s. Immediately after the eggs were ingested, a static scintigraphic image was taken in the anterior position with the patient lying supine. The image was recorded on an α -microdot computer. The procedure continued with a 1-min scan acquired in the anterior view every 15 min thereafter, for total of 120 min.

The emptying curve was established in healthy subjects ($n = 10$) by plotting the percentage of the total meal remaining within the stomach against time, as described by Horowitz *et al.* (9). A region of interest was drawn around the stomach, as depicted on the computer display of counts at each time point. In each patient, the value for 100% retention of the meal was derived from the maximum gastric count obtained in the first 45 min after the meal. The $T_{1/2}$ was 71 ± 18 min (mean ± 1 SD) and the percentage retained at 120 min was $20 \pm 17\%$ (mean ± 1 SD) in the control subjects. The uncorrected anterior view underestimates solid food emptying by approximately 7% (10). Patients with prolonged half-emptying time or percentage retained > 1 SD more than the mean at 120 min, *i.e.*, $> 40\%$ retained, were considered abnormal.

Statistical methods

The EGG data are expressed as means \pm SEM. Data from controls and patients were compared using unpaired Student's tests. $p < 0.05$ was considered significant.

RESULTS

Gastric myoelectrical activity in patients with mechanical obstruction and gastroparesis

Figure 1 shows a series of EGG tracings representative of gastric myoelectrical activity recorded from the four patients with idiopathic gastroparesis in whom mechanical obstruction was not initially suspected. The EGG traces from each patient demonstrates clear 3-cpm waves that are easily identified by visual inspection.

Figure 2 shows the EGG signal recorded from a patient with known pyloric stenosis secondary to chronic peptic ulcer disease and the RSA from the same EGG signal. The 3-cpm EGG waves are extremely clear, regular, and high in amplitude (inset). The running spectral analysis from 40 min of EGG signal recorded from the same patient shows remarkably regular 3-cpm peaks with virtually no variations

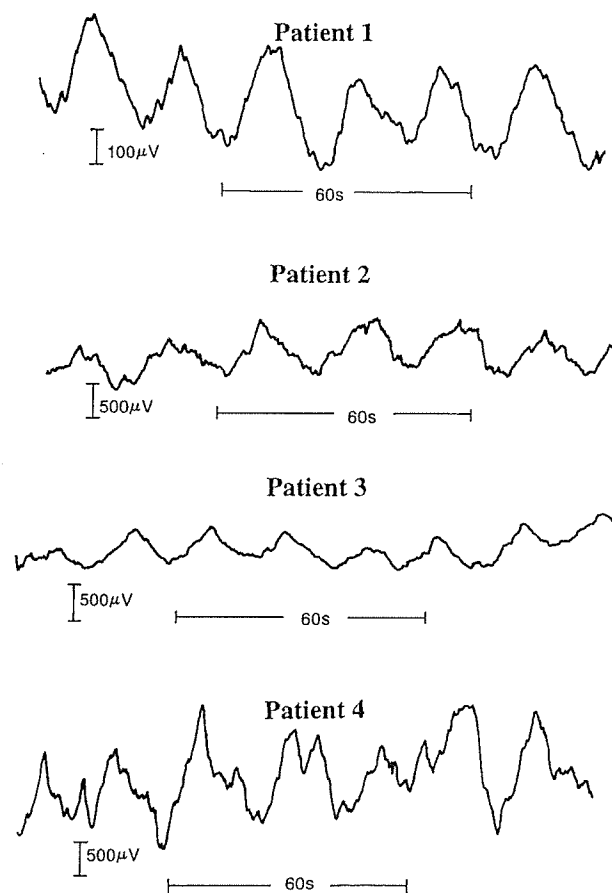


FIG. 1. EGG recordings showing normal 3-cpm waves in four patients with idiopathic gastroparesis in whom mechanical obstructions of the gastrointestinal tract were eventually discovered.

in frequency, a persistent regularity and lack of variability in rhythm not seen in the healthy controls.

The gastric emptying results from these patients with obstructions showed 75% to 100% of the egg meal retained at 2 h (Table 1). Three of the five patients with known obstructions did not undergo the solid-phase gastric emptying tests. One patient with unsuspected obstruction vomited the test meal.

Gastric myoelectrical activity in patients with idiopathic gastroparesis

Figure 3 shows an EGG recording (inset) and running spectral analysis of the EGG record from a patient with idiopathic gastroparesis. Waves of 1–2 cpm dominate the signal and no 3-cpm waves are seen. Furthermore, the running spectral analysis of approximately 30 min of EGG signal from this patient shows that the predominate EGG frequency is 1–2 cpm, with many large peaks in the 1- to 2-cpm range and few peaks in the normal 3-cpm range.

Gastric emptying results in the patients with idiopathic gastroparesis are shown in Table 2. The percentage retained at 120 min ranged from 42% to 90%. The $T_{1/2}$ ranged from 91 min to > 120 min.

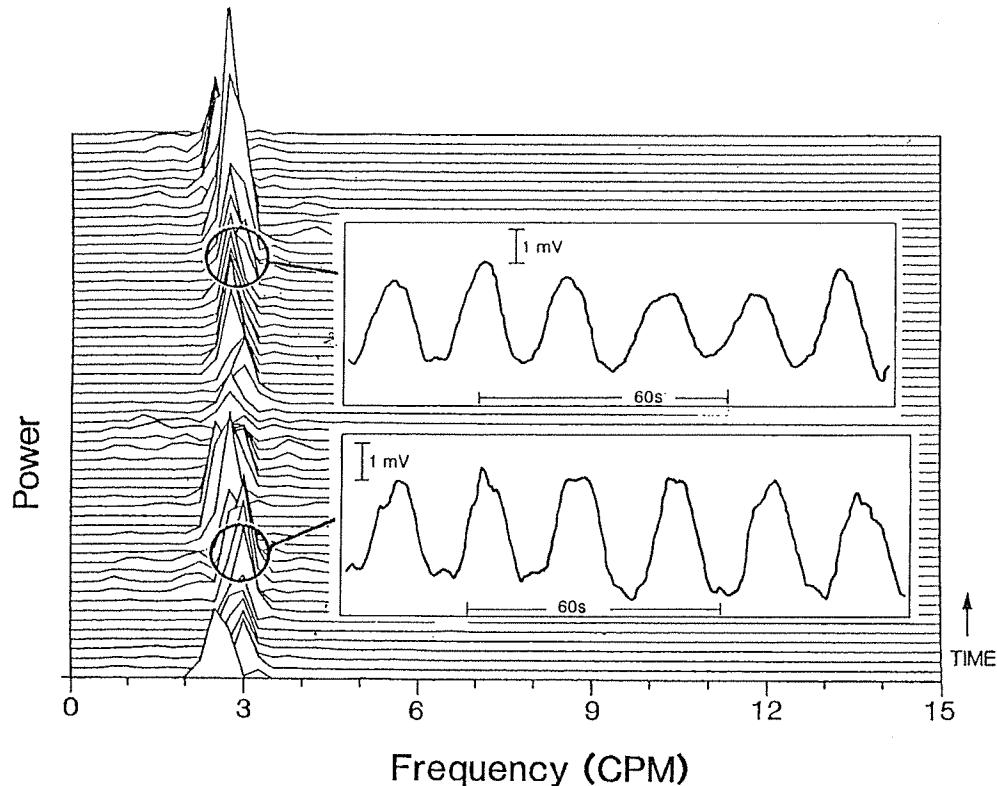


FIG. 2. EGG tracings (insets) and running spectral analysis recorded from a patient with gastroparesis and known gastric outlet obstruction due to pyloric stenosis. The EGG tracings show persistent, high-amplitude, distinct 3-cpm waves. The spectral analysis shows extraordinarily regular 3-cpm peaks with no variations in frequency.

TABLE 1
Solid-Phase Gastric Emptying Results in Patients With Obstruction of the Stomach and Duodenum

Patient	Age/Sex	T1/2	% Retained at 2 h
1. W.I.	44/Male	> 120	100%
2. C.H.	67/Male	> 120	94%
3. J.W.	35/Female	> 120	87%
4. S.O.	34/Female	> 120	Vomited
5. J.T.*	49/Male	> 120	Not done
6. R.M.*	20/Male	> 120	75%
7. M.G.*	43/Female	> 120	85%
8. B.J.*	55/Female	> 120	Not done
9. M.R.*	70/Female	> 120	Not done

* Patients with known obstructions before EGG testing.

Gastric myoelectrical activity in healthy controls

The EGG recordings from the healthy volunteers showed variability in EGG signals, with a mixture of normal 3-cpm EGG waves and occasional 1- to 2-cpm EGG waves. The inset in Figure 4 shows an example of a normal 3-cpm EGG pattern recorded from a control subject. Figure 4 also shows the running spectral analysis from 20 min of EGG signal recorded from the same control subject. The spectral analysis demonstrates the predominance of 3-cpm peaks with intermittent 1- to 2-cpm peaks in this control patient.

Quantitative analysis of gastric myoelectrical activity

Figure 5 shows the mean percentages of total EGG activity during fasting in the normal 3-cpm range, bradygastria range, tachygastria range, and the duodenal-respiration range from the three groups. The percentage of total power in the 3-cpm range in the obstructed patients was 51%; in contrast, the percentage of total power in the 3-cpm range in the patients with idiopathic gastroparesis was 20% ($p < 0.001$). Patients with mechanical obstruction had a greater percentage of 3-cpm activity than control subjects (51% vs 35%), and the difference was marginally significant ($p = 0.052$). The patients with idiopathic gastroparesis had a significantly smaller percentage of 3-cpm activity than controls (20% vs 33%, $p < 0.01$).

Figure 5 also shows that the percentage of 1- to 2.4-cpm bradygastria activity in the patients with mechanical obstructions with gastroparesis was approximately 35% of the total power. The patients with idiopathic gastroparesis, on the other hand, had significantly more 1- to 2.4-cpm bradygastria activity (60%) than the obstructed group ($p < 0.001$) and than control subjects, who had approximately 45% of the total EGG power in the 1- to 2-cpm range ($p < 0.01$). The patients with mechanical obstruction and gastroparesis had 10% of total EGG power in the tachygastria range, whereas the patients with idiopathic gastroparesis had 20% of the power in this range. Control subjects had 13% of total

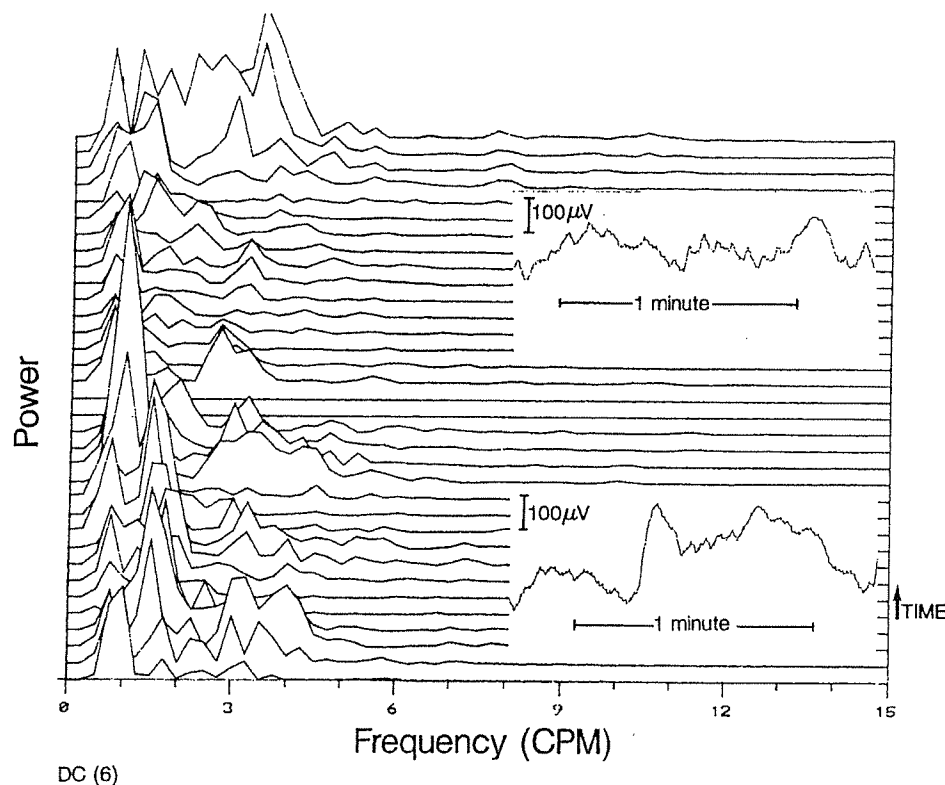


FIG. 3. EGG tracings (insets) and running spectral analysis from a patient with idiopathic gastroparesis showing bradygastria with mainly 1- to 2-cpm EGG waves. The spectral analysis shows predominance of peaks in the 1- to 2-cpm range and paucity of 3-cpm peaks.

TABLE 2
Solid-Phase Gastric Emptying Results in Patients With Idiopathic Gastroparesis

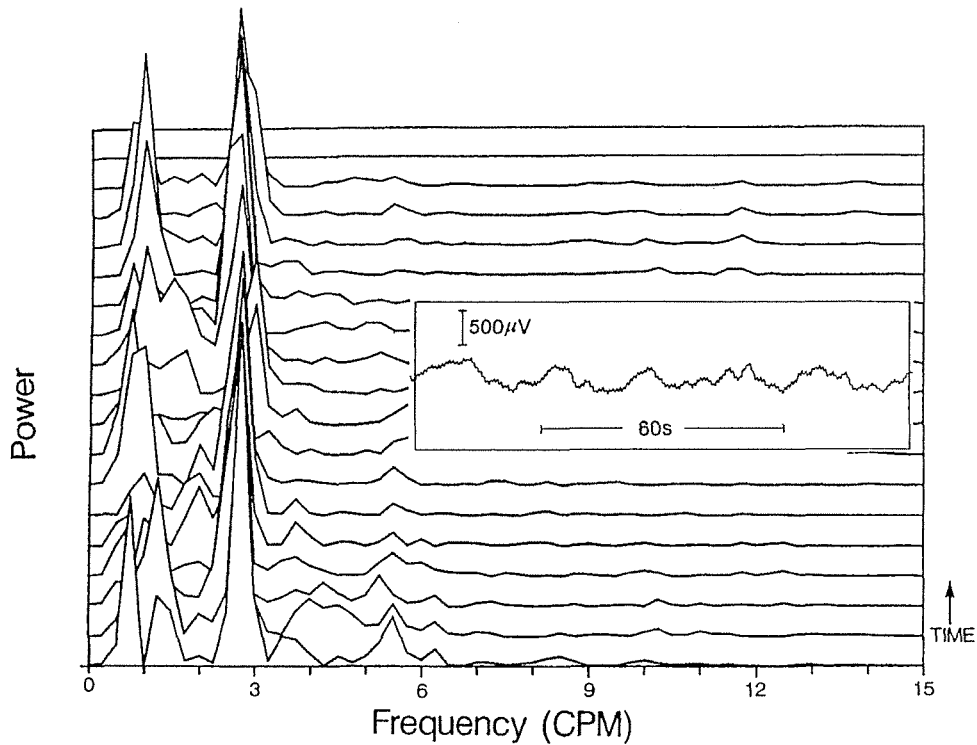
Patient	Age/Sex	T1/2 (min)	% Retained at 2 h
1. C.V.	37/Female	114	47
2. A.H.	53/Female	> 120	79
3. R.R.	62/Female	> 120	56
4. E.H.	53/Female	> 120	81
5. E.H.	62/Female	92	41
6. D.C.	37/Female	114	47
7. M.P.	33/Female	> 120	51
8. I.H.	37/Female	> 120	75
9. M.B.	33/Female	116	55
10. C.F.	20/Female	105	47
11. D.N.	30/Female	111	43
12. M.S.	69/Female	> 120	62
13. M.C.	74/Female	> 120	51
14. D.H.	58/Female	91	45
15. M.W.	41/Female	91	42
16. J.O.	39/Male	> 120	90
17. C.U.	39/Male	> 120	90
18. M.K.	49/Male	> 120	90
19. J.G.	22/Male	> 120	85
20. M.B.	37/Male	> 120	80

power in the tachygastria range. The differences among the three groups were not statistically significant ($p > 0.05$).

DISCUSSION

Patients with nausea, vomiting, and gastroparesis secondary to mechanical obstruction of the upper gastrointestinal tract had high-amplitude, remarkably consistent 3-cpm EGG patterns. This prominent 3-cpm myoelectrical pattern was an unexpected finding in the four patients with presumed idiopathic gastroparesis. Patients with gastroparesis from idiopathic or diabetic causes have tachygastrias and bradygastrias (5, 11, 12). The discordant findings of the strong 3-cpm EGG pattern and the proven gastroparesis led to further investigations and the discovery of the mechanical obstructions in these patients. In contrast, the patients with nausea, vomiting, and idiopathic gastroparesis had predominantly 1- to 2-cpm EGG patterns and significantly less 3-cpm activity than the obstructed patients. Thus, the obvious 3-cpm EGG pattern and high percentage of total power in the normal 3-cpm range differentiated gastroparesis due to mechanical obstruction from idiopathic gastroparesis.

Normal gastric emptying is dependent upon normal gastric electrical and contractile activity, pyloric relaxation and contraction, and duodenal motility. Gastric slow waves originate in the gastric pacemaker region near the junction of the body and fundus of the stomach along the greater curvature. The slow waves, or pacesetter potentials, control the frequency of gastric peristaltic contractions. The 3-cpm EGG



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FIG. 4. EGG recordings during fasting (inset) and running spectral analysis of the EGG from a healthy control. The EGG shows primarily low-amplitude 3-cpm waves; the RSA show peaks at 3 cpm and some 1- to 2-cpm peaks.

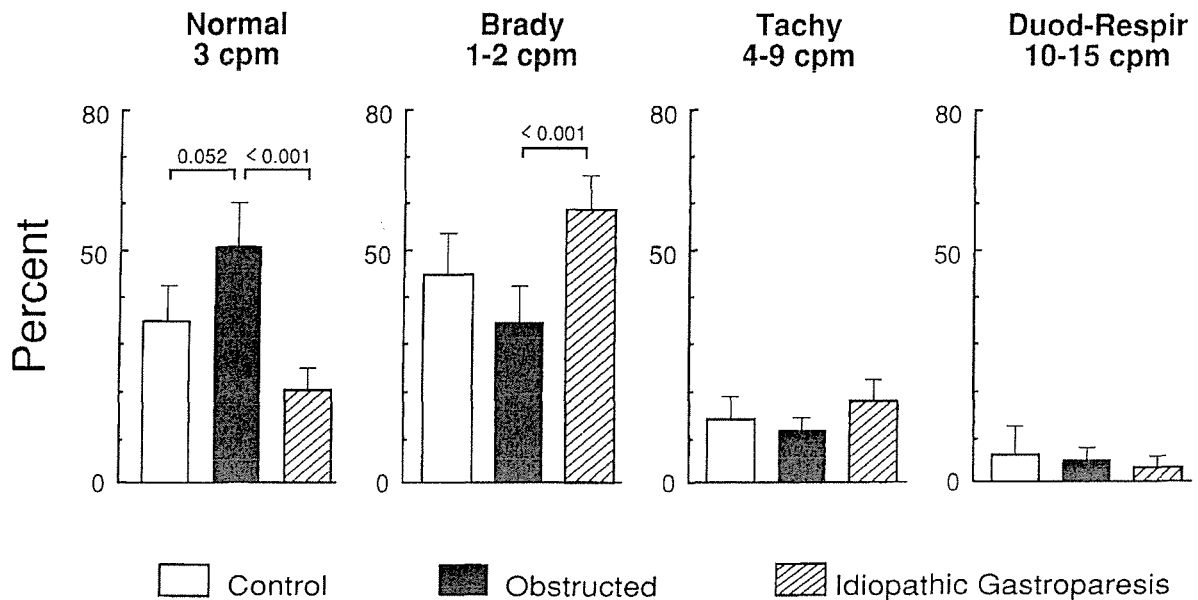


FIG. 5. Mean percentages of total EGG power in the Normal 3 cpm, Brady (bradygastria) 1- to 2-cpm, Tachy (tachygastria) 4- to 9-cpm, and Duod-Respir (duodenal-respiratory) 10- to 15-cpm ranges in control subjects and in patients with gastric outlet obstruction (obstructed) and with idiopathic gastroparesis. The bars indicate standard error of the mean.

waves recorded from cutaneous electrodes reflect normal gastric slow wave activity (3). The presence of 1- to 2-cpm (bradygastria) and 4- to 9-cpm (tachygastria) slow wave frequency indicates dysfunction of gastric neural or muscu-

lar activities (13). Gastric electrical or contractile dysfunction may lead to the development of gastric stasis and symptoms of nausea and vomiting. Patients with unexplained gastroparesis and gastric dysrhythmias should also

have endoscopic or radiographic studies to exclude obstructions if this possibility has not been considered. Major nonobstructive causes of gastroparesis include diabetes mellitus, partial gastrectomy and vagotomy, intestinal pseudo-obstruction, scleroderma, and anorexia nervosa (2). Several of these causes of gastroparesis have been associated with gastric dysrhythmias (11–17). On the other hand, the presence of a 3-cpm EGG pattern in a patient with gastroparesis should reinforce the need for studies to detect unsuspected obstructions.

The percentage of 3-cpm activity in the mechanically obstructed patients was approximately 50% of the total EGG power. A possible explanation for the higher percentage of total power in the normal range in the mechanically obstructed patients is hypertrophy of gastric smooth muscle secondary to the mechanical obstruction. The intragastric volumes and gastric diameters may have contributed to the marked 3-cpm EGG amplitude, but these factors were not measured in this study. However, the normal 3-cpm EGG frequency in the patients with mechanical obstruction and gastroparesis suggested that gastric neural or muscular functions were intact, and the high-amplitude regular 3-cpm waves suggested obstructive pathology. With aortic stenosis, for example, the amplitude of the QRS complex is increased. In an analogous fashion, patients with gastroparesis and mechanical obstructions of the stomach or duodenum had high-amplitude 3-cpm EGG waves.

The patients with idiopathic gastroparesis had a significantly decreased percentage of 3-cpm activity and significantly higher percentage of 1- to 2-cpm bradygastria activity than the obstructed patients and normal controls ($p < 0.01$). The underlying cause for the loss of 3-cpm power in patients with idiopathic gastroparesis is unknown. Possible causes include neurogenic or myogenic disorders of the stomach secondary to damage to the myenteric plexus, smooth muscle cells, and interstitial cells of Cajal, or changes in autonomic innervation. Damage to one or more of these areas may alter or diminish 3-cpm myoelectrical activity. For example, in patients with chronic intestinal pseudo-obstruction, EGG activity differentiated underlying pathologies. Predominant bradygastria patterns were found in patients with visceral myopathy, whereas tachygastria patterns predominated in patients with visceral neuropathy (13). Taken together, these data suggest that the majority of patients with idiopathic gastroparesis may have had myopathic dysfunction. In any case, the EGG patterns in the idiopathic gastroparesis patients were clearly distinct from those in the nine patients with gastroparesis due to mechanical obstruction.

In conclusion, gastric myoelectrical activity recorded with EGG revealed distinctive patterns in patients with gastroparesis due to mechanical obstruction and gastroparesis from unknown causes. In patients with tachygastria or bradygastria and gastroparesis, the abnormal myoelectrical

activities and delayed emptying are concordant and indicate severe neuromuscular dysfunction of the stomach. When a persistent and prominent 3-cpm EGG pattern is found in a patient with idiopathic gastroparesis, the findings are discordant and the possibility of a mechanical obstruction should be considered.

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