# Patterns of gastric myoelectrical activity in human subjects of different ages

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**Chen, J. D. Z., E. Co, J. Liang, J. Pan, J. Sutphen, R. B. Torres-Pinedo, and W. C. Orr.** Patterns of gastric myoelectrical activity in human subjects of different ages. *Am. J. Physiol.* 272 (*Gastrointest. Liver Physiol.* 35): G1022–G1027, 1997.—The aim of this study was to investigate the developmental change of gastric myoelectrical activity in humans. Five groups of healthy subjects were studied, including 10 preterm newborns, 8 full-term newborns, 8 full-term infants (ages 2–6 mo), 9 children (ages 4–11 yr), and 9 adults. Gastric myoelectrical activity was recorded using surface electrogastrography for 30 min before and 30 min after a test meal in each subject. Spectral analysis methods were applied to compute the parameters of the electrogastrogram (EGG). The results showed that the percentage of 2- to 4-cycles/min (cpm) slow waves was 26.6 ± 3.9% in the preterm newborns, 30.0 ± 4.0% in full-term newborns, 70 ± 6.1% in 2- to 6-mo-old infants ($P < 0.001$ compared with newborns), 84.6 ± 3.2% in 4- to 11-yr-old children ($P < 0.03$ compared with infants), and 88.9 ± 2.2% in the adults ($P > 0.05$ compared with children). In conclusion, gastric slow waves are absent at birth, and there is a maturing process after birth. Age-matched controls are necessary for the interpretation of EGG data from neonates and infants, whereas EGG data in children are the same as in adults.

electrogastrography; gastric motility; stomach; development

TWO TYPES OF GASTRIC myoelectrical activity can be measured by serosal or intraluminal electrodes: the slow wave and spike/second potentials. The gastric slow wave is present continuously 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 regular recurring changes in potential, propagating circumfluentially and distally toward the pylorus with increasing velocity and amplitude. The frequency of the gastric slow wave in healthy adult humans is about 3 cycles/min (cpm). It is known that the gastric slow wave controls the frequency and propagation of gastric contractions. Spike/second potentials are directly correlated with antral contractions. When a gastric slow wave is followed by spike/second potentials, an antral contraction occurs.

The most attractive method for recording gastric myoelectrical activity is surface electrogastrography (3). The surface electrogastrogram (EGG) represents a weighted summation of gastric myoelectrical activity of various regions of the stomach. Previous studies have shown that EGG is a reliable measurement of gastric slow waves (9, 13, 17, 29). Numerous studies have reported normal EGG patterns in healthy adult subjects (6). A higher prevalence of abnormal EGG patterns, such as gastric dysrhythmias, has been reported in patients and associated with gastrointestinal motor disorders, such as gastroparesis and symptoms of nausea and vomiting (1, 7, 14, 18, 20, 21, 27, 28, 32). The clinical use of electrogastrography as a diagnostic tool for the assessment of gastrointestinal motor disorder is being explored (24). Although the vast majority of studies are being performed in adults, increasing interest has developed in the clinical utilization of electrogastrography in children and infants. However, there is a lack of normative data in infants and children. It is not known whether normative EGG patterns obtained from adults could apply to infants and children. The aim of this study was to study gastric myoelectrical activity in healthy subjects of different ages and to investigate if EGG patterns are associated with age.

## METHODS

### *Subjects*

The study was performed in the following five groups of subjects: *1*) 10 preterm newborns (5 female, 5 male) with a mean age of 5 days (range 1–9 days) at the time of the study and a mean gestation age of 33.4 wk (range 30–36 wk) at birth; *2*) 8 full-term newborns (4 female, 4 male) with a mean age of 1.5 days (range 1–2 days) at the time of the study; *3*) 8 full-term infants (4 female, 4 male) with a mean age of 4.5 mo (range 2–6 mo) at the time of the study; *4*) 9 children (4 female, 5 male) with a mean age of 7.5 yr (range 4–11 yr); and *5*) 9 healthy adults (5 female, 4 male) with a mean age of 40 yr (range 25–58 yr). Subjects had no history of gastrointestinal motor disorder and no symptoms of nausea, vomiting, abdominal pain, or bloating during the study. The preterm newborns had no major systemic disease and were in stable condition during the study. All preterm and full-term newborns were healthy and growing. None of them were under intensive care. The study protocol was approved by the Human Investigation Committee at the University of Virginia Health Science Center and the Institutional Review Board at Integris Baptist Medical Center of Oklahoma. Written consent was obtained from the subject or the parent of the subject before the study.

### *Electrogastrography*

Gastric myoelectrical activity in each subject was measured using surface electrogastrography. Before the electrodes were attached, the abdominal skin was cleaned using sandy skin-preparation paste (Omniprep; Weaver, Aurora, CO) to reduce the impedance. Three silver-silver chloride EGG electrodes were placed on the abdomen, as shown in Fig.

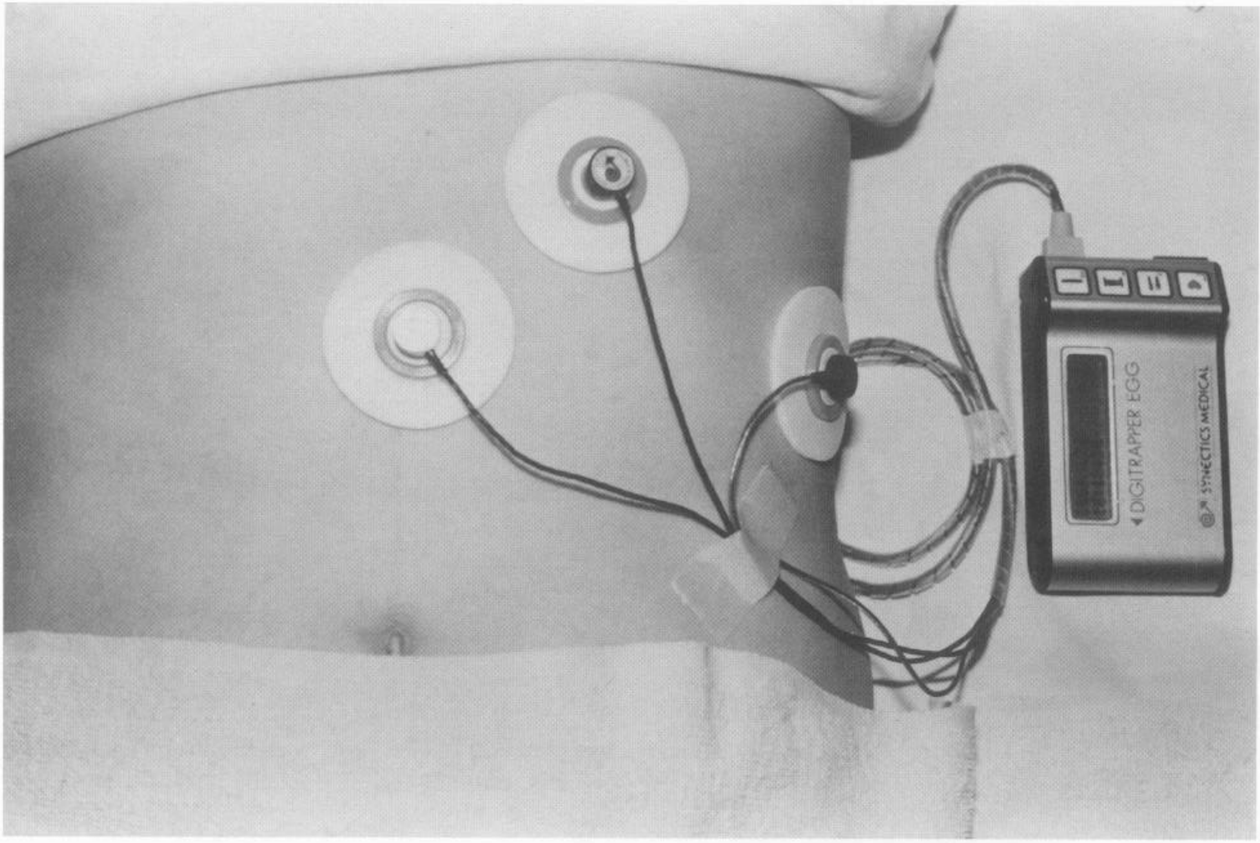


Fig. 1. Placement of electrodes. Two epigastric electrodes were connected to generate a bipolar electrogastrogram (EGG) signal. The other electrode was used as a reference.

1. Two epigastric electrodes were connected to yield a bipolar EGG signal. The other electrode was used as a reference. The EGG signal was recorded using a portable EGG recording device (Digitrapper EGG; Synetics Medical, Irving, TX) with a low and high cutoff frequency of 1 and 18 cpm, respectively.

*Experimental Protocol*

All subjects were fasted before the study. The preterm and full-term newborns, as well as the infants, were fasted for 3 h, whereas the children and adults were fasted overnight. The newborns and infants received either formula or breast-feeding. Three hours is enough time for the stomach to empty a liquid meal. Because the children and adults were eating solid meals, the study was performed after an overnight fast to guarantee that the baseline recording was in the fasting state. First, a 30-min or longer baseline recording of the EGG was performed, and then a test meal was given. After the meal, EGG recording was resumed for another 30 min or more. For the newborns and infants, the actual duration of the preprandial and postprandial EGG recordings was based on the quiescence of the subject. Typically, each recording period lasted for 40–60 min so that a clean period of 30 min was available after the deletion of recording portions contaminated by motion artifacts. Children and adults were allowed to watch television or video during the study. They were asked to be still and quiet. The recording was made in the Newborn Nursery for the full-term newborns, in the Neonatal Intensive Care Unit for the preterm newborns, and in the principal investigator's laboratory for the others. Dim light was used, and no one was allowed to talk during recording. All subjects were in a supine position for both preprandial and postprandial recordings. The test meal for the newborns was not standardized. Either formula or breast milk was given, based on the subject's need. The test meal for the infant group consisted of 4 oz of formula. The test meal for the 4- to 11-yr-old children and the adults consisted of two scrambled eggs, two pieces of toast, and 100 ml water. All adult subjects consumed the test meal completely. Each of the children finished >50% of the test meal.

*Data Analysis*

The EGG signal was on-line digitized with a sampling frequency of 1 Hz and stored on the portable recording device. At the end of study, the device was connected to a 486 personal computer and the EGG data were uploaded to the computer. Before quantitative and statistical analyses, the EGG recording was first displayed on the computer. All recording portions contaminated by motion artifacts were visually deleted. The pattern of the EGG was characterized by several quantitative parameters, including EGG dominant frequency and power and the percentage of normal gastric slow waves, as described below.

*EGG dominant frequency.* The frequency at which the EGG power spectrum has a peak power in the range 0.5–9.0 cpm was defined as the EGG dominant frequency. EGG dominant frequency has been shown to be equal to the frequency of the gastric slow wave measured from the implanted serosal electrodes (9, 13, 29). It was computed using the smoothed power spectral analysis method (4), which produced an average power spectrum for the EGG during the 30-min baseline and postprandial recordings. Figure 2 illustrates the

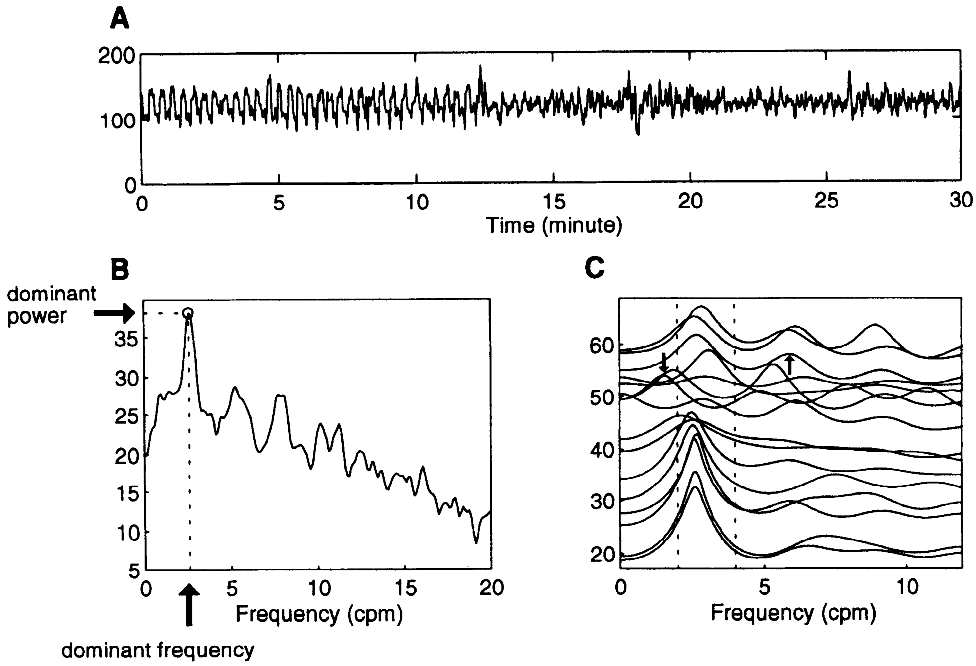


Fig. 2. EGG and its power spectra from an adult. *A*: 30-min EGG recording in the fasting state. *B*: power spectrum of 30-min EGG recording. *C*: running power spectra of 30-min EGG recording. Each line from *bottom* to *top* represents power spectrum of 2-min EGG data. *Left arrow* indicates bradygastria; *right arrow* indicates tachygastria. cpm, cycles/min.

definition of the dominant frequency. An EGG recording is shown in Fig. 2*A*, and the power spectrum of the recording calculated by the smoothed spectral analysis method is shown in Fig. 2*B*.

*EGG dominant power.* The power at the dominant frequency in the power spectrum of the EGG was defined as the EGG dominant power. Previous studies (8, 28) have shown that the relative change of the EGG peak power reflects gastric contractility. Decibel (dB) units were used to represent EGG power. Assuming a sinusoidal signal with amplitude ($A$), power ($P$) is expressed as

$$P(\text{dB}) = 10 \times \log_{10} A^2$$

Figure 2*B* illustrates the dominant power.

*Percentage of regular 2- to 4-cpm slow waves.* The percentage of 2- to 4-cpm slow waves is a quantitative assessment of the regularity of the gastric slow wave measured from the EGG. It was defined as the percentage of time during which normal 2- to 4-cpm gastric slow waves were observed in the preprandial or postprandial EGG recording. The percentage of normal 2- to 4-cpm slow waves was computed from the running power spectra of the EGG by the adaptive spectral analysis method (10). Using this method, we divided the preprandial or postprandial EGG recording into 2-min blocks without overlap. The power spectrum of each 2-min EGG was calculated and examined to see if the peak power was within the range 2–4 cpm. The 2-min EGG recording was defined as normal if the peak power was within the 2- to 4-cpm range. Otherwise, it was called dysrhythmia. An illustrative example for the computation of the 2- to 4-cpm slow waves is presented in Fig. 2*C*. It can be assessed from Fig. 2*C* that the percentage of normal 2- to 4-cpm slow waves in this recording is 86.7%, since 13 of the total 15 spectra have dominant frequencies in the range 2–4 cpm.

### *Statistical Analyses*

Statistical analyses were performed to investigate the difference of the EGG patterns among different groups of subjects. Paired and unpaired Student's $t$-tests were used to assess the difference. Statistical significance was assigned for $P < 0.05$. Data are mean ± SE.

## RESULTS

Regular gastric slow waves were recorded in healthy adults. A typical example is shown in Fig. 2. The mean percentage of normal 2- to 4-cpm slow waves in the 9 subjects was 88.9 ± 2.2% in the fasting state and 89.7 ± 1.4% after the test meal ($P > 0.05$). The dominant frequency was 2.85 ± 0.06 cpm in the fasting state and increased to 3.09 ± 0.09 cpm after the test meal ($P < 0.02$) (see Fig. 3). A 3-dB increase in the dominant power of the EGG (equivalent to 50% increase in amplitude) was observed after the test meal (see Fig. 4). This increase was, however, barely significant ($P = 0.06$).

The EGG results in the children were very similar to those in the adults. Regular 2- to 4-cpm slow waves

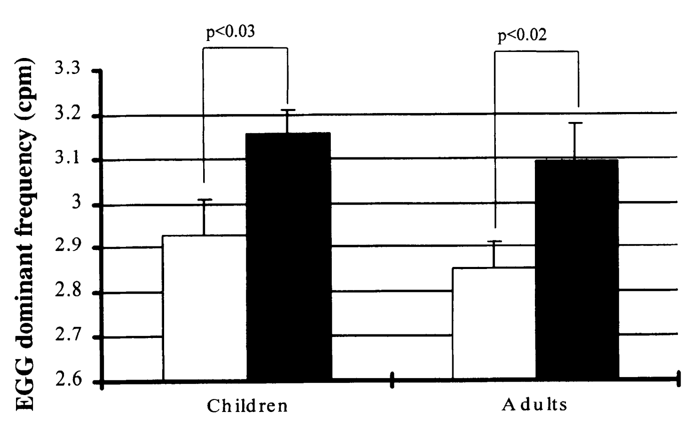


Fig. 3. Effects of solid test meal on EGG dominant frequencies in children and adults. Open bars, 30 min during fasting; filled bars, 30 min postprandial.

were recorded in both fasting and fed state (84.6 ± 3.17% vs. 86.7 ± 2.78%, $P > 0.05$). The dominant frequency of the EGG was 2.93 ± 0.8 cpm in the fasting state and 3.16 ± 0.05 cpm after the test meal (see Fig. 3). A significant increase in EGG dominant power was observed after the test meal (see Fig. 4). It was also found that the absolute value of the dominant power was significantly higher in the children than in the adults in both fasting and fed states (see Fig. 4).

Gastric slow waves similar to those in the groups of children and adults were also recorded in the group of infants, in whom the test meal did not induce any significant changes in EGG parameters, including the percentage of 2- to 4-cpm slow waves. The percentage of 2- to 4-cpm slow waves observed for the 60-min fasting and fed EGG was 70.0 ± 6.1%, which was significantly lower in comparison with that in the children and the adults (see Fig. 5). The mean dominant frequency was 3.00 ± 0.08 cpm, which was not different from that in the children and adults.

In both preterm and full-term newborns, there was an absence of regular gastric slow waves measured from the EGG. The test meal did not induce any significant changes in the parameters of the EGG, such as the percentage of 2- to 4-cpm slow waves. The percentage of the 2- to 4-cpm slow waves in the 60-min fasting and fed EGG was 26.6 ± 3.3% in the preterm newborns and 30.0 ± 4.0% in the full-term newborns. There was no difference in the percentage of the 2- to 4-cpm slow waves between the two groups, although the full-term newborns had a slightly higher value. The power spectrum averaged over the 30-min period showed no dominant frequency in both groups. See Fig. 6 for a typical example. No changes in the EGG were noted after the test meal.

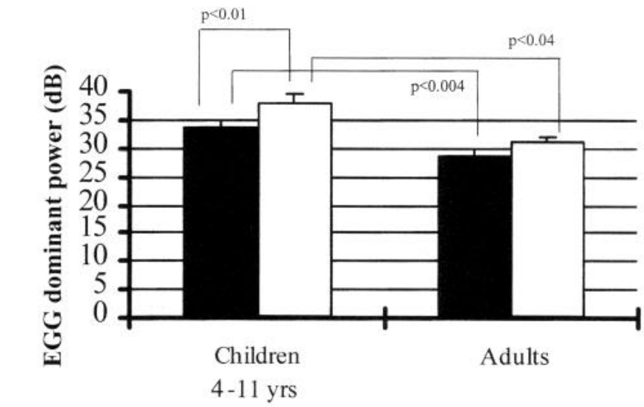


Fig. 4. Effects of solid test meal on EGG dominant power in children and adults. Filled bars, 30 min during fasting; open bars, 30 min postprandial.

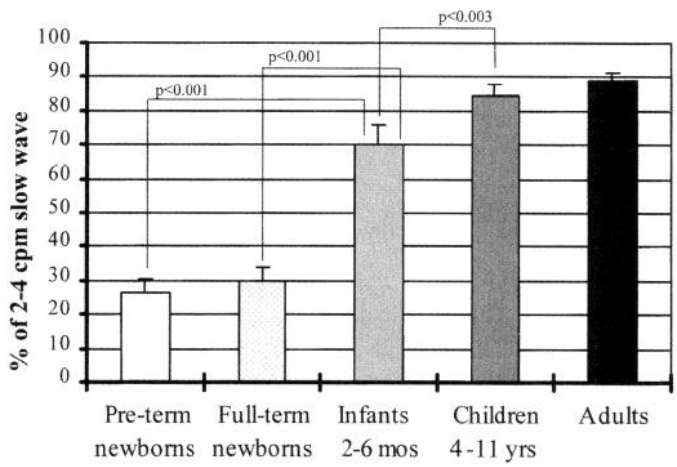


Fig. 5. Percentages of 2- to 4-cpm gastric slow waves in different groups of subjects.

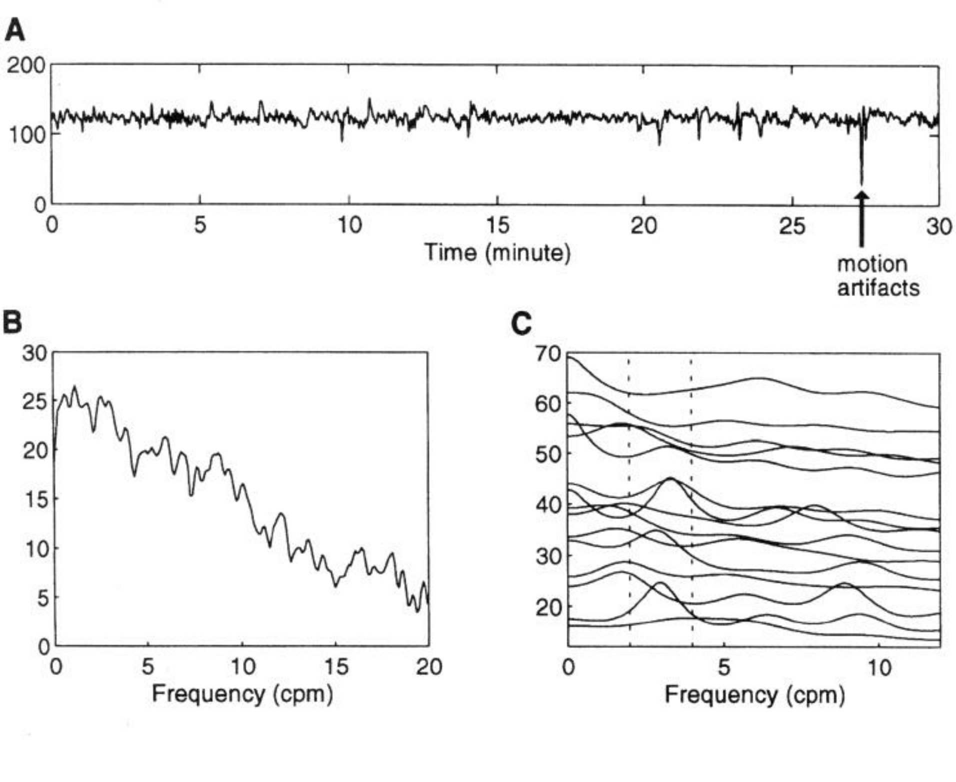


Fig. 6. EGG recording and its power spectra in a preterm newborn. *A*: 30-min EGG recording before deletion of motion artifacts in fasting state. *B*: power spectrum of 30-min EGG recording. No dominant frequency can be identified from the power spectrum. *C*: running power spectra of 30-min EGG recording. Each line from the *bottom* to *top* represents power spectrum of 2-min EGG data.

**DISCUSSION**

This study has shown that regular gastric slow waves of 2–4 cpm are absent at birth, present at the age of 2–4 mo, and well developed at the age of 4–11 yr (see Fig. 3). The EGG in healthy children is similar to that in healthy adults.

Since the first measurement of the EGG more than 70 years ago, numerous studies have been published about it (2, 11, 24, 31). None of the previous papers addressed the development of gastric myoelectrical activity. A recent study by Pfaffenbach et al. (25) investigated the effect of age and gender on EGG in healthy subjects; however, they only studied subjects ages 19 yr and older. Because of its noninvasive nature, the EGG has been used by more and more pediatricians to investigate the physiology and pathophysiology of gastric motility in pediatric patients. It has been generally assumed that EGG patterns in normal pediatric subjects are the same as those in healthy adults. This study, however, indicates that there is a maturing process of gastric myoelectrical activity in humans, especially in the early stages of life. Our data have shown that an absence of regular 2- to 4-cpm gastric slow waves in neonates is a normal developmental phenomenon. Accordingly, caution should be taken in interpreting an EGG recording from a neonate. When the EGG is applied in neonates and infants, normative EGG data should be obtained for different age groups, and age-matched controls are necessary for the interpretation of EGG obtained from diseased neonates and infants.

The absence of regular 2- to 4-cpm gastric slow waves observed in newborns seems to be in agreement with previous findings on gastric motility. Gastric motility, which is regulated by gastric myoelectrical activity, seems to be immature in newborns as well. Tonic intraluminal pressure increases in the fundus are necessary for the emptying of liquid meals, whereas antral peristalsis is important for the emptying of solid meals. It follows that functions of the fundus might be very important in infants whose diet consists of only milk. Using cineradiography, Tornwall et al. (34) found that there were no peristaltic contractions in the stomach during the first 2–4 days of life and speculated that within that time the stomach empties mainly by fundic tone. Gryboski (16) also reported an absence of gastric contractions in infants younger than 2 days. In the fasting state, gastric motility is characterized by cyclic recurring of migrating motor complex, which is composed of three phases. In newborns, there seems to be an absence of regular phase III activity and fasting gastric motility is characterized by clustered contractions, indicating a lack of coordination (19). Immature gastric motility might be attributed to the absence of regular gastric slow waves observed in this study.

The EGG in the preterm and in the full-term newborns were similar. This seems to suggest that the development of gastric myoelectrical activity is not very highly associated with the gestation age at birth. The significant difference between newborns and 2- to 6-mo-old infants suggests that there is a maturing process in the early months of life. It is postulated that feeding or eating may be a potent stimulus that plays an important role in the maturation of gastric myoelectrical activity. The absence of regular gastric slow waves in the newborns observed in this study is also in agreement with a previous study. Using similar electrogastrography, Koch et al. (23) recorded gastric myoelectrical activity in preterm and full-term infants with ages from 3 to 50 days. Using the percentage of total EGG power in the frequency range 2.5–3.6 cpm as a measure of normal gastric slow waves, Koch et al. (23) reported similar findings as in this study; that is, a low percentage of normal gastric slow waves, no difference between preterm and full-term infants, and no difference between fasting EGG and fed EGG. The aim of the study by Koch et al. (23) was to investigate the difference between the preterm and full-term infants. They did not study the development of gastric myoelectrical activity. They computed the energy of EGG power in the frequency range 2.5–3.6 cpm, which was not an accurate indicator of the regularity of the gastric slow wave.

On the basis of our results, it seems that the gastric slow wave is well established by the age of 5 mo. Although it is still significantly lower than in children ages 4 yr or older, the mean percentage of 2- to 4-cpm slow waves is 70%. That is, normal gastric slow waves are present in most of the recordings. Controversial findings have been previously reported regarding the effect of milk on EGG. Some investigators reported that whole milk and yogurt meals increase the amplitude of the 3-cpm slow wave in the EGG, whereas one of our previous studies (5) reported a decreased amplitude of the 3-cpm slow wave measured in the EGG in adults after ingestion of a test meal of milk with 10% fat. This study reported no change in EGG parameters after the test meal of milk.

The EGG patterns in the children ages 4 yr or older are very similar to those in the adults. The groups of children and adults have the following similar characteristics: *1*) a high percentage of regular 2- to 4-cpm slow waves in both fasting and fed state, which is unaffected by the test meal; *2*) a clear dominant frequency at ~3 cpm and a slight but significant increase in the dominant frequency of the EGG after the test meal; and *3*) an increase in the amplitude (or power) of the EGG at 3 cpm. With the same test meal, a more significant postprandial increase in the amplitude of the gastric slow wave was observed in the children than in the adults. Increase in the amplitude or power of the EGG at 3 cpm after a test meal has been reported in numerous studies. This postprandial increase is generally believed to be associated with the increased contractility of the stomach after the meal, although possible effects of gastric distension cannot be eliminated (12, 15, 22, 30, 31, 33). The postprandial increase in the amplitude of the 3-cpm activity found in the adults in this study is not as prominent as previous findings reported in the literature. This might be attributed to the low-caloric test meal used in this study. This study also indicates that the power of the EGG at 3 cpm is significantly higher in children than in adults, suggesting that electrogastrography may be more sensitive in children because the abdominal wall is usually thinner in children than in adults.

The developmental process of the gastric slow wave observed in this study has both physiological and clinical significance. Physiologically, this study indicates that gastric myoelectrical activity is not mature at birth and that there is a maturation process after birth. The maturation may be stimulated by eating, since there was no significant difference between the preterm and full-term infants. The noninvasive EGG method may be a good tool for assessing the physiological maturation of gastric function. Clinically, this study provides useful information on the physiology and pathophysiology of gastric function. Gastrointestinal symptoms such as nausea and vomiting have been associated with abnormal gastric myoelectrical activity. If we do not know when to expect a mature 3-cpm rhythm, it is difficult to ascribe some EGG abnormalities to account for symptoms. The results of this study suggest that irregular gastric slow waves in the early months of life are physiological and can be attributed to the maturation process, whereas abnormalities in the EGG in the later months (>5 mo) are probably pathophysiological.

In conclusion, gastric slow waves are absent at birth and there is a maturing process after birth. In the early months of life, the EGG pattern is associated with age, and age-matched controls are necessary for interpreting EGG data obtained from diseased neonates and infants. The normal EGG patterns in children are the same as those in adults.

The authors thank Regina Randall for preparation of the manuscript.

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Received 17 April 1996; accepted in final form 15 November 1996.

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