Digestive Diseases and Sciences, Vol. 40, No. 12 (December 1995), pp. 2614–2622

Inhibitory Effects of Cholecystokinin on Postprandial Gastric Myoelectrical Activity

J.D.Z. CHEN, PhD, Z.Y. LIN, S. PAROLISI, and R.W. McCALLUM, MD

While a number of studies have investigated the effects of cholecystokinin (CCK) on gastrointestinal motility, little is known on the effects of CCK on gastric myoelectrical activity, which regulates gastric motility. The aim of this study was to investigate the effects of intravenous infusion of CCK-8 on gastric myoelectrical activity in normal humans. Gastric myoelectrical activity was measured in 10 healthy subjects with a noninvasive electrogastrographic technique by placing abdominal electrodes on the epigastric area. Two study sessions were performed in each subject on two separate days with double-blinded infusion of either saline or CCK (24 pmol/kg/hr). The procedure for each session was as follows: (A) 30-min baseline fasting electrogastrogram (EGG); (B) start infusion, another 30-min EGG; (C) give meal, 60-min EGG; and (D) stop infusion, another 60-min EGG. The dominant frequency and peak power (amplitude) of the EGG, and the percentage of normal 2–4 cycles/min slow waves during each recording session were computed and compared between placebo and CCK. It was found that normal 3 cpm slow waves were recorded in all EGGs. Infusion of CCK had no effect on the frequency of the gastric slow wave and did not induce gastric dysrhythmias. It was also found that intravenous infusion of CCK significantly decreased the EGG peak power (amplitude) during the first hour after the meal (the infusion was given during this period) in comparison with placebo ($P < 0.05$). This inhibitory effect on EGG peak power was sustained but not significant during the second postprandial hour (the infusion was not given during this period). It was concluded that intravenous infusion of CCK at a physiological concentration significantly decreased the postprandial EGG amplitude in normal humans, suggesting an inhibitory effect on postprandial gastric motility, but did not change the frequency and regularity of the gastric slow wave.

KEY WORDS: cholecystokinin; gastric myoelectrical activity; electrogastrography; gastrointestinal motility; gastric emptying; stomach.

While effects of cholecystokinin (CCK) on gastrointestinal motility have been well documented, little is known of its effect on myoelectrical activity of the human stomach. CCK has been reported to cause relaxation of the human lower esophageal sphincter (1), decrease the intragastric pressure of the proximal stomach (2), increase antral smooth muscle contractions (3) and pyloric pressure (2), inhibit the interdigestive motility pattern of the small intestine, and induce contractions in the small and large intestines (3, 4). CCK delays gastric emptying of liquid meals and has been shown to be a possible physiological regulator of gastric emptying (5).

Significant effects of CCK on myoelectrical activity of the small and large intestines have been observed. In a canine study with implanted serosal electrodes along the small intestine, CCK disrupted the fasting pattern of myoelectrical activity and caused a dose-dependent increase in spike potentials (6). Similar

Manuscript received April 4, 1995; revised manuscript received August 3, 1995; accepted August 14, 1995.

From the Division of Gastroenterology, Department of Medicine, University of Virginia, Charlottesville, Virginia 22908.

Jiande Chen is now with the Institute for Healthcare Research, Baptist Medical Center of Oklahoma.

Address for reprint requests: Jiande Chen, Institute for Healthcare Research, Baptist Medical Center, 3300 NW Expressway, Oklahoma City, Oklahoma 73112.

effects were reported on colonic myoelectrical activity: CCK increased the number of spike potentials in the colon but did not affect the slow wave activity or frequency (4).

It is generally accepted that CCK released endogenously by a meal plays a role in the physiological regulation of gastric motility in humans. However, the effect of CCK on gastric myoelectrical activity has not been well documented. An *in vitro* study in canine antral circular muscle with intracellular microelectrodes showed that CCK increases the frequency and the amplitude and duration of the plateau of gastric action potentials (7). Little is known of the effect of CCK on myoelectrical activity of the human stomach. A recent preliminary study (8) reported the effect of CCK on gastric myoelectrical activity. It was found that exogenous CCK at a dose reproducing the postprandial plasma CCK peak decreased the frequency of the gastric slow wave in normal subjects and induced gastric dysrhythmias in idiopathic dyspeptic patients. The myoelectrical activity of the stomach was recorded using an intraluminal probe with a pair of suction needle electrodes. In a recent study (9), we investigated the effect of fat preload on gastric myoelectrical activity in humans using surface electrogastrography (EGG). It was observed that fat preload significantly decreased the postprandial EGG amplitude, implying a decrease in gastric contractility.

Two kinds of myoelectrical activities have been observed in the human stomach: the slow wave (or electrical control activity) and spike potentials (or electrical response activity) (10). The gastric slow wave is present all the time and originates in a region near the junction of the proximal one third and distal two thirds of the gastric corpus along the great curvature. It is characterized by recurring changes in potentials, propagating distally towards the pylorus with increasing velocity and amplitude. The frequency of the gastric slow wave in humans is 3 cycles/min (cpm), or 0.05 Hz. The gastric slow wave determines the maximal frequency and propagation of gastric contractions. Spike potentials are directly associated with antral contractions. The antral muscles contract when slow waves are superimposed with spike potentials (11).

Gastric myoelectrical activity can be measured either internally or cutaneously. An internal recording may be obtained from serosal electrodes implanted on the serosal surface of the stomach during an abdominal surgery (12–14) or from intraluminal electrodes attached to the mucosal side of the stomach (8, 15). The practical application of the serosal method is very much limited due to its invasive nature. While it is feasible, the intraluminal technique may not provide a reliable measurement of gastric myoelectrical activity due to the fact that the contact between the electrodes and the gastric mucosa is not always guaranteed during recording.

The most widely used method to record gastric myoelectrical activity is electrogastrography or EGG (16). Electrogastrography is the technique to obtain a cutaneous recording of gastric myoelectrical activity from abdominal surface electrodes (electrogastrogram) (17). The EGG is attractive not only because it is noninvasive but also because it does not disturb the on-going physiological process of the stomach. Previous studies have shown that the EGG is a reliable measurement of gastric myoelectrical activity (12, 14). The dominant frequency of the EGG accurately represents the frequency of the gastric slow wave while spike potentials are reflected in the EGG as an increase in amplitude.

The aim of this study was to investigate the effects of CCK on gastric myoelectrical activity in normal subjects using the electrogastrographic technique.

MATERIALS AND METHODS

Subjects

Ten healthy volunteers (five males, five females, age: 24–48 years) were studied. None of the subjects had a history or symptoms of gastrointestinal disease and took medication the week before and during the study. The research protocol was approved by the Human Investigation Committee at the University of Virginia Health Science Center and the written consent form was signed by all subjects before the study.

Electrogastrogram

Gastric myoelectrical activity in each subject was measured using surface electrogastrography. Prior to the attachment of electrodes, the abdominal surface where electrodes were to be positioned was shaved, if hairy, and cleaned with sandy skin-prep paste (Omni Prep, Weaver & Co., Aurora, Colorado) to reduce the impedance. Three silver–silver chloride ECG electrodes (DNM, Dayton, Ohio) were placed on the abdominal skin as shown in Figure 1. Two epigastric electrodes were connected to yield a bipolar EGG signal. The other electrode was used as a reference. The EGG signal was amplified using a PC-polygraf (Synectics Medical Inc, Irving, Texas) with low and high cutoff frequencies of 1–18 cpm, and simultaneously digitized and stored on the hard disk of a 486 personal computer using the computer software provided by the same company. The analog-to-digital converter was 12-bit and the sampling frequency was 2 Hz. The digitized EGG recording was on-line displayed on the computer screen. All recordings were made in a quiet room. The subjects were in a supine

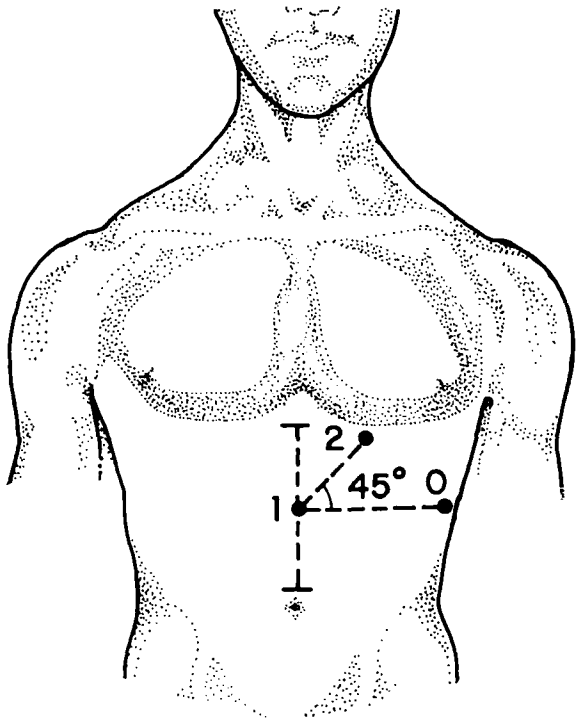

Fig 1. Position of the abdominal electrodes. Electrode 1: positioned midway between the xiphoid process and the umbilicus; electrode 2: 5 cm away from electrode 1; electrode 0: reference electrode. Bipolar EGG signal was derived from electrodes 1 and 2.

position and asked not to talk and to remain as still as possible during the recording to avoid motion artifacts.

Study Protocol

Each subject was studied twice on two separate days. The procedures for the two sessions were the same, except the content of the infusion, and are described as follows. The subject was fasted overnight before the study. After the placement of the electrodes on the abdomen and of an intravenous catheter on the left arm, a 30-min baseline EGG recording in the fasting state was made. Continuous intravenous infusion of either saline or CCK-8 was initiated after the baseline recording. A solid test meal of 500 kcal turkey sandwich was given 30 min after the start of the infusion. The meal was consumed within 15 min. One hour after finishing the test meal, the intravenous infusion was stopped but the EGG recording was continued for another hour. Both the investigators and the subjects were blinded to the content of the infusion, which was prepared by a research nurse with a random drawing and indicated in a sealed envelope. The envelope was opened after all EGG data were analyzed. The positions of the electrodes in the two sessions were exactly the same. The dose of the CCK was 24 pmol/kg/hr. This dose was shown to result in plasma CCK levels similar to the peak CCK levels seen after a meal (5). The infusion speed of saline was the same as the infusion of CCK by volume.

The degree of nausea during each recording period (with and without infusion of CCK/saline) was scored by all subjects at a range of 0–10 (0 being no nausea and 10 the most severe).

Data Analysis

Quantitative and statistical analyses of the EGG data were performed to investigate the effects of CCK on the frequency, amplitude, and regularity of the EGG in the fasting and fed state. A number of quantitative parameters were computed from the EGG, including EGG dominant frequency, EGG peak power, and the percentage of normal gastric slow waves (or dysrhythmias).

EGG Dominant Frequency. The frequency at which the EGG power spectrum has a peak power in the range of 0.5–9.0 cpm was defined as the EGG dominant frequency. The dominant frequency of the EGG has been shown to be equal to the frequency of the gastric slow wave measured from the implanted serosal electrodes (12). It was computed using the smoothed power spectral analysis method (18). The smoothed power spectral analysis was used to produce an averaged power spectrum for the EGG during each recording period including: (A) 30-min fasting with no infusion, (B) 30-min fasting with infusion, (C) first 60-min after the meal (with infusion), and (D) second 60-min after the meal (with no infusion).

EGG Peak Power. The power at the dominant frequency in the power spectrum of the EGG was defined as the EGG peak power. Previous studies (13, 19, 20) have shown that the relative change of the EGG peak power reflects gastric contractility. The EGG peak power was calculated from the smoothed power spectral analysis method. Decibel (dB) units were used to represent the power of the EGG. Assuming a sinusoidal signal with an amplitude of A, power P in dB is expressed as $P(\text{dB}) = 20 \times \log_{10}(A)$. An example for the computation of the EGG dominant frequency and power is shown in Figure 2. The top panel presents a 15-min EGG recording. Rhythmic slow waves can be observed on the tracing. The power spectrum of these 15-min EGG data is illustrated in the lower panel, which shows the frequency composition of the EGG. Based on this spectrum, the dominant frequency and peak power of the EGG recording are 3.1 cpm and 52 dB, respectively.

Postprandial EGG power increase was defined as the difference between the EGG peak powers after and before the test meal, ie, the EGG peak during recording period C minus that during the recording period B.

Percentage of Normal Slow Waves (or Dysrhythmias). Percentage of normal gastric slow waves (or dysrhythmias) was defined as the percent of time during which normal 2–4 cpm slow waves were present (or absent) over the entire observation period. It was computed using the adaptive running spectral analysis method (21). Each EGG recording was divided into blocks of 2 min without overlapping. The power spectrum of each 2-min EGG was calculated and examined to see if the peak power was within the range of 2–4 cpm. The 2-min EGG was called normal if the peak power was within the 2–4 cpm range. Otherwise, it was dysrhythmic. An illustrative example for the computation of the above EGG parameters is presented in Figure 3. It can be assessed from this figure that the percentage of normal slow waves in this recording is 80% since 12 of the total 15 spectra have dominant frequencies in the range of 2–4 cpm

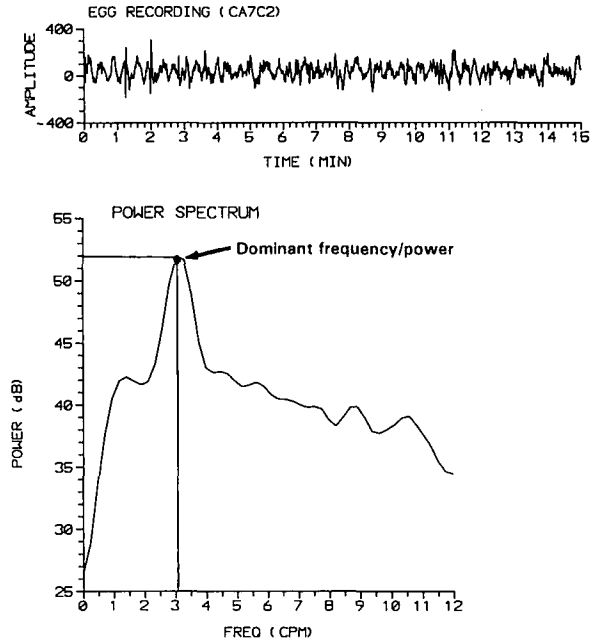

Fig 2. Computation of EGG dominant frequency and peak power. Upper panel: 15-min EGG recording; lower panel: power spectrum of the 15-min EGG. Dominant frequency and peak power of the EGG are computed from the power spectrum. In this figure, the dominant frequency and peak power are 3.01 cpm and 52 dB, respectively.

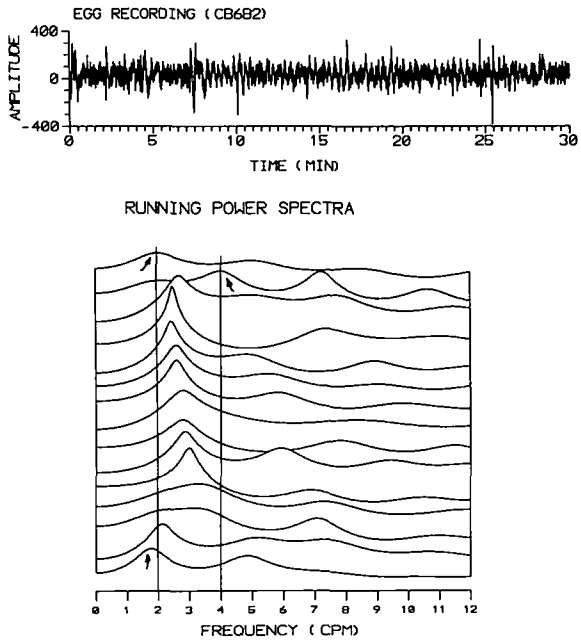

Fig 3. Computation of the percentage of 2–4 cpm slow waves. Upper panel: 30-min EGG recording; lower panel: running power spectra calculated using the adaptive spectral analysis method. Each line (from bottom to top) is the power spectrum of 2-min EGG data (no overlap). In this figure, 12 of the total 15 spectra have dominant frequencies in the 2–4 range, and therefore the percentage of 2–4 cpm slow waves is 80%.

(three spectra indicated with arrows have dominant frequencies outside the 2–4 cpm frequency range).

Statistical Analysis

Statistical analyses were performed to investigate the effects of CCK on the EGG parameters defined above, using the analysis of variance. Statistical significance was assigned for P values of <0.05. All data were presented in mean ± SEM.

RESULTS

Regular 3 cpm slow waves were observed during all periods of the recording and in all subjects. Typical tracings are presented in Figure 4. The top panel shows the 30-min baseline EGG recording and the lower panel, the 30-min EGG recording in the fasting state with intravenous infusion of CCK. The 3 cpm rhythmic activities are observed in these tracings. The percentages of 2–4 cpm waves (mean of 10 subjects) computed from the EGG recordings during different periods are presented in Figure 5. The normal 2–4 cpm gastric slow waves were present in 90% of each recording period. Intravenous infusion of CCK had no effect on the percentage of 2–4 cpm slow waves and did not induce any gastric dysrhythmias.

None of the subjects reported any nausea during any period of the recording. The nausea score was 0 ± 0 in all periods (A, B, C and D) of the recording in both sessions.

The dominant frequency of the EGG during each recording period is presented in Figure 6. The range of the mean dominant frequency over the 10 subjects was 2.88 to 3.11 cpm. No difference in the dominant frequency of the EGG was observed between the session with CCK infusion and the session with saline infusion. Comparing the dominant frequencies during the 30-min periods before and after the initiation of the infusion, we can see that CCK did not alter the dominant frequency of the EGG in the fasting state, nor did the saline. There was, however, a slight (6%) but significant increase of EGG dominant frequency induced by the test meal in both sessions of CCK infusion and saline infusion. The dominant frequency of the EGG during the second postprandial hour was lower than that during the first postprandial hour, but the difference was not statistically significant.

The effects of CCK on EGG amplitude (power) are presented in Figures 7 and 9 (below). The intravenous infusion of CCK did not change the peak power of the EGG in the fasting state. However, it significantly

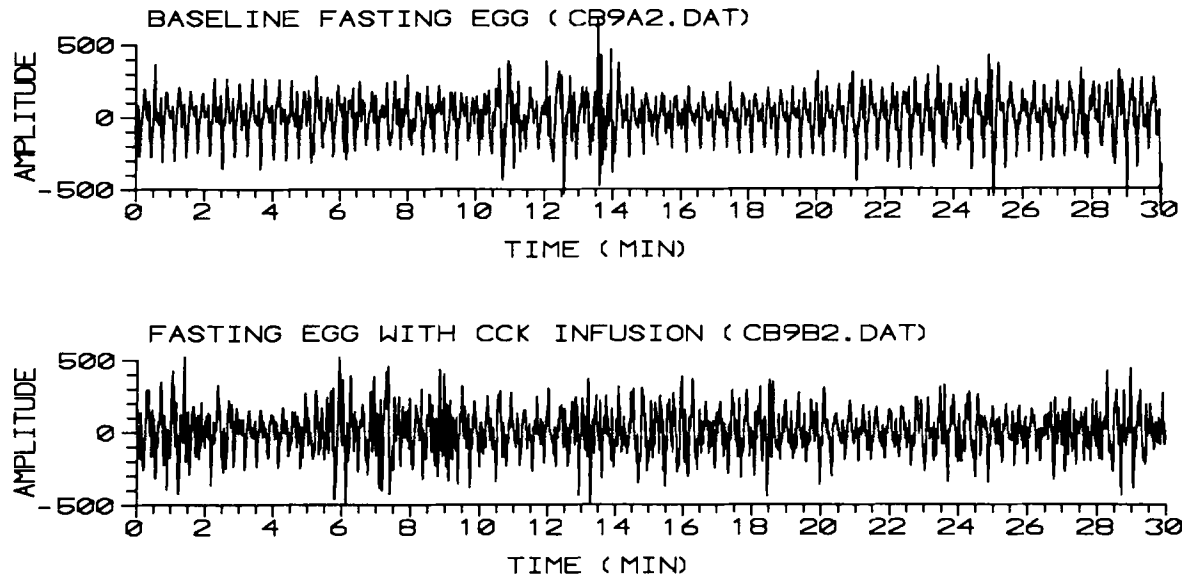

Fig 4. Typical EGG recordings in the fasting state obtained in one volunteer. Upper panel: baseline fasting EGG; lower panel: fasting EGG during intravenous infusion of CCK.

affected the peak power of the postprandial EGG. Figure 8 presents the power spectra of the 30-min EGG before and 60-min EGG after the test meal with the saline infusion (left panel) and the CCK infusion (right panel). During saline infusion, the peak power of the 60-min postprandial EGG showed a substantial increase (19.5 dB), whereas, a smaller increase (8.3 dB) was noted in the peak power of the postprandial EGG with the CCK infusion. Figure 9 presents the postprandial power increases (the peak power difference between the 60-min EGG right after and the 30-min EGG before the meal) with the saline infusion and the CCK infusion. The mean postprandial power increase in the 10 subjects was more than 8 dB (equivalent to about 100% increase in EGG amplitude) with the saline infusion and less than 4 dB (equivalent to about 50% increase in EGG amplitude) with the CCK infusion. This difference was statistically significant during the first postprandial hour ($P < 0.05$) but not during the second postprandial hour when the CCK infusion was not discontinued ($P > 0.05$).

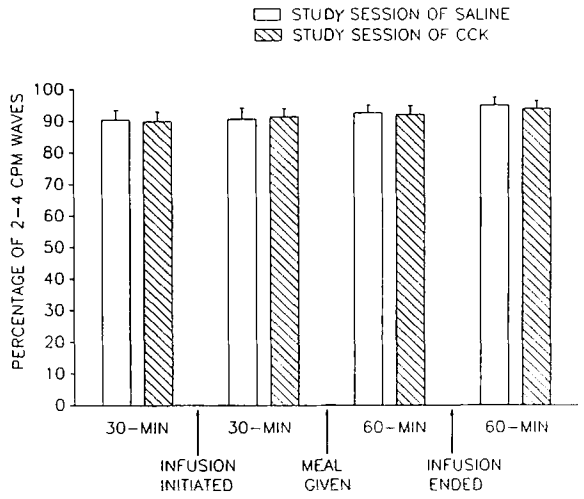

Fig 5. Percentages of 2–4 cpm slow waves during different periods of the EGG recordings.

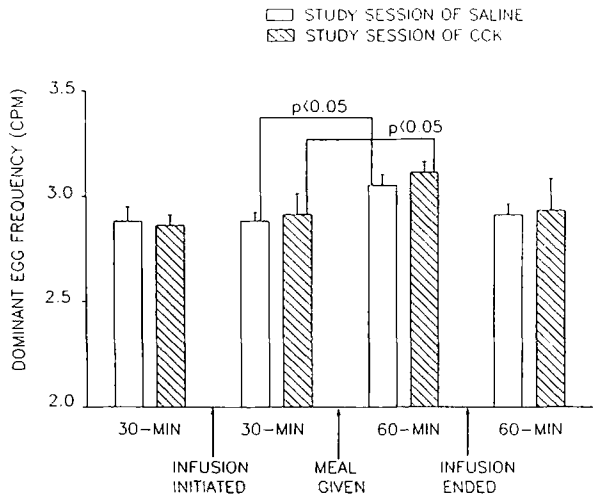

Fig 6. Dominant frequencies of the EGG during different periods of the recordings.

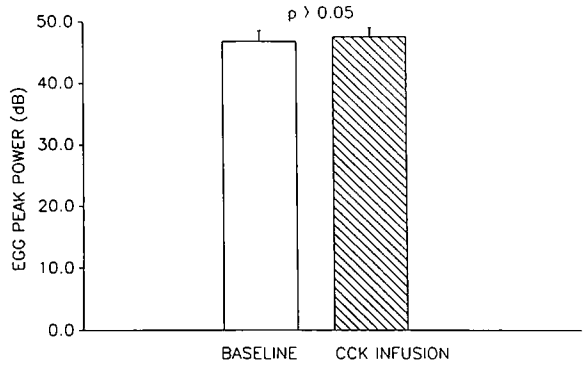

Fig 7. Peak powers of the EGG in the fasting state with and without intravenous infusion of CCK.

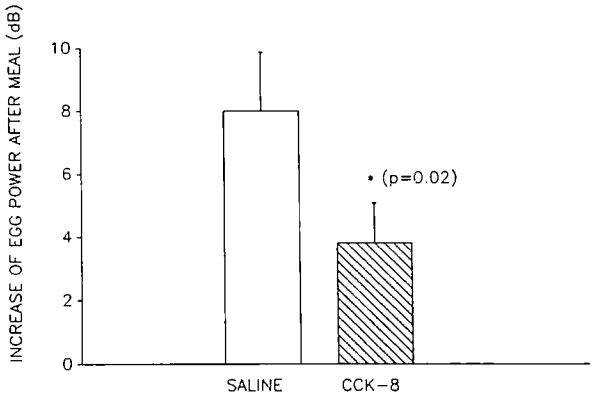

Fig 9. Effect of CCK on the postprandial EGG. The increase of EGG peak power after the meal was significantly less ($P < 0.05$) with CCK infusion than with saline infusion.

DISCUSSION

A number of previous studies have investigated the effects of CCK on gastrointestinal motility and gastric emptying. Experiments in humans (5) have indicated that gastric emptying is slowed by intravenous administration of exogenous CCK with a same dose as used in this current study. Similar results were also reported in primates (21). In dogs, Jin et al found that intravenous infusion of CCK-8 at 28 and 56 pmol/kg/hr dose-dependently decreased gastric emptying of a caloric amino acid liquid meal, whereas Loxiglumide, 22 μmol/kg/hr, significantly enhanced gastric emptying (23).

The effects of CCK on gastric myoelectrical activity were investigated using electrogastrography. The first EGG was recorded more than 70 years ago. The EGG is attractive because it is noninvasive and does not disturb the on-going physiological processes of the stomach. It has been applied to investigate the effects of exogenous stimulations and gastrointestinal hormones on gastric myoelectrical activity, including glucagon (24), domperidone (25), epinephrine (26), cisapride (27), and erythromycin (28). This noninvasive method has been validated in a number of previous studies. In one study conducted in our laboratory with simultaneous EGG and serosal recordings in humans it was found that the dominant frequency of the EGG was exactly the same as the frequency of the gastric slow wave measured from the implanted

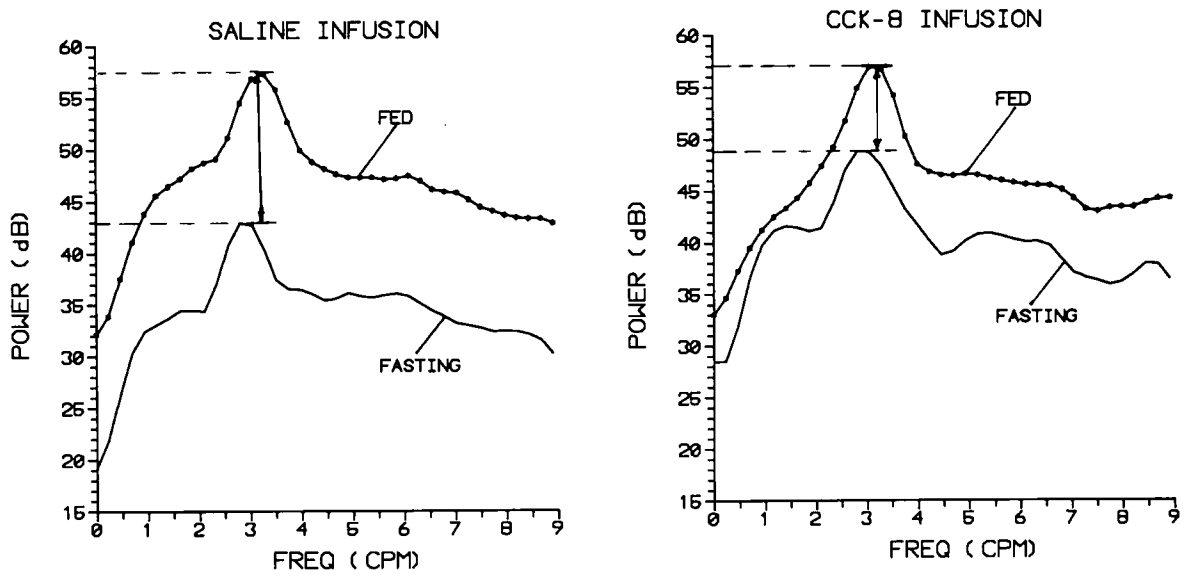

Fig 8. Smoothed power spectrum of the EGG. Left: the power spectra of the 30-min EGG before and 60-min EGG after the test meal with saline infusion. Right: the power spectra of the 30-min EGG before and 60-min EGG after the test meal with CCK infusion.

serosal electrodes (12). In a similar study, Familoni et al showed that gastric rhythmic abnormalities can be accurately detected from the EGG (13). Smout et al (14) reported the correlation between EGG amplitude and spike potentials in a canine study. It was found that spike potentials are reflected in the EGG as an increase in amplitude. Based on these previous studies, the effects of the CCK observed in the EGG could be interpreted as follows: intravenous infusion of CCK significantly inhibits spike potentials in the fed state but has no effects on the frequency and regularity of the gastric slow wave.

The decrease of postprandial peak power (or amplitude) of the EGG observed in our study suggests an inhibitory effect of the intravenous infusion of CCK on gastric motility. Numerous previous studies have shown an increase in EGG peak power after a test meal (29–32). The postprandial EGG power increase has been found to be associated with the increased contractility of the stomach after the meal (19). Similar correlation between EGG power and gastric motility was also observed in the fasting state (19, 33). In an overnight study in 10 normal subjects with simultaneous recordings of EGG and gastric manometry, it was found that EGG has a significantly higher power during the gastric contractions than during gastric motor quiescence (19). The absolute power of the EGG may be associated with several factors, including position of electrodes and the distance between signal source and the electrodes. However, the relative power of the EGG is associated only with the regularity of the gastric slow wave and gastric contractility. EGG power increases as gastric contractions occur. EGG power decreases when gastric slow waves become less regular (34). In this study the relative EGG power, ie, the difference before and after the test meal, was used and, therefore, the change of EGG power should only reflect the changes of the regularity of the gastric slow wave and gastric contractility. Since the regularity of the gastric slow wave was not altered by the intravenous infusion of CCK, it is suggested that the decrease of the postprandial EGG power was attributed to the inhibition of gastric contractility. This interpretation is also in agreement with the findings reported by Bortolotti et al (8). In a study with the same dose of CCK infusion, they noted a significant decrease in antral motility index in the manometric recordings obtained in five normal subjects.

Different explanations have been given on the meaning of the postprandial EGG power increase. Some investigators suggested that the increase of EGG power after a meal was due to physical distension of the stomach, which brings the signal source closer to the recording electrodes (35); some researchers found that the postprandial increase in EGG power resulted from the increased contractility of the stomach (19, 20). Others proposed that the increased EGG power might be attributed to both gastric distention and increased gastric contractility. However, a number of the most recent studies, including the current one, seem to indicate that the increased EGG power is very much associated with increased contractility of the stomach instead of gastric distention. Dr. Satake and colleagues recorded the change of EGG power before and after a meal with the simultaneous ultrasonographic measurement of the distance between the gastric wall and abdominal wall (36). It was reported that the increase of EGG power was not correlated with the distance between the gastric wall and abdominal wall. In a study performed in our laboratory, simultaneous EGG and serosal recordings of gastric myoelectrical activity were made in patients before and after a test meal of water (37). Changes of the power of the 3 cpm slow wave after the drink of water were observed in both EGG and serosal recordings. Moreover, it was found that the change of EGG power at the 3 cpm was significantly correlated with the change of the power of the 3 cpm slow wave measured by the serosal electrodes. In another study with simultaneous recordings of serosal gastric myoelectrical activity and gastric manometry, it was noted that the amplitude of the gastric slow wave increases when gastric contractions occur (19).

The inhibitory effect of the intravenous infusion of CCK on the postprandial EGG was very similar to the effect of fat preload previously observed in our laboratory (9). In that previous study 40 g of liquid fat (the same volume of water was used in the control session) was given in the fasting state after a baseline EGG recording. A solid test meal was then consumed 15 min after the ingestion of fat and the EGG recording was continuously made until 2 hr after the meal. It was found that the postprandial EGG peak power was significantly decreased with the fat preload. The frequency and regularity of the gastric slow wave were, however, not affected. The similarity of the findings between the fat preload and the infusion of CCK suggests that the inhibitory effects of fat preload on the postprandial EGG power may be attributed to the release of CCK after the ingestion of the fat.

The frequency of the EGG observed in this study was in agreement with previous findings. The domi-

nant frequency of the EGG (the frequency of the gastric slow wave) in normal humans has been consistently found to be about 3 cpm. The range of the dominant EGG frequency observed in our laboratory in more than 70 normal subjects was 2.4 to 3.7 cpm (32). A similar range was reported by other investigators (20, 38). In the current study the dominant frequency of the EGG was found to be in the range of 2.58 to 3.52 cpm and was not affected by the intravenous infusion of CCK.

This study showed that the intravenous infusion of CCK does not induce gastric dysrhythmia. The percentage of normal 2–4 cpm slow waves was 90% during each period of the recording. There was no difference between the two sessions of CCK and saline and no difference between the baseline fasting EGG and the fasting EGG with CCK infusion. A number of previous studies have shown that exogenous stimulation by certain gastrointestinal hormones and pharmacological and prokinetic agents, such as glucagon, insulin, secretin, pentagastrin, and erythromycin, may induce gastric dysrhythmias (28, 39, 40). Tachygastria, bradygastria and arrhythmia were induced in dogs with intravenous infusion of met-enkephalin and β-endorphin (41). Intravenous infusion of glucagon in human volunteers caused gastric dysrhythmias associated with decreased antral motility (22). Gastric dysrhythmias are often observed to be associated with nausea and vomiting, such as nausea and vomiting of pregnancy (42), motion sickness (43), and gastroparesis (39, 44, 45). In a study reported previously (28), we investigated the effect of intravenous infusion of erythromycin on gastric myoelectrical activity in normal humans using the same electrogastrographic technique. A significant decrease of the percentage of the normal 2–4 cpm slow wave was observed with intravenous infusion of erythromycin. The decrease was attributed to the decrease of the gastric slow wave frequency from 3 cpm to below 2 cpm (bradygastria). The induction of the bradygastria (or the decrease of the percentage of the normal 2–4 cpm slow waves) with erythromycin infusion was observed to be associated with nausea and vomiting. In the control session with intravenous infusion of saline in that previous study (28), the nausea score was 0 and normal 2–4 cpm slow waves were present. In the session with intravenous infusion, however, the nausea score was 4.5 and two subjects vomited during the infusion. That no gastric dysrhythmia was induced with intravenous infusion of CCK in this current study is consistent with the absence of nausea and vomiting.

In conclusion, this paper indicates that intravenous infusion of CCK at a physiological dose significantly decreases the peak power (or amplitude of) of the postprandial EGG but has no effects on the frequency and regularity of the EGG.

REFERENCES

1. Resin H, Stern HD, Strudevant RA, Isenberg JI: Effect of the C-terminal octapeptide of cholecystokinin on lower esophageal sphincter pressure in man. Gastroenterology 64:946–949, 1973
2. Yamagishi T, Debas HT: Cholecystokinin inhibits gastric emptying by acting on both proximal stomach and pylorus. Am J Physiol 234:E375–E378, 1978
3. Schang JC, Kelly KA: Inhibition of canine interdigestive proximal gastric motility by cholecystokinin octapeptide. Am J Physiol 240:G217–G220, 1981
4. Snape WJ, Carlson GM, Cohen S: Human colonic myoelectric activity in response to prostigmin and the gastrointestinal hormones. Am J Dig Dis 22:881–887, 1977
5. Liddle RA, Morite ED, Conrad CK, Williams JA: Regulation of gastric emptying in humans by cholecystokinin. J Clin Invest 77:992–996, 1986
6. Mukhopadhyay AK, Thor PJ, Copeland EM, Johnson LR, Weisbrodt NW: Effect of cholecystokinin on myoelectrical activity of small bowel of the dog. Am J Physiol 232:E44–E47, 1977
7. Morgan KG, Schmalz PF, Go VLW, Szurszewski JH: Electrical and mechanical effects of molecular variants of CCK on antral smooth muscle. Am J Physiol 235:E324–E329, 1978
8. Bortolotti M, Sarti P, Brunelli F, Mazza M, Barbara L: Influence of CCK on gastric myoelectric and manometric activities of patients with chronic idiopathic dyspepsia. Am J Gastroenterol 86:1309, 1991 (abstract)
9. Chen J, Davenport K, McCallum RW: Effect of fat preload on gastric myoelectrical activity in normal humans. J Gastrointest Motil 5:281–287, 1993
10. Sarna SK: Gastrointestinal electrical activity; terminology. Gastroenterology 68:1631–1635, 1975
11. Szurszewski JH: Electrophysiological basis of gastrointestinal motility. In: Physiology of the Gastrointestinal Tract. LR Johnson (ed). New York, Raven Press, 1987, pp 383–422
12. Chen J, Schirmer BD, McCallum RW: Serosal and cutaneous recordings of gastric myoelectrical activity in patients with gastroparesis. Am J Physiol 266:G90–G98, 1994
13. Familoni BO, Bowes KL, Kingma YJ, Cote KR: Can transcutaneous recordings detect gastric electrical abnormalities? Gut 32:141–146, 1991
14. Smout AJPM, van der Schee EJ, Grashuis JL: What is measured in electrogastrography? Dig Dis Sci 25:179–187, 1980
15. Hamilton JW, Bellahsene B, Reichelderfer M, Webster JG, Bass P: Human electrogastrograms: Comparison of surface and mucosal recordings. Dig Dis Sci 31:33–39, 1986
16. Chen J, McCallum RW: Electrogastrography: Principles and Applications. New York, Raven Press, 1994
17. Alvarez WC: The electrogastrogram and what it shows. J Am Med Assoc 78:1116–1118, 1922
18. Chen J: A computerized data analysis system for electrogastrogram. Comput Biol Med 22:45–58, 1992
19. Chen J, Richards RD, McCallum RW: Identification of gastric

contractions from the cutaneous electrogastrogram. Am J Gastroenterol 89:79–85, 1994
20. Smout AJPM, Jebbink HJA, Samsom M: Acquisition and analysis of electrogastrographic data—the Dutch experience. *In* Electrogastrography: Principles and Applications. J Chen, RW McCallum (eds). New York, Raven Press, 1994, pp 1–30
21. Chen J, Stewart WR, McCallum RW: Adaptive spectral analysis of episodic rhythmic variations in gastric myoelectric potentials. IEEE Trans Biomed Eng 40:128–135, 1993
22. Dubois A, Bruley des Varannes S, Mizrahi M, Fiala N, Solomon T, Turkelson C: Role of cholecystokinin in the regulation of gastric function after caloric meals. Gastroenterology 100:A439, 1991
23. Jin H-O, Lee KY, Chang T-M, Chey WY, Dubois A: Physiological role of Cholecystokinin on gastric emptying and acid output in dogs. Dig Dis Sci 39:2306–2314, 1995
24. Abell TL, Malagelada J-R: Glucagon-evoked gastric dysrhythmias in humans shown by an improved electrogastrographic technique. Gastroenterology 88:1932–1940, 1985
25. Koch KL, Stern RM, Stewart WR, Vasey MW: Gastric emptying and gastric myoelectrical activity in patients with diabetic gastroparesis: Effect of long-term domperidone treatment. Am J Gastroenterol 84:1069–1075, 1989
26. Kim CH, Azpiroz F, Malagelada J-R: Characteristics of spontaneous and drug-induced gastric dysrhythmias in a chronic canine model. Gastroenterology 90:421–427, 1986
27. Cucchiara S, Minella R, Riezzo G, Vallone G, Vallone P, Castellone F, Auricchio S: Reversal of gastric electrical dysrhythmias by cisapride in children with functional dyspepsia. Dig Dis Sci 37:1136–1140, 1992
28. Chen J, Yeaton P, McCallum RW: Effect of erythromycin on gastric myoelectrical activity in normal human subjects. Am J Physiol 263:G24–G28, 1992
29. Chen J, McCallum RW: The response of electrical activity in normal human stomach to water and solid meals. Med Biol Eng Comput 29:351–357, 1991
30. Desvarannes SB, Mizafi M, Dubois A: Relation between postprandial gastric emptying and cutaneous electrogastrogram in primates. Am J Physiol 261:G248–G255, 1991
31. Geldof H, Van der schee EJ, Smout AJPM, Van de merwe JP, Van blankenstein M, Grashuis JL: Myoelectrical activity of the stomach in gastric ulcer patients: An electrogastrographic study. J Gastrointest Motil 1:122–130, 1989
32. Koch KL, Stewart WR, Stern RM: Effect of barium meals on gastric electromechanical activity in man. Dig Dis Sci 32:1217–1222, 1987
33. Geldof H, van der Schee EJ, Grashuis JL: Electrogastrographic characteristics of interdigestive migrating complex in humans. Am J Physiol 250:G165–G171, 1986
34. Chen J, McCallum RW: EGG parameters and their clinical significance. *In* Electrogastrography: Principles and Applications. J Chen, RW McCallum (eds). New York, Raven Press, 1994, pp 45–73
35. Brown BH, Smallwood RH, Duthie HL, Stoddard CJ: Intestinal smooth muscle electrical potentials recorded from surface electrodes. Med Biol Eng 13:97–102, 1975
36. Satake M, Hongo M, Fukudo S, Nomura T, Shoji T: Postprandial increase in electrogastrogram (EGG) power and the distance between the gastric and the abdominal wall. Proceeding of the 3rd International Workshop on Electrogastrography, San Diego, May 1995, p 44
37. Lin ZY, Chen JDZ, McCallum RW, Schirmer BD: Postprandial amplitude changes in electrogastrogram accurately reflect changes of gastric slow waves. Proceeding of the 3rd international workshop on electrogastrography, San Diego, May 1995, p 28
38. Koch KL, Stern RM: EGG data acquisition and analysis—the Penn State experience. *In* Electrogastrography: Principles and Applications. J Chen, RW McCallum (eds). New York, Raven Press, 1994, pp 31–44
39. Abell TL, Camilleri M, Hench VS, Malagelada J-R: Gastric electromechanical function and gastric emptying in diabetic gastroparesis. Eur J Gastroenterol Hepatol 3:163–167, 1991
40. Hasler W, Owyang C: Peptide-induced gastric arrythmia: A new cause of gastroparesis. Regul Pept Lett 2:6–12, 1990
41. Kim CH, Hanson RB, Abell TL, Malagelada J-R: Effect of inhibition of prostaglandin synthesis on epinephrine-induced gastroduodenal electromechanical changes in humans. Mayo Clin Proc 64:146–157, 1989
42. Koch KL, Stern RM, Vasey MW: Gastric dysrhythmias and nausea of pregnancy. Dig Dis Sci 35:961–968, 1990
43. Stern RM, Koch KL, Stewart WR: Spectral analysis of tachygastria recorded during motion sickness. Gastroenterology 92:92–97, 1987
44. Chen J, McCallum RW: Gastric slow wave abnormalities in patients with gastroparesis. Am J Gastroenterol 87:477–482, 1992
45. Geldof H, Van der schee EJ, Van blankenstein M, Grahuis JL: Electrogastrographic study of gastric myoelectrical activity in patients with unexplained nausea and vomiting. Gut 26:799–808, 1986