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Effect of Barium Meals on Gastric Electromechanical Activity in Man

A Fluoroscopic–Electrogastrographic Study

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The relationship between the cutaneously recorded electrogastrogram (EGG) and gastric contractions in man is unclear. We investigated: (1) the relationship between the electrogastrogram (EGG) signals and gastric contractions elicited by barium meals and (2) the effects of barium meals on frequency and amplitude of EGG signals. As documented by fluoroscopy in four healthy subjects, barium meals stimulated three per minute gastric peristalsis which corresponded with simultaneously recorded three cycle per minute (cpm) EGG waves. Eighteen other healthy volunteers ingested 45% (w/v) or 60% barium suspensions. As determined by Fourier analysis, the dominant EGG frequency before barium was 3 cpm in 16 subjects; two subjects had no distinct frequency peaks. After barium ingestion, the mean amplitude or power at 3 cpm and 1 cpm increased, but the increase was significant only after 45% barium. In conclusion: (1) individual EGG waves after barium reflect gastric peristaltic sequences, which are reflected in increases in amplitude or power of 3 cpm EGG activity; (2) density or viscosity of the barium meal affects the gastric myoelectric response; and (3) mechanical correlates of 1 cpm EEG activity are unknown.

KEY WORDS: barium sulfate; electrogastrography; gastric myoelectric activity; fluoroscopy; viscosity; density.

Barium sulfate suspensions elicit peristaltic contractions which originate in the orad corpus and migrate toward the pylorus (1–3). On the basis of intraluminal pressure changes and delivery of barium into the duodenum, such peristaltic waves were termed type I and II (1, 2). The frequency of barium-induced peristalses detected by radiographic methods is 3 per minute in man and approximately 5 per minute in dog (1–3).

Gastric peristalses are associated with myoelectric phenomena termed slow waves (also basic electrical rhythm, pacesetter potentials, or electrical control activity) and spike activity (also spike bursts, action potentials, or electrical response activity). Slow waves originate on the greater curvature near the orad one third of the corpus where spontaneous depolarizations occur at a frequency of 3 cycles per min (cpm) in man (4, 5) and 5 cpm in dog (6, 7). Such activities are not found in the fundus which is electrically silent (8). Slow waves modulate the frequency and propagation velocity of circular muscle contractions which are associated with spike activity. Thus, myoelectric correlates of

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gastric peristalses are spike activity phase-locked to slow waves which propagate aborally from corpus through antrum to pylorus (8).

Gastric myoelectric activity may be recorded from electrodes positioned on the abdominal surface. Such signals or electrogastrograms (EGGs) are waveforms with approximate frequencies of 3 cpm in man (9–12) and 5 cpm in dog (13). The frequency of EGG waves is similar to the frequency of slow waves simultaneously recorded from serosal or mucosal electrodes (9–11, 13). Furthermore, postprandial increases in the amplitude of the EGG signal in dog correlates with the onset of spike activity and contractions of the circular muscle layer (13). The amplitude of the 3 cpm signal recorded from mucosal and skin electrodes in man also increased after the subject ingested milk (11). Thus, the amplitude of the postprandial EGG signal may be considered the electrical summation of spike activity and accompanying repolarizations elicited by the particular meal and the ongoing slow wave activity (13).

Analysis of the EGG signal by Fourier transformation (FT) yields the frequency spectra contained in the raw EGG signal (9, 11, 13). The dominant gastric slow wave frequency derived from FT or running spectral analysis is approximately 3 cpm in man (9, 11, 14) and 5 cpm in dog (13, 14), frequencies consistent with hand-scored recordings from serosal, mucosal, or cutaneous recordings (9–14). Low-frequency components (ie, approximately 1 cpm) in the EGG signal have also been reported in man and dog (15, 16). In addition, FT analysis provides a measure of the power or intensity of each frequency contained in the EGG signal. Power reflects the amplitude of the raw signal at that frequency and its prevalence in the time segment analyzed. In dog, for example, the onset of circular muscle contractions and spike activity after meals is associated with increases in the amplitude of 5 cpm EGG waves, and the increase in amplitude of 5 cpm waves is also reflected by an increase in FT-derived power at 5 cpm (13).

Our aim was to determine the effect of a nonnutritive liquid on gastric myoelectric activity as measured by EGG and analyzed by FT. We hypothesized that barium-induced gastric peristalses, with accompanying electrical correlates of propagated spike bursts time-locked to the gastric slow waves, would alter the baseline EGG signal in man. Furthermore, the relationship between EGG waves and the gastric contractions elicited by barium was examined directly by recording the EGG during fluoroscopy of the barium-filled stomach.

MATERIALS AND METHODS

Subjects. Twenty-two healthy subjects, 12 men and 10 women, ranging in age from 18 to 22 were studied. No subject had a history of gastrointestinal diseases. Studies were approved by the Clinical Investigation and Radiation/Isotope Committees in January 1982.

Electrogastrography. Three standard Ag–AgCl electrodes (model TDE-20, Med Associates, East Fairfield, Vermont) were filled with electrode jelly (Redux creme, Hewlett Packard, Waltham, Massachusetts) and positioned on the abdominal surface over the region of the stomach. The proximal electrode (E1) was located immediately below the left costochondral margin in the midclavicular line, the distal electrode (E3) was located midway between the umbilicus and the xiphoid process, and the middle electrode (E2) was positioned midway between E1 and E3; a reference electrode was placed on the right volar forearm (17).

Electrodes were connected to a rectilinear recorder (Beckman R612, Beckman Instruments, Fullerton, California) through modified 9835A couplers. The time constant was 3.0 sec (0.016 Hz) and the high-frequency cutoff was 0.08 Hz. Sensitivity settings ranged from 0.005 to 0.01 mV/mm. Paper speed was 1 mm/sec. The EGG signals were stored on magnetic tape (Honeywell 5600 recorder, Honeywell Test Instruments, Denver, Colorado) and were digitized offline by a DEC PDP/11 computer at a sample rate of 1.138 Hz for the time periods from 7.5 min prior to ingestion of barium (time 0), from time 0 to 7.5 min (P1), and from 7.5 to 15 min after barium (P2).

Electrogastrography during Ingestion of Barium. Subjects fasted at least 4 hr before testing and rested comfortably in a semireclining position during the study. Baseline EGG recordings were obtained for 15 min. The subjects then consumed a barium sulfate suspension (E.Z. Paque, E.Z.M. Company, Inc., Wesburg, New York) brought up to a density of 45 or 60% (w/v) with room-temperature water. Total volume of the suspension was 150 ml. Nine subjects consumed the 45% suspension; nine other subjects ingested the 60% barium suspension. A Ford cup viscometer with a hole of 0.4 cm in diameter was used to determine viscosity of the barium suspensions; at room temperature, 45 and 60% barium suspensions had viscosities of 29.8 and 65.0 centistokes, respectively.

Simultaneous Electrogastrography and Fluoroscopy after Barium. In four additional healthy fasted subjects, EGG signals were obtained before and after ingestion of 45% barium. Sixty to 90 sec of fluoroscopy of the barium-filled stomach were videotaped while the EGG was simultaneously recorded. Total radiation, estimated as entrance skin exposure, was 1.8 R. These subjects assumed a prone position during the study.

Computer Analysis of Electrogastrograms. Data streams of 512 points were tapered using a weighting function. Spectral analyses were performed for the 512-point series

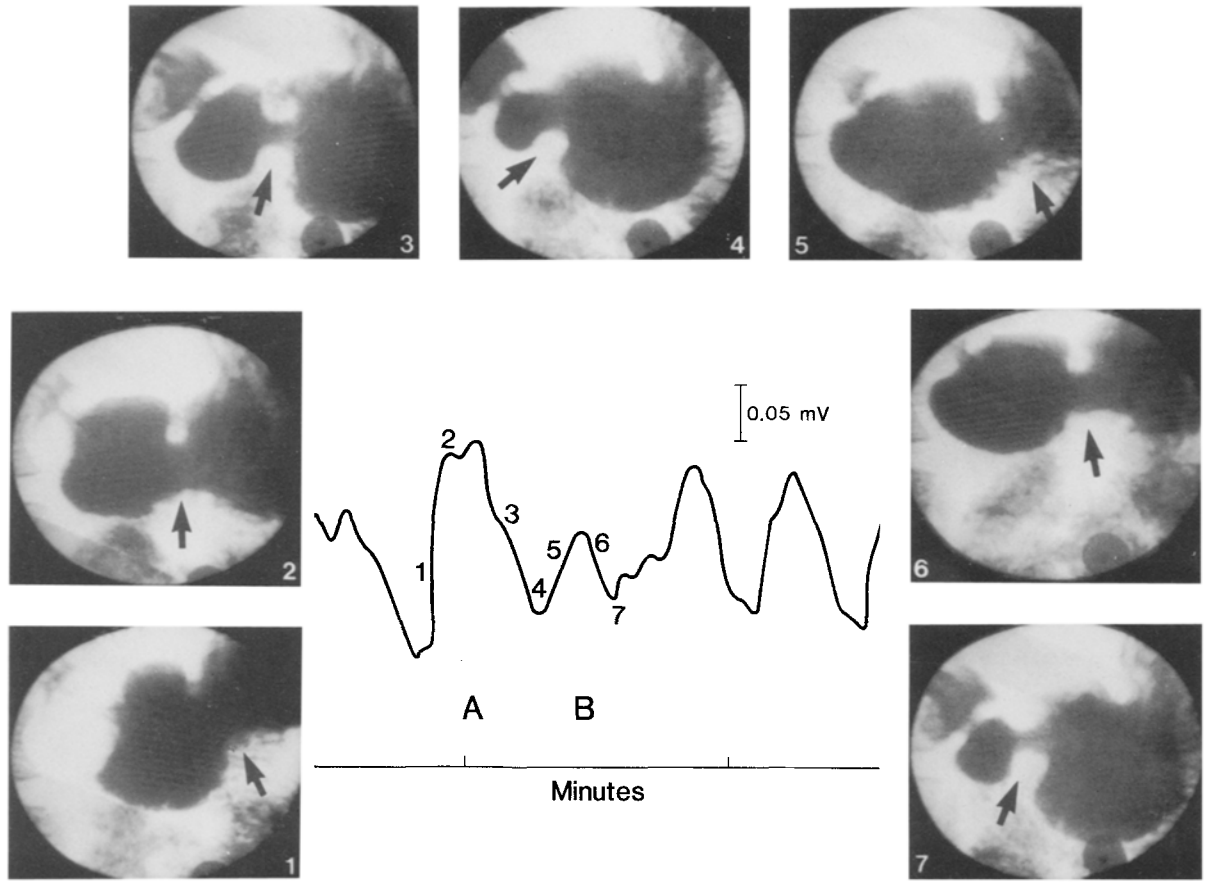

Fig 1. Simultaneously recorded EGG waves and radiographs of the barium-filled stomach obtained during fluoroscopy. EGG waves A and B were recorded from a cutaneous electrode which is seen at the bottom of each frame. The radiographs in frames 1–4 and 5–7 show two consecutive peristaltic waves (indicated by arrows). Propagation of the first peristaltic wave from corpus to distal antrum (frames 1–4) corresponds with portions of EGG myoelectric wave A which are also numbered 1–4. The second peristaltic wave (frames 5–7) corresponds with portions of EGG wave B numbered 5–7. See text for additional details.

of preconditioned data for each 7.5-min period before and after barium (18). The frequency resolution of the FT was 0.0022 Hz. Power spectra between 0.534 cpm (0.0089 Hz) and 1.866 cpm (0.0311 Hz) and between 1.998 cpm (0.333 Hz) and 3.336 cpm (0.0556 Hz) were then compared using analysis of variance. Prior to the analysis of variance, the relevant spectral estimates were log transformed to achieve more normal distributions. The degrees of freedom for all analysis of variance factors were adjusted where relevant using the Greenhouse-Geisser procedure (19).

RESULTS

Electrogastrography and Fluoroscopy After Barium. Postbarium EGG waves and simultaneously recorded fluoroscopy of the barium-filled stomach are shown in Figure 1. Videotape frames from two consecutive gastric peristalses (frames 1–7) are shown with the corresponding portions (numbers 1–7) on the EGG waves A and B. As the first peristaltic wave commenced on the greater curvature of the corpus (frame 1), the EGG wave A rose from baseline (number 1); as the peristaltic wave moved distally (frame 2 and 3), the EGG wave peaked (number 2); and as the peristaltic wave moved through the distal antrum (frame 4) and dissolved, the EGG signal returned toward baseline (numbers 3 and 4). Barium was emptied into the duodenum by this peristaltic sequence as seen in frame 4. The electromechanical sequence was repeated during the next peristaltic sequence (frames 5–7 and EGG wave B). Each EGG wave (A or B) primarily reflected the sum of electrical events associated with the contractile activity of a single gastric peristaltic contraction. A similar relationship between EGG waves and gastric peristalses was observed in each of the four subjects in whom simultaneous EGG and fluoroscopy recordings were obtained.

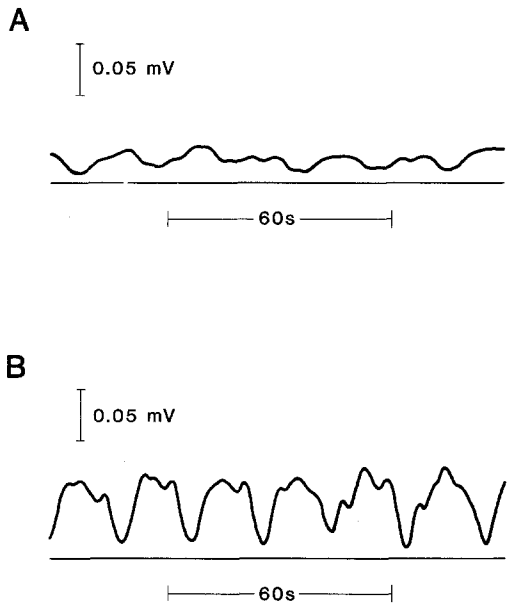

Fig 2. Gastric myoelectric activity recorded from a cutaneous electrode before (A) and after (B) a 45% barium meal. Panel A shows low-amplitude 3-cpm EGG activity recorded before the subject ingested the 150-cc barium meal. Panel B shows EGG activity recorded 3 min after the subject ingested the barium. Compared with EGG activity in panel A, the amplitude of each EGG wave is increased after barium; the EGG frequency remains approximately 3 cpm.

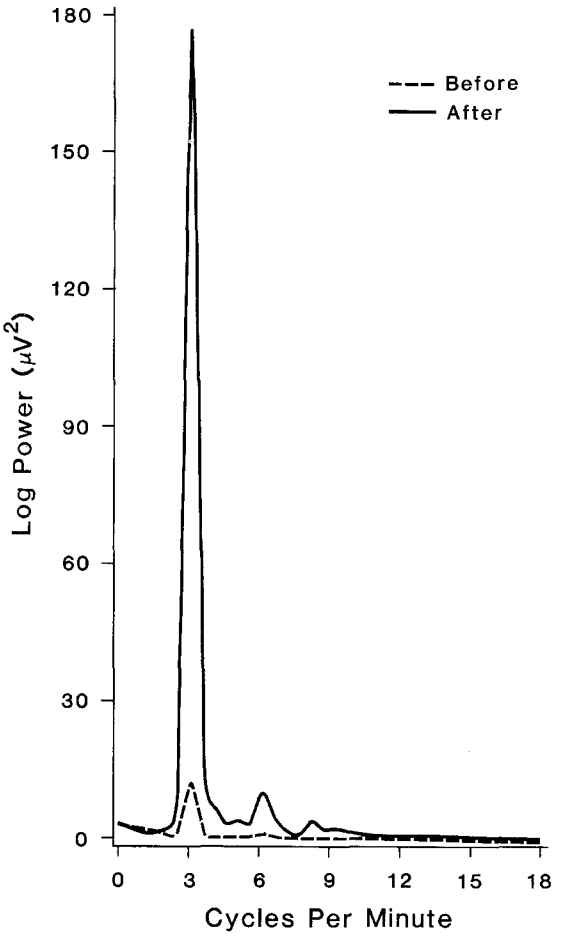

Fig 3. Fourier analysis of the EGG signal shown in part in Figur 2A and 2B. This plot shows the frequency spectra and power of the EGG signal recorded during the 7.5 min before and the 7.5 min after ingestion of 45% barium. Before barium (dashed line), a peak at 3 cpm is seen; after barium (solid line), the power at 3 cpm increased. The peaks at 6 and 9 cpm represent harmonics.

Figure 2A and B shows cutaneously recorded gastric myoelectric activity before and after one of the 18 healthy subjects ingested a 45% suspension of barium sulfate. Before ingestion of barium, low-amplitude 3-cpm activity was noted (Figure 2A); 3 min after ingestion of barium, the amplitude of the EGG signal clearly increased (Figure 2B).

FT-derived frequencies obtained from the EGG recordings shown in Figure 2A and 2B are shown in Figure 3. Results from 7.5 min of EGG signal before barium (dashed line) and the 7.5 min after ingestion of barium (solid line) are shown. Before barium, a peak at 3 cpm is apparent. In 16 of the 18 subjects, the spectral plots showed predominant baseline frequency peaks at approximately 3 cpm; two subjects had indistinct frequency peaks. Nine of the subjects with prominent 3-cpm peaks before barium also had a 1-cpm peak. After barium (Figure 3, solid line), the power at 3 cpm increased during the time when barium was emptied from the stomach by three per minute peristaltic waves. Harmonic frequency peaks at 6 and approximately 9 cpm are also seen.

Figure 4 shows the changes in FT-derived power at 3 cpm before and after nine subjects ingested 45% barium sulfate suspensions. Compared with baseline, a progressive increase in the power at 3 cpm occurred after 45% barium and the increase in power was significant ($P < 0.01$) during the 7.5 to 15-min period (P2). Power at 3 cpm increased above baseline levels during the 0 to 7.5-min period (P1) in six of nine subjects and during P2 in eight of nine subjects. Overall, the 45% barium suspension elicited an increase in power at 3 cpm in each subject during either P1 or P2. Compared with baseline, the power at 1 cpm also increased progressively and significantly after 45% barium during P1 ($P < 0.05$) and P2 ($P < 0.01$). Power at 1 cpm increased in six of nine and seven of nine subjects during P1 and P2, respectively. Overall, power at 1 cpm increased in eight of nine subjects after the 45% barium.

Changes in power at 3 cpm and 1 cpm also

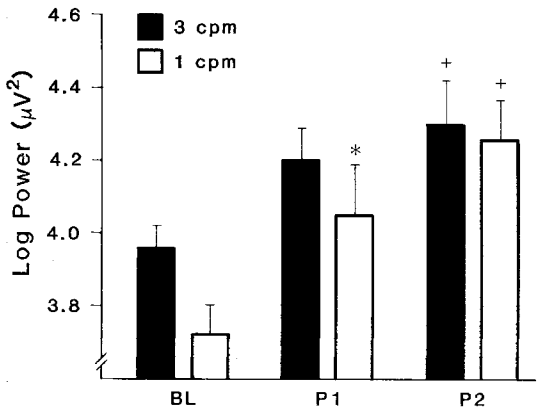

Fig 4. Effect of 45% barium sulfate suspensions on frequency and power (± SEM) of EGG activity derived from Fourier analysis. BL (baseline) indicates data from the 7.5-min period before nine subjects ingested barium; P1 and P2 indicate the 0 to 7.5- and 7.5- to 15.0-min periods after ingestion of barium, respectively. After barium, the power at 3 cpm increased progressively and reached statistical significance during P2; the power at 1 cpm increased significantly during P1 and P2. $*P < 0.02$; $+P < 0.01$.

occurred after nine other subjects ingested 60% barium and are shown in Figure 5. Compared with baseline, the power at 3 cpm increased slightly during P1 and P2; these changes did not reach statistical significance. The 60% barium also failed to elicit a significant change in power at 1 cpm. Individually, an increase in power at 3 cpm after barium was found in four of nine subjects during P1 and in only two of nine subjects during P2. Increases in power at 1 cpm occurred in three of nine and four of nine subjects during P1 and P2, respectively.

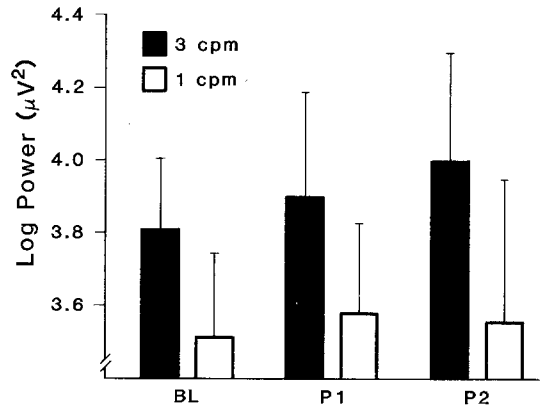

Fig 5. Effect of 60% barium suspensions on EGG activity in nine subjects. BL, P1, and P2 are the same as in Figure 4. After 60% barium, power (± SEM) at 3 cpm increased slightly whereas no change in power occurred at 1 cpm.

DISCUSSION

The present studies demonstrate that 3 per minute gastric peristalses after ingestion of barium correlate with 3-cpm EGG waves in man. Previous studies in man and dog have shown the frequency of gastric slow waves recorded by mucosal or serosal electrodes is similar to the frequency of surface-recorded EGG waves (9–14). Furthermore, studies in dog have shown postprandial increases in EGG amplitude correspond with the onset of spike activity phase-locked to gastric slow waves (13); studies in man also show increases in EGG amplitude after various meals (11). Thus, the EGG signal reflects the omnipresent slow wave activity and, when present, the onset of spike activity. By using noninvasive measures of gastric myoelectric and mechanical activity, the present findings indicate that after barium ingestion, a single EGG wave reflects a single gastric peristaltic sequence.

FT analyses of the EGG records showed that the average power at 3 cpm increased after ingestion of the barium meals, particularly after the 45% suspension. The 3-cpm myoelectric activity originates in the corpus–antrum, not the fundus. Thus, the increase in power at 3 cpm after barium indicated the onset of contractile activity of the corpus–antrum, contractile activity organized as peristaltic sequences as indicated by the fluoroscopic records.

Recent studies in dog and man showed that the addition of guar or psillium to saline meals increased the viscosity and slowed the gastric emptying rate of saline (20, 21). In regards to actual gastric contractile events, Prove and Ehrlein showed that medium- and high-viscosity liquid meals elicited lesser peristaltic indentations on the canine gastric wall (ie, weaker contractions) than low-viscosity liquid meals (22). Thus, high-viscosity liquids elicit weaker antral contractions which would be associated with fewer action potentials and smaller increases in the EGG signal amplitude and power when compared with low-viscosity fluids. Low-viscosity fluids, in contrast, elicit relatively stronger antral peristalses (22) which would be associated with greater action potential activity and increased EGG amplitude and power. Consistent with these notions, the lower-viscosity 45% barium meal elicited significant increases in the power at 3 cpm and 1 cpm, whereas the higher-viscosity 45% barium did not.

It is also possible, however, that the differences in EGG power after barium may reflect differences

in the density of the barium meals, rather than the viscosity. Barium suspensions are non-Newtonian liquids (23); thus, barium meals will have pseudoplastic or dilatant flow characteristics, and the viscosity of the meal may, in fact, change during the mixing activities which occur during gastric emptying. Therefore, whether or not the FT-derived changes in power correlate with differences in the density or the viscosity of the barium meals cannot be determined by the present studies.

Fourier analysis also revealed the range of cyclical activity normally presented in EGG signal recorded from healthy individuals. The 1-cpm peaks, for example, were found during baseline and post-barium periods. The 1-cpm EGG activity in dog correlates with particularly strong antral contractions which occur intermittently during phase II and during phase III activity fronts of the interdigestive cycle (15). On the other hand, 1- to 2-min duration increases in fundic pressure of fasting dogs (type III waves) have been described (24). In addition, balloon distension of the fundus elicits fundic contractions of approximately 1 min duration (25). Myoelectric activity associated with these fundic contractions has not been reported. FT-derived 1-cpm peaks, which correlate with one per minute mechanical events as reflected in magnetogastrograms, have been reported in man (16). However, whether 1-cpm activity in man represents fundic and/or antral motor events remains to be determined.

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