

Correlation of electrogastrography and gastric emptying rate estimated by ^{13}C -octanoic acid breath test in healthy volunteers

Jan Bureš¹, Marcela Kopáčová¹, Viktor Voříšek², Josef Bukač³, David Neumann⁴, Pavel Živný², Vladimír Palička², Stanislav Rejchrt¹

¹2nd Department of Internal Medicine, Charles University in Praha, Faculty of Medicine at Hradec Králové, University Teaching Hospital, Hradec Králové, Czech Republic

²Institute of Clinical Biochemistry and Diagnostics, Charles University in Praha, Faculty of Medicine at Hradec Králové, University Teaching Hospital, Hradec Králové, Czech Republic

³Department of Medical Biophysics, Charles University in Praha, Faculty of Medicine at Hradec Králové, Czech Republic

⁴Department of Paediatrics, Charles University in Praha, Faculty of Medicine at Hradec Králové, University Teaching Hospital, Hradec Králové, Czech Republic

Summary

Gastric emptying is one of the most important motor functions of the gastrointestinal tract. Direct measurement of gastric emptying is considered to be a crucial diagnostic test for gastrointestinal motor dysfunction. The aim of this prospective project was to assess possible correlation of electrogastrography and ^{13}C -octanoic acid breath test as a measure of gastric emptying in healthy adult volunteers (5 men and 5 women, aged 20-48 years, mean 32; 50 % of subjects were *Helicobacter pylori*

positive). There was a significant negative correlation between half-life of elimination in ^{13}C -octanoic acid breath test (using a solid test meal) and percent activity of normal rhythm in postprandial electrogastrography recording ($r = -0.632$; $p = 0.0498$). *Helicobacter pylori* negative subjects had a higher percent activity of a normal rhythm and faster gastric emptying of solids compared to *Helicobacter pylori* positive persons, this difference was not statistically significant. In conclusion, electrogastrogra-

phy and gastric emptying rate, assessed by ^{13}C -octanoic acid breath test, are suitable non-invasive complementary methods to investigate the motor function of the stomach. The major parameters of electrogastrography and half-life of elimination (in ^{13}C -octanoic acid breath test) mutually correlate in healthy subjects.

KEY WORDS: GASTRIC EMPTYING, ^{13}C -OCTANOIC ACID BREATH TEST, ELECTROGASTROGRAPHY, HEALTHY VOLUNTEERS

Souhrn

Korelace elektrogastrografie a rychlosti žaludeční evakuace stanovené dechovým testem s kyselinou ^{13}C -oktanovou u zdravých dobrovolníků

Evakuace žaludku je jednou z nejdůležitějších motorických funkcí gastrointestinálního traktu. Přímé měření žaludečního vyprazdňování má zásadní význam pro diagnostiku dysmotilitních poruch trávicího ústrojí. Cílem této prospektivní studie byla korelace elektrogastrografie a dechového testu s kyselinou ^{13}C -oktanovou jako ukazatele žaludeční evakuace u zdravých dospělých dobrovolníků (5 mužů, 5 žen, ve

věku 20–48 let, průměr 32; 50 % osob bylo *Helicobacter pylori* pozitivních). Byla zjištěna statisticky významná negativní korelace poločasu eliminace (dechového testu s kyselinou ^{13}C -oktanovou při použití pevného testačního pokrmu) s procentuálním zastoupením normálního rytmu při postprandiálním záznamu elektrogastrografie ($r = -0,632$; $p = 0,0498$). U *Helicobacter pylori* negativních osob bylo vyšší procentuální zastoupení normálního rytmu a rychlejší žaludeční vyprazdňování pevné potravy ve srovnání s *Helicobacter pylori* pozitivními osobami, tento rozdíl však

nebyl statisticky významný. Elektrogastrografie a rychlost žaludeční evakuace, stanovená dechovým testem s kyselinou ^{13}C -oktanovou, jsou vhodné neinvazivní, navzájem se doplňující metody k vyšetření motorické funkce žaludku. Hlavní ukazatele elektrogastrografie a poločas eliminace dechového testu s kyselinou ^{13}C -oktanovou spolu u zdravých osob navzájem korelují.

KLÍČOVÁ SLOVA: EVAKUACE ŽALUDKU, DECHOVÝ TEST S KYSELINOU ^{13}C -OKTANOVOU, ELEKTROGASTROGRAFIE, ZDRAVÍ DOBROVOLNÍCI

INTRODUCTION

Gastric emptying is one of the most important motor functions of the gastrointestinal tract. Direct measure-

ment of gastric emptying is considered to be a crucial diagnostic test for gastrointestinal motor dysfunction. Scintigraphy has been assumed to be

a “gold standard” for gastric emptying evaluation to date [7,53]. However, it needs expensive equipment and induces a significant radiation burden [46].

Octanoic acid, an eight-carbon medium-chain fatty acid, is not absorbed from the stomach. However, once it reaches the duodenal lumen, octanoic acid is rapidly absorbed through intestinal mucosa and oxidised to CO₂ in the liver. Ghoo et al [20] proposed a radioactive carbon-labelled octanoic acid breath test for non-invasive measurement of gastric emptying rate of solids. Subsequently radioactive carbon ¹⁴C has been replaced by ¹³C. Carbon ¹³C is a non-radioactive, natural and stable isotope and thus its use has been widely recommended both for research and clinical practice [56]. Several breath tests with stable isotopes have been developed to reliably assess gastric emptying of both solids and liquids [46]. Breath tests using ¹³C-labelled test meals are based on the principle that the gastric emptying of the tracer substance proceeds simultaneously with the emptying of the labelled phase of the test meal. After delivery from the stomach the tracer is rapidly absorbed and oxidised to labelled carbon dioxide which is rapidly exhaled [3,19]. Because gastric emptying is the rate-limiting step for the absorption of medium-chain fatty acids, the fraction of ¹³C expired in the breath (as ¹³CO₂) indicates the rate of gastric emptying [58]. In spite of several different protocols published, the ¹³C-octanoic acid breath test has not been standardized yet. We developed our own method of the ¹³C-octanoic acid breath test [6], expressing results of the breath test as a half-life of elimination. The half-life of elimination (t^{1/2}E) of the administered carbon ¹³C (in minutes) is a linear function of half-time of gastric emptying, duodenal absorption, transport and intermediate metabolism of ¹³C-octanoic acid [6,13]. According to different studies, the intermediate metabolism of ¹³C-octanoic acid represents 66 min [20] or 76.5 ± 7.5 min in adult subjects [6].

Surface electrogastrography (EGG) is a non-invasive method for clinical assessment of gastric myoelectrical activity. Neuromuscular activities of the stomach generate electrical phenomena termed “gastric slow waves”. They originate in a “pacemaker region” located on the greater curvature of the stomach near the junction of the fundus and proximal gastric corpus. The normal gastric slow-wave frequency is 3 cycles per minute (a 3-cpm rhythm) [8,9,11,12,18,27].

Simultaneous investigation of both EGG and ¹³C-octanoic acid breath test may be useful to evaluate the efficiency of gastric emptying and underlying myoelectrical activity [49]. However, the relationship of EGG and gastric emptying rate remains controversial [2,39,50]. The aim of this prospective project was to assess possible correlation of EGG and ¹³C-octanoic acid breath test as a measure of gastric emptying in healthy adult volunteers.

METHODS

Healthy volunteers

Ten healthy volunteers entered the study, 5 men and 5 women (aged 20-48 years, mean 32). 50 % of subjects were *Helicobacter pylori* positive. All persons underwent all EGG and 2 ¹³C-octanoic acid breath tests (one with a solid meal and another one with a semi-solid test meal) within two weeks.

Electrogastrography

Surface cutaneous EGG was recorded using a Digitrapper EGG (Synectics Medical AB, Stockholm, Sweden) in the morning both fasting (30 min) and after meals (30 min). The standard solid test meal was used containing scrambled egg (+ 3 g of sunflower oil), white bread (40 g), butter (10 g) and still water (200 mL), with a total energy value of 1,178 kJ [29]. Patients were lying in a supine position during the EGG recording. Running spectral analysis (based on Fourier transform)

was used for the evaluation of the EGG. Results were expressed as running spectrum percent activity. Spectral peaks were classified into 4 rhythm categories: bradygastria (EGG wave pattern < 2.4 cycles per minute - cpm), normal slow-wave rhythm (2.4–3.6 cpm; normal three-cycle per minute rhythm), tachygastria (3.6–9.9 cpm) and duodenal rhythm (10–15 cpm) [27].

The ¹³C-octanoic acid breath test

The ¹³C-octanoic acid breath test was performed using 100 mg ¹³C-sodium octanoate (Cambridge Isotope Laboratories, Andover, USA) for each test. The solid test meal was of the same content and energy as that for EGG. The semi-solid meal (1,020 kJ) contained milk pudding (200 g) and still water (200 mL). Duplicate breath samples were obtained before (time zero) and every 15 min after eating the test meal during the following 255 min. Altogether 720 breath samples were analysed twice by means of isotope ratio mass spectrometry (AP 2003, Analytical Precision, Northwich, United Kingdom). Mass spectrometry results were expressed as the difference of ¹³CO₂/¹²CO₂ ratios in the measured sample of exhaled breath and reference gas (SIAD Szendioxid, MSZ 209 15; CO₂ 99.995 %). Helium was used as a carrier (SIAD 6.0; He > 99.9995 %). The baseline value at time was zero (δ_0) and particular values at relevant time t (δ_t) were used for calculation of both tests in all subjects [6]. To assess the half-life of elimination (t^{1/2}E), we modelled the process of elimination with the incomplete gamma-function, which has a convenient form for the empirical plotting of breath test data [42].

Helicobacter pylori status

Helicobacter pylori status was investigated by means of ¹³C-urea breath test. Citric acid solution (3 g dissolved in 150 mL of still water) was used as a test drink [30]. All subjects ingested

100 mg ^{13}C -urea (Helicobacter Test Hp Plus, Utandningstester i Sverige AB, Göteborg, Sweden) dissolved in 50 mL of still water with 1 g citric acid. Baseline and test breath samples were collected in duplicate at time 0 and after 30 min. Breath samples were analyzed twice by means of isotope ratio mass spectrometry (AP 2003, Analytical Precision, Northwich, United Kingdom). Cut-off was 3.5 (grey zone range 3.3–3.7). No borderline or discrepant results were found.

Statistical analysis

Data were statistically treated by means of descriptive statistics, paired t-test and Spearman rank order correlation using the SigmaStat software (Jandel Corp., Erkrath, Germany).

RESULTS

The overall results of ^{13}C -octanoic acid breath test and EGG are given in Tabs 1 and 2. The half-life of elimination using a solid test meal was significantly longer compared to a semi-solid test meal ($p < 0.001$). Running spectrum percent activity of EGG was not significantly different in fasting and postprandial recording and they did not correlate mutually. There was a significant negative correlation between half-life of elimination in ^{13}C -octanoic acid breath test (using a solid test meal) and a 3-cpm percent activity in

postprandial EGG recording ($r = -0.632$; $p = 0.0498$). There was no correlation between running spectrum percent activity and half-life of elimination when a semi-solid test meal was used, see Figure for details. There were no significantly different results between men and women. Helicobacter pylori negative subjects had a higher percent activity of a 3-cpm rhythm and faster gastric emptying of solids compared to Helicobacter pylori positive persons (Tab. 3). However, this difference was not statistically significant.

DISCUSSION

The aim of our study was to estimate possible correlation of EGG and ^{13}C -octanoic acid breath test as a measure of gastric emptying in healthy adult volunteers. EGG is a non-invasive means of recording human gastric myoelectrical activity or slow waves from cutaneous leads placed over the stomach. In healthy volunteers, EGG exhibits sinusoidal waveforms with a predominant frequency of 3 cycles per minute. Some patients with nausea, vomiting, or other dyspeptic symptoms exhibit EGG rhythm disturbances or blunting of meal-evoked EGG signal amplitude increases. These abnormalities correlate to some degree with delayed gastric emptying of solids. In selected patients, EGG may be complemen-

tary to gastric emptying testing [44,60].

The gastric emptying of solid, semi-solid and liquid meals differs greatly. Storing of solids (predominantly in the fundus) causes a characteristic lag phase before the emptying as a suspension of small particles starts in an approximately linear fashion. The gastric emptying of liquids follows a non-linear exponential pattern and it is more affected by volume and gravity [3]. Gastric slow waves control the frequency and propagation of the gastric contractions. Since the dominant EGG frequency reflects the frequency of the gastric slow waves, this dominant frequency is associated with gastric motility and determines the maximum frequency of gastric contractions [10,16,26].

In our study, normal 3-cpm rhythm (2.4–3.6 cpm) for > 60 % of recording time during fasting was found in 7/10 (for > 70 %: 6/10) healthy subjects. In the first postprandial 30 min, normal 3-cpm rhythm (2.4–3.6 cpm) for > 60 % of recording time was found in 6/10 (for > 70 %: 4/10) healthy volunteers. The lower limit (mean minus 2 SD) of percentage time of normal 3-cpm rhythm in our setting was 60 % (in fasting) and 55 % (in postprandial period), respectively. According to the American Motility Society [44], normal EGG frequency (2.0–4.0 cpm) should

Table 1 Electrogastronomy in ten healthy adult subjects. Results are given as running spectrum percent activity (mean \pm standard deviation).

Recording	3-cpm	Bradycardia	Tachycardia	Duodenal activity
Fasting	72.8 \pm 16.9	8.4 \pm 5.5	18.8 \pm 13.2	0
Postprandial	66.3 \pm 15.6	6.9 \pm 6.8	27.1 \pm 15.2	0

Note: 3-cpm - three cycles per minute

Table 2 Results of ^{13}C -octanoic acid breath test (half-life of elimination in minutes) in ten healthy adult volunteers.

^{13}C -OABT	Mean	Std. Dev.	Median	IQR
Solid test meal	136	10.5	136	135–143
Semi-solid test meal	123	16	121	106–135.5

Note: ^{13}C -OABT – ^{13}C -octanoic acid breath test; Std. Dev. – standard deviation; IQR – inter-quartile range

Table 3 Results of ¹³C-octanoic acid breath test (half-life of elimination in minutes) and EGG recording in Helicobacter pylori positive and negative healthy adult subjects.

Parameter	Fasting EGG 3-cpm (in per cent activity)	Postprandial EGG 3-cpm (in per cent activity)	¹³ C-OABT using a solid test meal (in minutes)	¹³ C-OABT using a semi-solid test meal (in minutes)
Helicobacter pylori positive subjects	65.3 ± 14.3	57.3 ± 8.1	141.5 ± 8	111.5 ± 8
Helicobacter pylori negative subjects	80.3 ± 17.2	75.3 ± 16.7	131 ± 10	112 ± 8

Note: 3-cpm - three cycles per minute

comprise ≥ 70 % of recording time. This 70% value is based on 4 studies that had lower limits (mean minus 2 SD) of 100, 58, 65 and 79 % [10,35, 43,48]. Neither these studies nor the document of the American Motility Society consider the Helicobacter pylori status of healthy subjects. This issue still remains rather controversial. The possible impact of Helicobacter pylori infection on EGG is discussed below.

EGG (recording of 30–60 min) is appropriate and produces reliable and predictable results [33]. We are aware of some possible limits of our study. Frequency analysis of the gastric slow waves exhibits only good to moderate reproducibility [23]. Short-term reproducibility of the postprandial time share of normogastria showed 86% agreement [23]. We did not evaluate the postprandial-to-fasting power ratio [55], frequency dynamics are considered to be a more reliable EGG parameter by some authors [38,39]. In a 24-hour EGG recording in healthy volunteers the gastric slow-wave rhythm is omnipresent but short periods of tachygastria could be found (not associated with any symptoms). A stable dominant frequency (for > 60 % of the time) was found only in one quarter of healthy volunteers. Dominant frequency varies during the day (maximum frequency at midday and minimum frequency during the night) [36]. All our EGG recordings were performed in the morning.

The possible relationship between EGG and gastric emptying also

remains controversial [2,27,28,39, 50]. There could probably be a difference between healthy status and disease (i.e. diabetes mellitus, systemic sclerosis, functional dyspepsia, gastrectomy etc.). We have found a significant negative correlation between the half-life of elimination in ¹³C-octanoic acid breath test (using a solid test meal) and a 3-cpm percent activity in postprandial EGG recording. Similar results in healthy subjects were also published by Hongo et al [22]. All postprandial peristalsis, gastric contractile force were reduced and gastric emptying delayed in elderly compared to young healthy volunteers. The ¹³C-acetate breath test, another test of gastric emptying, was used in that study [51]. However, other studies found no age or gender related difference in EGG recordings [33,54]. In an experimental setting in dogs, gastric emptying correlated with the strength of gastric contractions in a frequency range identical to that of the gastric slow waves (major parameter of gastric myoelectrical activity) [61].

A lot of papers on EGG and gastric emptying in miscellaneous diseases have been published. Functional dyspepsia represents the most controversial issue in this aspect.

A high proportion of adult patients with functional dyspepsia (up to 60 %) had delayed gastric emptying (assessed by scintigraphy) and abnormalities in gastric myoelectrical activity [35, 47]. Parkman et al [45] studied EGG and solid-phase gastric emptying scintigraphy in functional dyspepsia.

The EGG was abnormal in 11/22 (50 %) patients with delayed gastric emptying compared with 11/50 (22 %) with normal gastric emptying. The total symptom scores were higher in patients with both delayed gastric emptying and abnormal EGG [45]. 60 % of 30 children with functional dyspepsia had either slow gastric emptying (47 %) or abnormal EGG (50 %). Gastric emptying negatively correlated with fasting bradygastria. Gastric emptying was delayed in 73 % of patients with an abnormal EGG but was slow in only 20 % of subjects with normal EGG [17]. Van der Voort et al [59] investigated functional dyspepsia, irritable bowel syndrome and healthy controls. Disturbed gastric emptying correlated with a lack of postprandial increase in the EGG amplitude. Prokinetics (erythromycin) improved both gastric emptying and gastric electrical activity [59]. Gastric slow waves correlated negatively with gastric emptying (assessed by radionuclide scintigraphy) in functional dyspepsia according to another study [62]. However, negative studies in functional dyspepsia have also been published. EGG and gastric emptying scintigraphy did not correlate in children with vomiting and/or abdominal pain [1].

EGG values obtained in type-2 diabetics did not correlate with simultaneous radionuclide scintigraphy (40 % with delayed gastric emptying) [48]. Cucchiara et al [14] found a significant inverse correlation between gastric emptying rate and fed-to-fasting

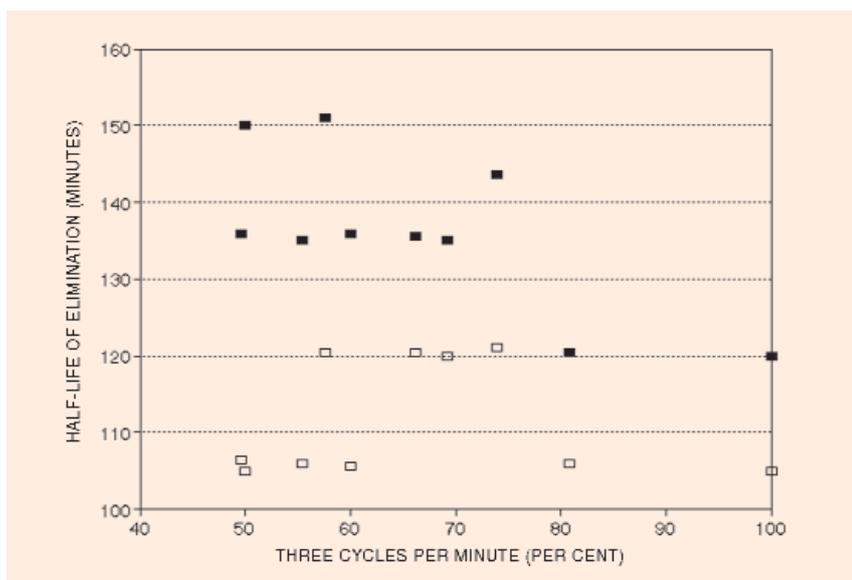


Figure
Results of ^{13}C -octanoic acid breath test (half-life of elimination in minutes) and electrogastrography (postprandial recording: three cycles per minutes in per cent) in ten healthy volunteers.
Closed symbols - solid test meal, open symbols - semi-solid test meal used.

ratio of the dominant EGG power both in type-1 diabetic children and healthy control subjects. Gastric emptying was delayed in 26/40 (65 %) diabetics and EGG dysrhythmias were more frequent compared to healthy children. Even more there was a significant correlation between serum glycosylated haemoglobin (HbA_{1c}) and gastric emptying delay [14].

Adolescent patients with bulimia who complained of dyspeptic symptoms had EGG abnormalities and delayed gastric emptying (assessed by scintigraphy). These abnormalities were not found in anorexia nervosa [15].

Half of our healthy volunteers were *Helicobacter pylori* positive. That reflects the current prevalence of *Helicobacter pylori* in the Czech Republic (42 %) [5]. In this study *Helicobacter pylori* negative subjects had higher percent activity of a 3-cpm rhythm and faster gastric emptying of solids compared to *Helicobacter pylori* positive persons. However, this difference was not statistically significant, probably due to a limited number of studied subjects. Possible influence of *Helicobacter pylori* infection on gastric myoelectrical activity has been studied intensively [4,24,25]. However,

this issue remains controversial. Several papers have been published with both positive [34,52] and negative results [37]. Miyaji et al [40] found that gastric emptying, antral myoelectric activity and symptom scores in functional dyspepsia were improved by the eradication of *Helicobacter pylori*. In a Polish study [57], EGG, antral manometry and gastric emptying (assessed by ultrasonographic measurement of antral diameter) were investigated in *Helicobacter pylori* positive subjects with functional dyspepsia before and 1 month after eradication therapy. EGG showed significant dysrhythmias (with tachygastria up to 25 %) before eradication. Antral manometry failed to exhibit gastric phase III of the migrating motor complex in 7/12 subjects before eradication but could be observed again in 7/10 patients 1 month after successful eradication. Authors concluded that changes in gastric electrical control activity and antral hypomobility were associated with *Helicobacter pylori* infection [57]. However, according to other studies published so far, eradication of *Helicobacter pylori* infection has no impact on gastric emptying in patients with functional

dyspepsia [21,31,32]. Murakami et al [41] found that gastric emptying was significantly delayed in functional dyspepsia compared to healthy control subjects but with no difference between *Helicobacter pylori* positive and negative persons.

In conclusion, EGG and gastric emptying rate, assessed by ^{13}C -octanoic acid breath test, are suitable non-invasive complementary methods to investigate the motor function of the stomach. The major parameters, 3-cpm rhythm (in EGG) and half-life of elimination (in ^{13}C -octanoic acid breath test) mutually correlate in healthy subjects.

The study was supported by research project MZO 00179906 from the Ministry of Health of the Czech Republic.

References

1. Barbar M, Steffen R, Wyllie R, Goske M. Electrogastrography versus gastric emptying scintigraphy in children with symptoms suggestive of gastric motility disorders. *J Pediatr Gastroenterol Nutr* 2000; 30: 193-197.
2. Bortolotti M. Electrogastrography: a seductive promise, only partially kept. *Am J Gastroenterol* 1998; 93: 1791-1794.
3. Braden B. ^{13}C -acetate breath test (p 165-170). In: Perri F, Andriulli A (eds). *Clinical Application of Breath Tests in Gastroenterology and Hepatology*. Rome: International University Press 1998.
4. Budzynski A, Bobrzynski A, Lorens K et al. The influence of cholecystokinin on gastric myoelectrical activity in duodenal ulcer following *Helicobacter pylori* eradication: an electrogastrographic study. *J Physiol Pharmacol* 2002; 53: 171-182.
5. Bureš J, Kopáčová M, Koupil I et al. Epidemiology of *Helicobacter pylori* infection in the Czech Republic. *Helicobacter* 2006; 11: 56-65.
6. Bureš J, Kopáčová M, Voříšek V et al. Examination of gastric emptying

rate by means of ^{13}C -octanoic acid breath test. Methods of the test for adults and results of the investigation of healthy volunteers (in Czech). *Čas Lék Čes* 2005; 144(suppl 3): 18-22.

7. Camilleri M. Etiology and diagnosis of delayed gastric emptying. *UpToDate* 2007; vol 15.1. www.uptodate.com

8. Camilleri M, Hasler WL, Parkman HP et al. Measurement of gastrointestinal motility in the GI laboratory. *Gastroenterology* 1998; 115: 747-762.

9. Chang FY. Electrogastrography: basic knowledge, recording, processing and its clinical applications. *J Gastroenterol Hepatol* 2005; 20: 502-516.

10. Chen J, McCallum RW. Gastric slow wave abnormalities in patients with gastroparesis. *Am J Gastroenterol* 1992; 87: 477-482.

11. Chen JD, Pan J, McCallum RW. Clinical significance of gastric myoelectrical dysrhythmias. *Dig Dis* 1995; 13: 275-290.

12. Chen JZ, McCallum RW. Electrogastrographic parameters and their clinical significance (p 45-73). In: Chen JZ, McCallum RW (eds). *Electrogastrography. Principles and Applications*. New York: Raven Press 1994.

13. Choi MG, Camilleri M, Burton DD et al. ^{13}C -octanoic acid breath test for gastric emptying of solids: accuracy, reproducibility, and comparison with scintigraphy. *Gastroenterology* 1997; 112: 1155-1162.

14. Cucchiara S, Franzese A, Salvia G et al. Gastric emptying delay and gastric electrical derangement in IDDM. *Diabetes Care* 1998; 21: 438-443.

15. Diamanti A, Bracci F, Gambarara M et al. Gastric electric activity assessed by electrogastrography and gastric emptying scintigraphy in adolescents with eating disorders. *J Pediatr Gastroenterol Nutr* 2003; 37: 35-41.

16. Dolina J, Hep A, Prášek J, Dítě P. Will electrogastrography be a new diagnostic method in gastroenterology? (in Czech). *Čes Slov Gastroent* 1997; 51: 177-180.

17. Friesen CA, Lin Z, Hyman PE et al. Electrogastrography in pediatric functional dyspepsia: relationship to gastric emptying and symptom severity. *J Pediatr Gastroenterol Nutr* 2006; 42: 265-269.

18. Friesen CA, Lin Z, Schurman JV et al. An evaluation of adult electrogastrography criteria in healthy children. *Dig Dis Sci* 2006; 51: 1824-1828.

19. Galmiche JP, Delbende B, Perri F, Andriulli A. (13)C octanoic acid breath test. *Gut* 1998; 43(suppl 3): S28-S30.

20. Ghoo YF, Maes BD, Geypens BJ et al. Measurement of gastric emptying rate of solids by means of carbon-labeled octanoic acid breath test. *Gastroenterology* 1993; 104: 1640-1647.

21. Goh KL, Paramsothy M, Azian M et al. Does *Helicobacter pylori* infection affect gastric emptying in patients with functional dyspepsia? *J Gastroenterol Hepatol* 1997; 12: 790-794.

22. Hongo M, Okuno Y, Nishimura N et al. Electrogastrography for prediction of gastric emptying state (p 257-269). In: Chen JZ, McCallum RW (eds). *Electrogastrography. Principles and Applications*. New York: Raven Press 1994.

23. Jonderko K, Kasicka-Jonderko A, Krusiec-Swidergol B et al. How reproducible is cutaneous electrogastrography? An in-depth evidence-based study. *Neurogastroenterol Motil* 2005; 17: 800-809.

24. Kamiya T, Kobayashi Y, Hirako M et al. Gastric motility in patients with recurrent gastric ulcers. *J Smooth Muscle Res* 2002; 38: 1-9.

25. Kamiya T, Kobayashi Y, Misu N et al. Gastric myoelectrical activity in patients with recurrent gastric or duodenal ulcers. *J Smooth Muscle Res* 2003; 39: 1-10.

26. Koch KL. Electrogastrography: physiological basis and clinical application in diabetic gastropathy. *Diabetes Technol Ther* 2001; 3: 51-62.

27. Koch KL, Stern RM. Electrographic data acquisition and analysis. The Penn State experience (p 31-44). In:

Chen JZ, McCallum RW (eds). *Electrogastrography. Principles and Applications*. New York: Raven Press 1994.

28. Koch KL, Stern RM. Nausea and vomiting and gastric dysrhythmias (p 309-330). In: Chen JZ, McCallum RW (eds). *Electrogastrography. Principles and Applications*. New York: Raven Press 1994.

29. Kopáčová M et al. Use of Functional Breath Tests in Gastroenterology (in Czech). Hradec Králové: Nucleus HK 2006: 136.

30. Kopáčová M, Bureš J, Voříšek V et al. Comparison of different protocols for (13)C-urea breath test for the diagnosis of *Helicobacter pylori* infection in healthy volunteers. *Scand J Clin Lab Invest* 2005; 65: 491-498.

31. Koskenpato J, Korppi-Tommola T, Kairemo K, Farkkila M. Long-term follow-up study of gastric emptying and *Helicobacter pylori* eradication among patients with functional dyspepsia. *Dig Dis Sci* 2000; 45: 1763-1768.

32. Leontiadis GI, Minopoulos GI, Maltezos E et al. Effects of *Helicobacter pylori* infection on gastric emptying rate in patients with non-ulcer dyspepsia. *World J Gastroenterol* 2004; 10: 1750-1754.

33. Levanon D, Zhang M, Chen JD. Efficiency and efficacy of the electrogastrogram. *Dig Dis Sci* 1998; 43: 1023-1030.

34. Lin Z, Chen JD, Parolisi S et al. Prevalence of gastric myoelectrical abnormalities in patients with non-ulcer dyspepsia and *H. pylori* infection: resolution after *H. pylori* eradication. *Dig Dis Sci* 2001; 46: 739-745.

35. Lin Z, Eaker EY, Sarosiek I, McCallum RW. Gastric myoelectrical activity and gastric emptying in patients with functional dyspepsia. *Am J Gastroenterol* 1999; 94: 2384-2389.

36. Lindberg G, Iwarzon M, Hammarlund B. 24-hour ambulatory electrogastrography in healthy volunteers. *Scand J Gastroenterol* 1996; 31: 658-664.

37. Lu CL, Chen CY, Chang FY et al. Impaired postprandial gastric myoelectrical activity in Chinese patients with nonulcer dyspepsia. *Dig Dis Sci* 2001; 46: 242-249.
38. Mintchev MP, Bowes KL. Computer simulation of the impact of different dimensions of the stomach on the validity of electrogastrograms. *Med Biol Eng Comput* 1998; 36: 7-10.
39. Mintchev MP, Kingma YJ, Bowes KL. Accuracy of cutaneous recording of gastric electrical activity. *Gastroenterology* 1993; 104: 1273-1280.
40. Miyaji H, Azuma T, Ito S et al. The effect of *Helicobacter pylori* eradication therapy on gastric antral myoelectrical activity and gastric emptying in patients with non-ulcer dyspepsia. *Aliment Pharmacol Ther* 1999; 13: 1473-1480.
41. Murakami K, Fujioka T, Shiota K et al. Influence of *Helicobacter pylori* infection and the effects of its eradication on gastric emptying in non-ulcerative dyspepsia. *Eur J Gastroenterol Hepatol* 1995; 7(suppl 1): S93-S97.
42. Neumann D, Bukač J, Voříšek V et al. Assessment of gastric emptying by ¹³C-octanoic acid breath test. Mathematical analysis of elimination: moment method of incomplete gamma function estimation (in Czech). *Klin Biochem Metabol* 2002; 10(31): 206-212.
43. Parkman HP, Harris AD, Miller MA, Fisher RS. Influence of age, gender, and menstrual cycle on the normal electrogastrogram. *Am J Gastroenterol* 1996; 91: 127-133.
44. Parkman HP, Hasler WL, Barnett JL, Eaker EY. *Electrogastrography: a document prepared by the gastric section of the American Motility Society Clinical GI Motility Testing Task Force*. *Neurogastroenterol Motil* 2003; 15: 89-102.
45. Parkman HP, Miller MA, Trate D et al. Electrogastrography and gastric emptying scintigraphy are complementary for assessment of dyspepsia. *J Clin Gastroenterol* 1997; 24: 214-219.
46. Perri F, Festa V, Quitadamo M et al. ¹³C-octanoic acid breath test (p 157-163). In: Perri F, Andriulli A (eds). *Clinical Application of Breath Tests in Gastroenterology and Hepatology*. Rome: International University Press 1998.
47. Pfaffenbach B, Adamek RJ, Bartholomaeus C, Wegener M. Gastric dysrhythmias and delayed gastric emptying in patients with functional dyspepsia. *Dig Dis Sci* 1997; 42: 2094-2099.
48. 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: 1445-1450.
49. Rossi Z, Forlini G, Fenderico P et al. Electrogastrography. *Eur Rev Med Pharmacol Sci* 2005; 9(suppl 1): 29-35.
50. Sanmiguel CP, Mintchev MP, Bowes KL. Electrogastrography: a noninvasive technique to evaluate gastric electrical activity. *Can J Gastroenterol* 1998; 12: 423-430.
51. Shimamoto C, Hirata I, Hiraike Y et al. Evaluation of gastric motor activity in the elderly by electrogastrography and the (13)C-acetate breath test. *Gerontology* 2002; 48: 381-386.
52. Shiotani A, Iguchi M, Inoue I et al. Association between gastric myoelectrical activity and intraluminal nitric oxide. *Aliment Pharmacol Ther* 2002; 16(suppl 2): 44-51.
53. Siegel JA, Urbain J-L, Adler LP et al. Biphasic nature of gastric emptying. *Gut* 1988; 29: 85-89.
54. Simonian HP, Panganamamula K, Parkman HP et al. Multichannel electrogastrography (EGG) in normal subjects: a multicenter study. *Dig Dis Sci* 2004; 49: 594-601.
55. Smout AJPM, Jebbink HJA, Samsom M. Acquisition and analysis of electrogastrographic data (p 3-30). In: Chen JZ, McCallum RW (eds). *Electrogastrography. Principles and Applications*. New York: Raven Press 1994.
56. Stellaard F, Geypens B. European interlaboratory comparison of breath ¹³CO₂ analysis. *Gut* 1998; 43(suppl 3): S2-6.
57. Thor P, Lorens K, Tabor S et al. Dysfunction in gastric myoelectric and motor activity in *Helicobacter pylori* positive gastritis patients with non-ulcer dyspepsia. *J Physiol Pharmacol* 1996; 47: 469-476.
58. van den Driessche M, Peeters K, Marien P et al. Gastric emptying in formula-fed and breast-fed infants measured with the ¹³C-octanoic acid breath test. *J Pediatr Gastroenterol Nutr* 1999; 29: 46-51.
59. van der Voort IR, Osmanoglou E, Seybold M et al. Electrogastrography as a diagnostic tool for delayed gastric emptying in functional dyspepsia and irritable bowel syndrome. *Neurogastroenterol Motil* 2003; 15: 467-473.
60. Verhagen MA, Van Schelven LJ, Samsom M, Smout AJ. Pitfalls in the analysis of electrogastrographic recordings. *Gastroenterology* 1999; 117: 453-460.
61. Xu X, Wang Z, Hayes J, Chen JD. Is there a one-to-one correlation between gastric emptying of liquids and gastric myoelectrical or motor activity in dogs? *Dig Dis Sci* 2002; 47: 365-372.
62. Zhang H, Xu X, Wang Z et al. Correlation between gastric myoelectrical activity recorded by multi-channel electrogastrography and gastric emptying in patients with functional dyspepsia. *Scand J Gastroenterol* 2006; 41: 797-804.

Correspondence to:

Adresa pro korespondenci:
prof. MUDr. Jan Bureš, CSc.
Sokolská 581
500 05 Hradec Králové
Czech Republic
e-mail: bures@lfhk.cuni.cz