2003. Vol. 24. No. 4. 92-101
Korean Journal of Oriental Medicine

Original Articles

Incomplete Relationship between Dominant Power of Electrogastrography and Gastric Myoelectrical Activity in Patients with Functional Dyspepsia

Sook-Young Han, Sang-Hyub Yoon, Jin-Sung Kim, Bong-Ha Rhyu, Ki-Won Rhyu

Department of Gastroenterology, College of Oriental Medicine, Kyung Hee University

Background & Aims : The aim of this study was to investigate the change of dominant power with observation of gastric myoelectrical activity and its parameter linkage in electrogastrography.

Methods : Electrogastrography was performed on a total of 123 subjects (113 patients with functional dyspepsia, 10 healthy controls) for 30 min in fasting state and 50 min in postprandial state. Average myoelectrical activity per frequency and accumulated electrical activity of 5 min duration in each bradygastria, normogastria, and tachygastria were measured at the moment of frequency switchover of slow wave. Assumed parameter linkages were also investigated among dominant frequency, % of normal regularity, and dominant power (or power ratio).

Results : Average myoelectrical activity per frequency was highest in bradygastria (mean 1.10-1.47 Volt/s), next highest in normogastria (mean 0.50-0.82 Volt/s), and lowest in tachygastria (mean 0.44-0.47 Volt/s). Average accumulated myoelectrical activity was highest in normogastria (mean 114.90-126.29 Volt/ss), next highest in tachygastria (mean 71.02-90.00 Volt/ss), and lowest in bradygastria (mean 12.93-51.94 Volt/ss).

Significance of parameter linkages were noted in dominant frequency ($p< 0.01$) and in % of normal regularity ($p< 0.01$), but not in dominant power in case of frequency shift from bradygastria to normogastria ($p=0.376$).

Conclusion : Dominant power is not a parameter that reflects the gastric myoelectrical activity related with only gastric contraction. Bradygastric dominant power does not follow the inter-parameter linkage of electrogastrography for gastric motility assessment. *(Korean J of Oriental Med 2003;24(4):92-101)*

Key Words: EGG (electrogastrography), bradycardia, tachycardia, DF (dominant frequency), DP (dominant power)

Introduction

Surface electrogastrography (EGG) is a noninvasive measurement for recording the gastric myoelectrical activity on the abdomen that consists of slow waves and spikes.

Received 16 October 2003; revised 26 October 2003; accepted 3 November 2003
Correspondence to:Sang Hyub Yoon, Department of Gastroenterology, College of Oriental Medicine, Kyung Hee University, Seoul, Korea; Tel: 82-2-958-9142 Fax: 82-2-958-9136, E-mail: sookza@freechal.com

The slow wave originates in the corpus of the stomach and propagates toward the pyloric region with increasing velocity and amplitude[1]. The concomitant settlement of amplitude magnitude and shape in the occurrence of slow wave frequency has been reported in previous studies[2]. It is well known that gastric myoelectrical activity is related with gastric motility[3] and gastric contraction is a very important factor for explaining pathophysiology of gastric dysmotility. Gastric contraction in EGG has been mainly estimated from changes in dominant power or power ratio[4,5].

However, whether they actually reflect gastric contraction is still in doubt. Currently accepted opinion is that decreased power ratio is related to hypomotility[6,7]. In spite of serving as an important index for reflecting gastric contraction, dominant power (or power ratio, PR) is yet unstable and must be examined carefully.

Most previous studies on EGG parameters in functional dyspepsia were analyzed within normogastria[8-12]. In a case where frequency of slow wave switched over from normogastria to bradygastria or to tachygastria, variations of % of normal regularity and PR related with frequency have not yet been reported. This suggests that a linkage survey among EGG parameters of dominant frequency (DF), % of normal regularity, and PR was not fully performed in the meantime. Moreover, this event has never been verified in surface EGG. Accordingly, we believed that a linkage survey of parameter would reveal why dominant power is unable to reflect actual gastric contraction.

The aim of this study was to investigate the changes of dominant power (or power ratio) through the concomitant observation of both magnitude and shape of gastric myoelectrical potentials and parameter linkage of electrogastrography at the time of frequency switchover of slow waves in patients with functional dyspepsia.

Materials and Methods

1. Subjects

The study was performed on 113 patients with functional dyspepsia (35.38±12.68 yrs, 43 males, 70 females) and 10 healthy subjects (32.83±8.63 yrs, 5 males, 5 females). The healthy subjects had no history of gastrointestinal symptoms and revealed no organic changes in stomach by endoscopy. The selection of these patients was based on the Roma II criteria with a history of the symptoms for at least three months (continuous or intermittent). Some patients were confirmed with a negative endoscopy immediately after EGG. Most of the patients with final findings via endoscopic examination within a year refused the follow-up gastroendoscopy because of endoscopic distress, and reported no further progress of symptoms. Patients with a history of secondary related motility diseases or gastrointestinal surgery or concomitant medication limited to prokinetic agents, anticholinergic agents, or calcium channel blockers were excluded from this study.

The study protocol was approved by the Human Investigation Ethic Committee at the Oriental Hospital of Kyung Hee Medical Center, Kyung Hee University. A written consent form was signed by all subjects before the study.

2. EGG measurement

Gastric myoelectrical activity was recorded using surfaceelectrogastrography.

Recording was performed in the morning (9:30 a.m.) after an overnight fast. Electrodes were placed on the abdominal skin. The skin was rubbed until it turned slightly pinkish with an abrasion of 70% ethyl alcohol in order to reduce impedance at the recording sites. If abdominal hair was present, it was shaved off with a razor. Three silver-silver chloride EGG electrodes (Grass gold disc) filled with electrogel cream (Grass EC2) were placed on the abdomen. Electrode 1 was placed on the midpoint between umbilicus and xiphoid process. Electrode 2 was placed at a position 5 cm to the left of Electrode 1 and about 1 cm below the edge of the rib cage. A reference electrode was placed in the lower quadrant close to the left costal margin. A 10-15 min period was allowed to "settle down" the electrode-jell-skin interfaces before starting the EGG.

A bipolar EGG signal was derived from Electrode 1 and 2, and then it was amplified using a Grass physiography (model 7p511) with low and high cutoff frequencies of 0.01 and 0.5 Hz, respectively. Simultaneous on-line digitations with a sampling frequency of 1 Hz were performed using an A/D converter and PowerLab chart software (version 4.12). Digitized data were downloaded on to a computer hard disk for offline analysis. The EGG recording was made in a quiet and slightly darkened room. The studied subjects laid in the supine position and were asked not to move, fall asleep, or talk and to remain as still as possible to avoid motion artifacts during the measurement period. Feeding and eating were done in a normal sitting position. EGG was recorded for 30 min in the fasting state for a base measurement and 50 min in the postprandial state within 10 min of ingestion of a standardized test meal. The standard meal was made up of two scrambled eggs, two pieces of toasted bread (45 g), and 180 ml of unsweetened orange juice.

1) Data sampling for analysis of myoelectrical activity in slow wave frequency

Sampling was obtained from postprandial EGG which included spontaneous frequency shifting and representation of real digestion state after eating. Postprandial EGG revealed durations of over 10 min for each bradygastria, normogastria, and tachygastria before and after spontaneous frequency shifting. To avoid inter-frequency confusion of sampling, a time barrier of 2.5 min was placed at both sides of the suspected point of frequency transition. Data sampling for bradygastria, normogastria, and tachygastria were obtained from separate 5 min recordings at both ends of the time barrier. However, data sampling in case of bradytachyarrhythmias was different from that of frequency shifting. Partial sampling of its tachygastria was performed in suitable data recorded after advent of bradygastric electrical potentials; sampling for bradygastria was substituted by sum of bradygastric potentials sustained for 5 min in the total recording time.

2) Calculation of gastric myoelectrical potentials

Electrical activity was measured by using differential function in PowerLab chart software during recording. Myoelectrical activity per frequency was represented as maximum values (positive up) treated by cycle variable functions in chart program, which was adjusted for timing and shape of original frequency recorded. Magnitude was expressed as unit of Volt/s. Average electrical activity per frequency representing portion of bradygastria, normogastria, and tachygastria in each patient is calculated by averaging 9 frequencies chosen from a 5 min period: 3 frequencies of maximum value, 3 of middle, and 3 of minimum. A 5 min period was chosen because the least surplus time left for the calculation of data was 7 min 30 seconds. This value was used as a basal data representing their portion in individual patients. Accumulated myoelectrical activity (as an absolute value) depended just on the 5 min period calculated for average myoelectrical activity per frequency. It was measured using integral function in chart software. Magnitude of integrated electrical activity was expressed as unit of Volt/s. s.

3) EGG analysis

Prior to the evaluation of the EGG recordings, we inspected all the recorded data visually and removed the data that contained motion artifacts. They were subjected to computerized spectral analysis using the programs developed previously[13,14].

Dominant frequency, % of normal slow waves, and dominant power were computed and used in assessing the EGG recordings. Criteria of normogastria is from 2 to 4 cpm/min.

Less then 2 cpm is regarded as bradygastria; more then 4 cpm, tachygastria.

3. Study protocol

1) Measurement of gastric myoelectrical activities

Shape of slow waves and gastric myoelectrical activities were measured and compared in respect to frequency shifting of three types; initially from bradygastria to normogastria (B-T type), normogastria-tachygastria (N-T type), and mixed bradygastria-tachygastria (MBT type) from the beginning.

2) Survey of parameter linkage and validity

Linkage survey of EGG parameters began under the conception that normal condition of slow waves guarantees the most optimal contractility in the stomach.

Because patients with bradygastria are rare, they were divided into 2 groups; a bradygastria group to observe the linkage between bradygastria and normogastria, and a non-bradygastria (tachygastria and normogastria) group. Parameter linkage was investigated twice; first on groups and second on segmentum of single EGG which showed frequency transposition. Significance assessment was done by postprandial parameters. Normal healthy controls were used as reference.

(1) Bradygastria group

There were no patients with bradygastria who showed the same course as in the non-bradygastria group. Therefore, a different method of observation was used. We selected three patients (41.01±0.8 yrs) whose bradygastria was sustained for longer than 10 min and followed by normogastria in postprandial EGG. Analysis on bradygastria or normogastria was done with their segmentum of EGG.

(2) Non-bradygastria group

Considering the changes in DF before and after eating, patients (34.97±12.94 yrs) in this group were divided into 4 patterns; preprandial tachygastria-postprandial tachygastria (T-T pattern), preprandial tachygastria - postprandial normogastria (T-N pattern), preprandial normogastria - postprandial normogastria (N-N pattern), and preprandial normogastria - postprandial tachygastria (N-T pattern).

4. Statistical analysis

Mann-Whitney and Kruskal-Wallis tests were performed for statistical analysis. *P* value of < 0.05 was recognized as statistically significant.

Results

1. Analysis of potentials magnitude and shape in frequency of bradygastria, normogastria, and tachygastria at the time of switchover

Magnitude and shape in potentials were different according to the frequency state of slow waves. Bradygastria had a larger amplitude of 1.78 Volt/s, a longer interval of about 2 min between slow waves, and a biphasic appearance. Normogastria appeared as having a moderate amplitude of mean 0.42 Volt/s, an interval of mean 20 sec, and a regularly formal shape. Tachygastria exhibited a smaller amplitude of mean 0.25 Volt/s, an irregular interval, and a dense and unfixed form(Fig. 1).

2. Changes of gastric myoelectrical activities

Differences of slow wave frequency explained those in gastric myoelectrical activities. Average myoelectrical activity per frequency and average accumulated myoelectrical activity showed inverse relationship to each other in bradygastria, normogastria, and tachygastria cases. Statistical significance was seen in both their values ($p<0.01$, respectively). Average myoelectrical activities per frequency were in the order of: bradygastria (mean 1.10-1.47 Volt/s) > normogastria (mean 0.50-0.82 Volt/s) > tachygastria (mean 0.44-0.47 Volt/s). Average accumulated electrical activities were in the order of: normogastria (mean 111.92-114.90 Volt/ss) > tachygastria (mean 71.02-87.31 Volt/ss) > bradygastria (mean 12.93-51.94 Volt/ss) (Table 1, Fig. 2).

3. Validity and linkage on EGG parameters

Validity was acceptable in dominant frequency and in % of normal regularity but not in dominant power. Statistical significance in postprandial DF was seen in both bradygastria group (1.33±0.49 vs. 2.77±0.38 cpm, $p<0.01$) and non-bradygastria group (12.63±6.10 vs. 3.12±0.30 vs. 3.17±0.24 vs. 9.93±4.60 cpm, $p<0.01$). DF in normal healthy controls was 3.200.12 cpm. % of normal regularity in slow waves was proportionally increased in both groups ($p<0.01$, respectively) when slow waves were moving toward 3 cpm. In the bradygastria group, % of normal regularity was increased from (39.44±23.35%) to (79.19±3.64%). In the non-bradygastria group, % of normal regularity was increased in the order of: N-N pattern (80.76±13.93%), T-N (75.20±16.59%), N-T (50.85±12.96%), T-T (50.70±10.79%). However, the average % of normal regularity in the patient group did not exceed that of normal healthy controls (94.15±2.81%). Dominant power in the bradygastria group did not exhibit statistical significance (25.48±1.54 dB vs. 24.821.00 dB, p=0.376), while power ratio in the non-

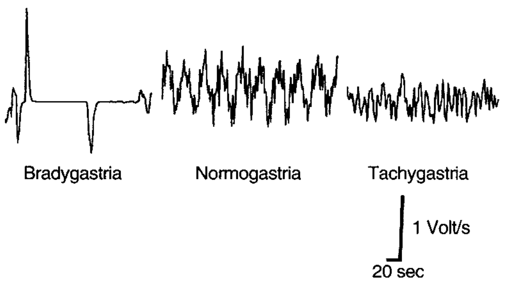

Fig. 1. Shapes of myoelectrical potentials to individual frequency of bradygastria, normogastria, and tachygastria in postprandial EGG.
Calibration is 1 Volt/s. Positive up. Duration is 20 seconds.

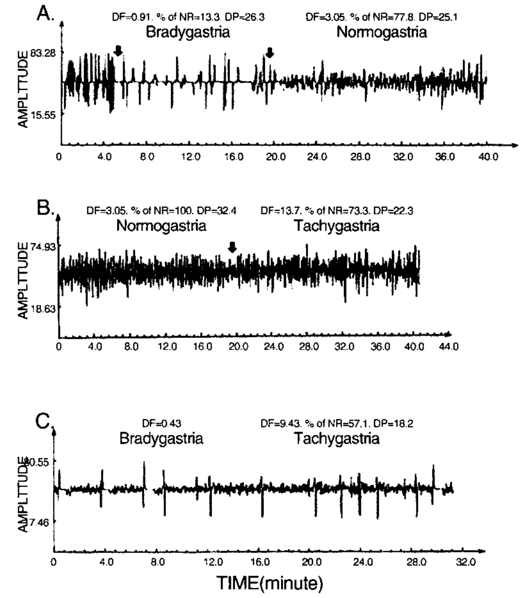

Fig. 2. Typical recordings showing spontaneous switchover of slow wave frequency in postprandial EGG.
A is transposition of bradygastria to normogastria (B-N type). Pure bradygastric duration was maintained for 14 min. 6 min after starting of record was excluded because of patient' s motion artifact. Single bradygastric frequency was often seen in normogastric region in keeping regular interval.
B is transposition of normogastria to tachygastria (N-T type), duration of tachygastria was 12 min.
C is a case of mixed bradygastria-tachygastria (MBT type). % Of normal regularity and power ratio in bradygastria could not be calculated. Arrow indicates the switchover point.
DF is dominant frequency; NR, normal regularity; DP, dominant power.

Table 1. Change of Myoelectrical Activity to Frequency Situation of Slow Waves in Frequency Switchover

Type	Average myoelectrical activity per frequency(Volts/s)				Average accumulated myoelectrical activity of 5 min(Volts/s)			
	Bradygastria	Normogastria	Tachygastria		Bradygastria	Normogastria	Tachygastria	
B - N	1.47±0.55	0.50±0.10		$P<0.01$	51.94±20.49	114.90±55.85		$P<0.01$
N - T		0.82±0.22	0.44±0.12	$P<0.01$		126.29±42.61	90.00±30.78	$P<0.01$
MBT	1,10±0.29		0.47±0.21	$P<0.01$	12.93± 8.45		71.02±38.31	$P<0.01$

All data is mean±S.D. B-N type is a case switchovered from bradygastria to normogastria(N=3); N-T, from normogastria to tachygastria(N=3); MBT is a case of mixed bradytachyarrhythmias(N=3). P value was obtained by Mann-Whitney test.

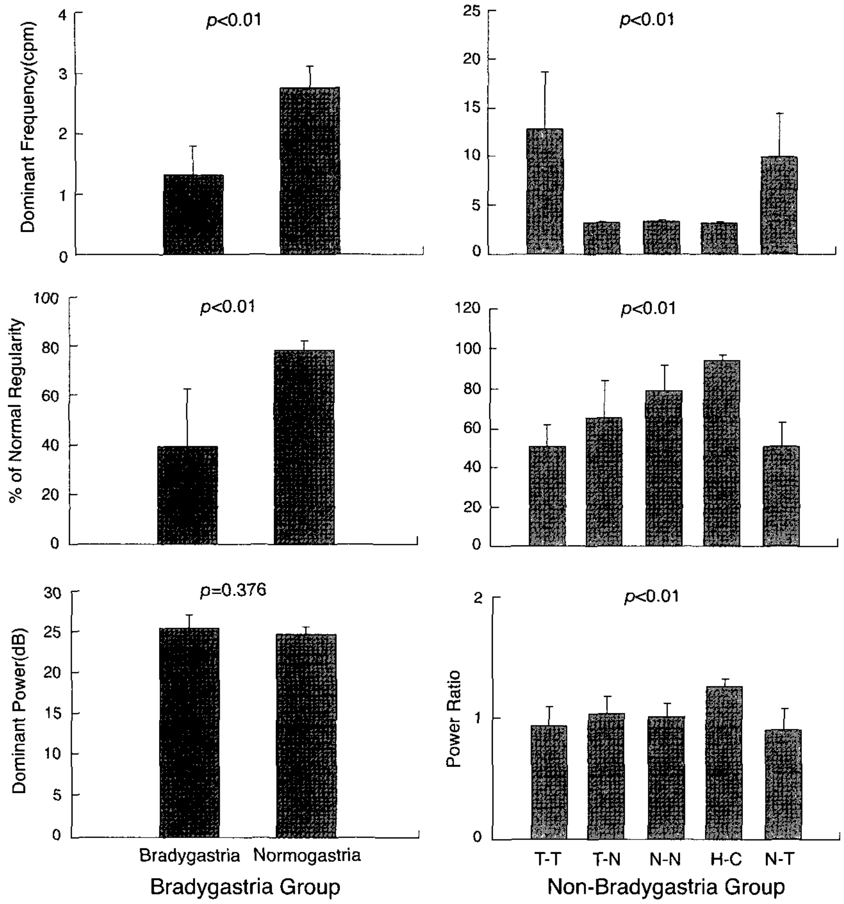

Fig. 3. Linkage of EGG parameters.

Left column shows bradygastria-normogastria relationship. Parameters were obtained from each of EGG segmentum seen in the course of frequency transposition (N=3;duplicated in Table 1).

Right column is for tachygastria-normogastria relationship. According to state of dominant frequency before and after eating, patients were divided into 4 patterns, T-T (tachygastria-tachygastria, N=13), T-N (tachygastria-normogastria, N=27), N-N (normogastria-normogastria, N=54), and N-T(normogastria-tachygastria, N=10).

H-C indicates normal healthy controls (N=10). Postprandial EGG parameter was used for statistical comparison. All data is mean ± SD. *P* value was obtained by Mann-Whitney and Kruskal-Wallis test.

bradygastria group showed statistical significance (0.93 ±0.16 vs. 1.10±0.15 vs. 1.09±0.19 vs. 0.92±0.17 folds, *p*<0.01). Power ratio in normal healthy controls was 1.26±0.07 folds(Fig. 3).

Segmental analysis during frequency transposition of slow wave showed similar tendency like the result of groups mentioned above: B-N type, which transited from bradygastria to normogastria, showed increased DF from 0.91cpm to 3.05 cpm, increased % of normal regularity from 13.33 to 77.8%, and nearly unchanged power ratio from 26.3 to 25.1 dB. N-T type, from normogastria to tachygastria, showed increased DF from 3.05 to 13.71 cpm, decreased % of normal regularity of 100 to 73.3%, and decreased power ratio of 32.4 to 22.3 dB. MBT type, in which bradygastria-tachygastria are mixed, showed dominant frequency of

0.43 cpm in bradygastria; dominant frequency of 9.43 cpm, % of normal regularity of 57.1% and dominant power of 18.2 dB in tachygastria(Fig. 2).

Discussion

This study was done to explore the reason why dominant power (or power ratio) in EGG does not entirely correspond to the real gastric contraction in the stomach.

To achieve the purpose of this study, the changes between gastric myoelectrical activity and EGG parameters were investigated in frequency transposition of slow waves, and validity of parameter correlation was evaluated in patients with functional dyspepsia.

Dominant frequency in EGG reflects that of slow waves[15]. Physiologic basis for slightly elevated frequency of slow waves after eating in normal health has not been well known[16,17]. However, in clinical practice, dysrhythmias related with dysmotility disorders such as functional dyspepsia[8-12], gastroparesis[18,19], and intestinal pseudoobstruction[20] have received more attention since the first report in 1978 [21]. Pathologic tachygastria is related to gastric hypomotility, but relation of bradygastria and gastric motility is still obscure[6].

To know the differences in dysmotility between bradygastria and tachygastria, we examined potential shape and gastric myoelectrical activity per frequency of each bradygastria, normogastria, and tachygastria in patients with functional dyspepsia. The results of dysrhythmic shapes in this study were well consistent with those of previous studies done in humans[22] and in animals[23,24], which showed larger amplitude and longer interval in bradygastria, and smaller and irregular form in tachygastria. We noticed peculiar aspects, including a biphasic shape of electrical potential in bradygastria. Though stimuli of the vagal nerve in EGG is reflected as the elevated amplitude of slow waves[25], potential shape of surface EGG in bradygastria might be dependent more on the effect produced by the slow wave itself than the excessive excitation of nerve activity. The lesser dependence of nerve activity in bradygastria was presumed to be shown because EGG measurement was done in the same condition in every patient. The magnitude of the contractile event in the antrum is dependent on the amplitude and duration of the depolarization achieved during the plateau phase of slow wave[26]. There were no clues to understanding the biphasic appearance of potentials in bradygastria; nevertheless, this study suggests the possibility that it may originate from direct excitation of gastric muscle by slow wave potentials.

In general, amplitude of slow wave in antrum is primarily dependent on the occurrence site of frequency such as pacesetter or ectopic region. A certain extent of amplitude in antrum may be velocity propagation-dependent. Its velocity propagation-dependency cannot help being explained by relation of frequency, duration, and moving distance of slow waves in the stomach. Nevertheless, there are various evidences supporting our hypothesis without direct measurement of their relation. There is a report that amplitude of slow waves is increased with the increase of velocity[1]. Especially, increase in potentials of bradygastria in the antrum may be due to velocity propagation-dependency or due to episodes of compensatory pause associated with advent of tachygastria or normogastria[24]. Canine in vitro experiments confirmed that when the interval between slow waves is longer, conduction velocity is rapid; tachygastria with shortened interval and lowered amplitude is associated with slowed velocity[2,27].

These findings seem to suggest a positive relationship between velocity propagation in the antrum and myoelectrical activity.

On the other hand, total accumulated contractility is thought to be more important in dynamics of the digestive process, because it is directly related to the amount of the job carried out by the stomach itself. From this basis, we compared the 5 min recordings of accumulated gastric myoelectrical activities among bradygastria, normogastria, and tachygastria. Contrary to the amplitude of frequency, average accumulated myoelectrical activity was highest in normogastria and lowest in bradygastria. This result in myoelectrical activity indicates that actual gastric contraction associated with digestion may depend more on amount of accumulated electrical potentials than the state of electrical potential per frequency. Thus, the frequency of slow waves seems to affect the efficiency of myoelectrical activity in gastric motility. This result also indicates that dyspeptic patients with bradygastria may have the worst symptoms among the three kinds of dyspeptic patients. As frequency of slow wave is one of the factors that define the effectiveness of gastric muscle contraction, DF must be preferentially considered more than % of normal regularity and dominant power in assessing the gastric motility. Regretfully, DF seems to be regarded as less applicable as an index in the assessment of actual gastric motility.

% of normal regularity and power ratio, unlike dominant frequency, have been widely used as parameters in discriminating the effects of prokinetic drugs[28,29], gastric pacing[30], electroacupuncture stimulation[31,32], and other measurements[33,34] in gastric motility assessment. % of normal regularity reflects degree of regulation in gastric slow waves, which is defined as percentage of the events of 2-4 cpm time slow waves through the entire recording. Increased % of normal regularity in healthy controls after eating rather than fasting[8,9,12,35] may be attributable to improved gastric motility. When frequency of slow waves is either increased or decreased abnormally, dropping of % of normal regularity in both cases must confirm the obvious presence of the necessary-sufficient condition as an index for the gastric motility assessment.

Though there has not been enough comment on parameter changes in dyspeptic patients with bradygastria until recently, the finding of accumulated myoelectrical activity enabled us to understand the condition of bradygastric motility fairly well. In addition, the accumulated myoelectrical activity suggested that functional dyspeptic patients with normogastria might have variety of gastric contractilities because EGG defines a wide range of 2-4 cpm as normal slow waves. If gastric motility can be modulated by the extrinsic and intrinsic factors that regulate the spread of slow waves[36], it is necessary for EGG to have narrower range of normal slow wave frequency that guarantees equal gastric contraction.

Power ratio represents fasting vs. postprandial rate in dominant power, and amplitude of dominant power has been regarded as the parameter reflecting the gastric contraction. Current opinion is that power ratio cannot reflect gastric contractility entirely; decreased power ratio is merely related to hypomotility[6]. There is no clear explanation for this. Moreover, its changes in bradygastria-normogastria cases discussed before in the study have never been introduced, like DF and % of normal regularity.

Average power ratio in patients with functional dyspepsia was decreased more than that of healthy controls, which is consistent with previous findings[37]. Almost unchanged dominant power was shown in bradygastria regardless of changes in slow wave frequency, while power ratio in tachygastria-normogastria was proportionally dependent on DF and % of normal regularity. This study clearly revealed that dominant power does not always reflect the actual gastric contraction related with myoelectrical activity. It was an interesting finding that bradygastric dominant power is nearly the same level as in normogastria. This event could not be interpreted by any of the myoelectrical activities in this study. Hence, we believe that dominant power concomitantly reflects both gastric contractility related with electrical activity and another effect not related with electrical activity in gastric smooth muscle. Even though we have no relevant explanations for similar dominant power between them and another effect, Koch' s result suspected the extensibility of muscle portion not involved into direct contraction in gastric smooth muscle. He reported that diet constitution could influence the changes of power ratio, demonstrating that 60% barium meal reveals constant power ratio of 1 cpm independent of time course but not in 45% barium meal[38]. At any rate, Koch' s and our results led to the conclusion that power ratio does not have a necessary and sufficient condition as an index, and that it is not a fully reliable parameter for the assessment of gastric motility in EGG. Accordingly, a new perspective on dominant power and power ratio may be needed when understanding its physiologic background and role in EGG.

In summary, this study showed that the incomplete relationship between dominant power of electrogastrography and gastric myoelectrical activity appears in bradygastria of patients with functional dyspepsia and dominant power does not always accept the gastric myoelectrical activity related with gastric contraction. It seems that DF and % of normal regularity have validity as indices for the assessment of gastric motility in electrogastrography.

References

1. Hinder RA, Kelly KA. Human gastric pacesetter potential. Site of origin, spread and response to gastric section and proximal gastric vagotomy. Am J Surg. 1978;116:29-33.
2. Publicover NG, Sanders KM. Effects of frequency on the wave from of propagated slow waves in canine gastric antral muscle. J Physiol. 1986;371:179-189.
3. Chen JD, McCallum RW. Clinical applications of electrogastrography. Am J Gastroenterol. 1993;88(9): 1324-1336.
4. Chen JD, Richard R, McCallum RW. Identification of gastric contractions from the cutaneous electrogastrogram. Am J Gastroenterol. 1994;89(1):79-85.
5. Lin Z, Chen JDZ, Schirmer BD, McCallum RW. Postprandial response of gastric slow waves: correlation of serosal recordings with the electrogastrogram. Dig Dis Sci. 2000; 45(4):645-651.
6. Chen JDZ, McCallum RW. Electrogastrographic parameters and the clinical significance in Electrogastrography: principles and applications. New York: Raven. 1994:45-73.
7. Chen JD, Ke MY, Lin XM, Wang Z, Zhang M. Cisapride provides symptomatic relief in functional dyspepsia associated with gastric myoelectrical abnormality. Aliment Pharmacol Ther. 2000;14(8): 1041-1047.
8. Lin X, Levanon D, Chen JDZ. Impaired postprandial gastric slow waves in patients with functional dyspepsia. Dig Dis Sci. 1998;43(8):1678-1684.
9. Lu CL, Chen CY, Chang FY, Kang LJ, Lee SD, Wu HC, Kuo TS. Impaired postprandial gastric myoelectrical activity in Chinese patients with nonulcer dyspepsia. Dig Dis Sci. 2001; 46(2):242-249
10. Pfaffenbach B, Adamek RJ, Bartholomaus C, Wegener M. Gastric dysrhythmias and delayed gastric emptying in patients with functional dyspepsia. Dig Dis Sci. 1997;42(10): 2094-2099.
11. Lin Z, Chen JDZ, Parolisi S, Shifflett J, Peura DA, McCallum RW. Prevalence of gastric myoelectrical abnormalities in patients with nonulcer dyspepsia and H. pyloric infection. Dig Dis Sci. 2001;46(4):739-745.
12. Chen JD, Lin X, Zhang M, Torres-Pinedo RB, Orr W. Gastric myoelectrical activity in healthy children and children with functional dyspepsia. Dig Dis Sci. 1998;43(11):2384-2391.
13. Chen J. A computerized data analysis system for electrogastrogram. Com Biol Med. 1992; 22:45-58.
14. Chen J, Stewart WR, McCallum RW. Adaptive spectral analysis of episodic rhythmic variations in gastric myoelectrical potentials. IEEE Trans Biomed

Eng. 1993;40: 128-135.
15. Hamilton JW, Bellahsene BE, Reichelderfer M, Webster JG, Bass P. Human electrogastrograms: comparison of surface and mucosal recordings. Dig Dis Sci. 1986;31(1):33-39.
16. Pfaffenbach B, Adamek RJ, Kuhn K, Wegener M. Electrogastrography in healthy subjects; evaluation of normal values, influence of age and gender. Dig Dis Sci. 1995;40(7): 1445-1450.
17. Levanon D. Zhang M, Chen JDZ. Efficiency and efficacy of the electrogastrogram. Dig Dis Sci. 1998; 43(5):1023-1030.
18. Chen J, McCallum RW. Gastric slow wave abnormalities in patients with gastroparesis. Am J Gastroenterol. 1992;87(4):477-482.
19. Abell TL, Camilleri M, Malagelada JR. High prevalence of gastric electrical dysrhythmias in diabetic gastroparesis. Gastroenterology. 1985;88: A1299.
20. Debinski HS, Ahmed S, Milla PJ, Kamm MA. Electrogastrography in chronic intestinal pseudo-obstruction. Dig Dis Sci. 1996;41(3):508-515.
21. Telander RL, Morgan KG, Kreulen DL, Schemalz PF, Kelly KA, Szurszewski JH. Human gastric atony associated with tachygastria and gastric retention. Gastroenterology. 1978;75: 495-501
22. You CH, Chey WY. Study of electromechanical activity of the stomach in human and in dogs with particular attention to tachygastria. Gastroenterology. 1984;86(6):1460-1468.
23. Kim CH, Azproz F, Malagelada JR. Characteristics of spontaneous and drug induced gastric dysrhythmias in a chronic canine model. Gastroenterology. 1986;90(2): 421-427.
24. Qian LW, Pasricha PJ, Chen JDZ. Origins and patterns of spontaneous and drug-induced canine gastric myoelectrical dysrhythmias. Dig Dis Sci. 2003;48(3): 508-515.
25. Cooker AR. Control of gastric emptying and motility. Gastroenterology. 1975;68:804-816.
26. Szurszewski JH. Electrical basis for gastrointestinal motility. In: Johson LR, ed. Physiology of the gastrointestinal tract. New York: Raven. 1981:1435-1466.
27. Sarna SK, Daniel EE. Electrical stimulation of gastric electrical control activity. Am J Physiol. 1973;225: 125-131.
28. Rothstein RD, Alavi A, Reynolds JA. Electrogastrography in patients with gastroparesis and effect of long-term cisapride. Dig Dis Sci. 1993;38(8):1518-1524.
29. Chen J, Yeaton P, McCallum RW. Effect of erythromycin on gastric myoelectrical activity in normal human subjects. Am J Physiol. 1992;263(1 pt 1):G24-G28.
30. Qian L, Lin X, Chen ZDL. Normalization of atropine-induced postprandial dysrhythmias with gastric pacing. Am J Physiol. 1999;276:G387-G392.
31. Lin X, Liang J, Ren J, Mu F, Zhang M, Chen JDZ. Electrical stimulation of acupuncture points enhances gastric myoelectrical activity in humans. Am J Gastroenterol. 1997; 92(9):1527-1530.
32. Chang CS, Ko CW, Wu CY, Chen GH. Effect of electrical stimulation on acupuncture points in diabetic patients with gastric dysrhythmia: a pilot study. Digestion. 2001;64(3):184-90.
33. Chen JDZ, Pan J, Orr WC. Role of sham feeding in postprandial changes of gastric myoelectrical activity. Dig Dis Sci. 1996;41(9):1706-1712.
34. Lu CL, Shidler N, Chen JDZ. Enhanced postprandial gastric myoelectrical activity after moderate-intensity exercise. Am J Gastroenterol. 2000;95:425-431.
35. Leahy A, Besherdas K, Clayman C, Mason L, Epstein O. Abnormalities of the electrogastrogram in functional gastrointestinal disorders. Am J Gastroenterol. 1999;94(4):1023-1028.
36. Publicover NG, Sanders KM. Myogenic regulation of propagation in gastric smooth muscle. Am J Physiol. 1985;248(5 Pt 1):G512-520.
37. Camilleri M, Hasler W, Parkman HP, Quigley EM, Soffer E. Measurement of gastrointestinal motility in the GI laboratory. Gastroenterology. 1998;115:747-762.
38. Koch KL, Stewart WR, Stern RM. Effect of barium meals on the gastric electromechanical activity in man; a fluroscopic-electrogastrographic study. Dig Dis Sci. 1987; 32(11):1217-1222.