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Topographical Electrogastrograms After Radical Esophagectomy with Colonic Replacement

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Abstract
Purpose. To characterize the functional substitution of colon for the esophagus, we compared the electrogastrogram (EGG) maps and spectral frequencies and power of preoperative controls with patients who had undergone colonic replacement.
Methods. Monopolar EGGs were recorded and spectrally analyzed at 27 locations on the thoracoabdominal surface. The spectral powers of five frequency groups were converted into EGG maps.
Results. In contrast to the epigastric concentrations of maximal power foci in a preoperative 3-cpm (cycles per minute) group, those of the colon replacement subjects seemed not to be concentrated in the epigastric region. Power in the 6-cpm colon replacement group were significantly greater and those in the 3-cpm colon replacement group were significantly less than those in the preoperative controls. Spectral frequencies in the 1- and 3-cpm colon replacement groups were significantly higher than those in the preoperative controls.
Conclusions. The colonic and gastric EGG activities had 3-cpm, and probably 6-cpm in common. However, the colonic EGG activities were significantly different from the gastric EGG activities in frequency in the 3-cpm group, and in amplitude in both the 3- and 6-cpm groups. Thus, the replaced colon seems to preserve the original colonic EGG activity.

Key words Electrogastrography · Colon replacement · Topographic map · Isopower electrogastrographic map · Maximal power focus

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Introduction

We recorded the 24-h ambulatory intraluminal pressure of the replaced colon in patients who underwent radical esophagectomy and colonic replacement. The replaced colon behaves like the original colon in its postprandial increase in motor activity and diurnal rhythm, and seems to be a good substitute for the esophagus. However, the frequency characteristics of motor activity of the replaced colon are still unclear.[1]

Topographic electrogastrogram (EGG) maps correspond to the topographic electroencephalograms used frequently in the clinical setting. We previously suggested that infraumbilical 3-cpm (cycles per minute) and 6-cpm EGG activities reflected the colonic ones because the infraumbilical maximal power foci (MPFs) in 3 (2.5–4.9) cpm and 6 (5.0–7.4) cpm groups disappeared after total colectomy, with the help of topographic EGG maps.[2,3] Therefore, we recorded and spectrally analyzed the EGG activities at 27 locations on the thoracoabdominal surface (Fig. 1). The topographic EGG maps after colon replacement could then be compared with those of preoperative controls.

In colon replacement, the transverse colon, with part of the ascending and part of the descending colon, is interposed between the remaining esophagus and duodenum in the original location of the removed stomach (Fig. 2). Therefore, spectral EGG activities of the replaced colon could be compared with preoperative ones. The frequency characteristics may promote our understanding of the good functional substitution of colon for the esophagus.

Materials and Methods

The methods of drawing the topographic or isopower EGG maps were described previously.[2–4] Briefly, we recorded monopolar EGGs at 27 locations on the

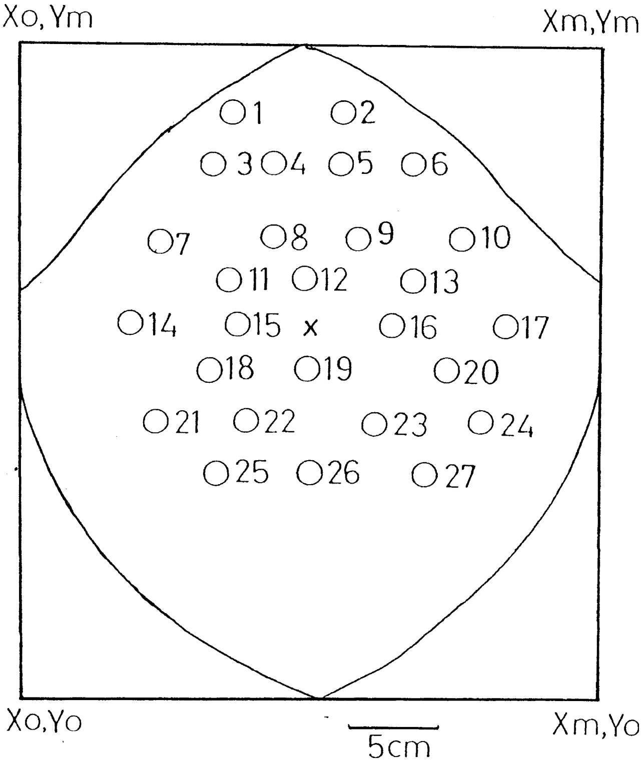

Fig. 1. Schematic locations of the 27 electrogastrogram (EGG) electrodes on the thoraco-abdominal surface. ×, navel; *Xo*, right thoracoabdominal edge; *Xm*, left thoraco-abdominal edge; *Yo*, horizontal symphysis line; *Ym*, horizontal xyphoid line. The costal arch and iliac crest lines were seen

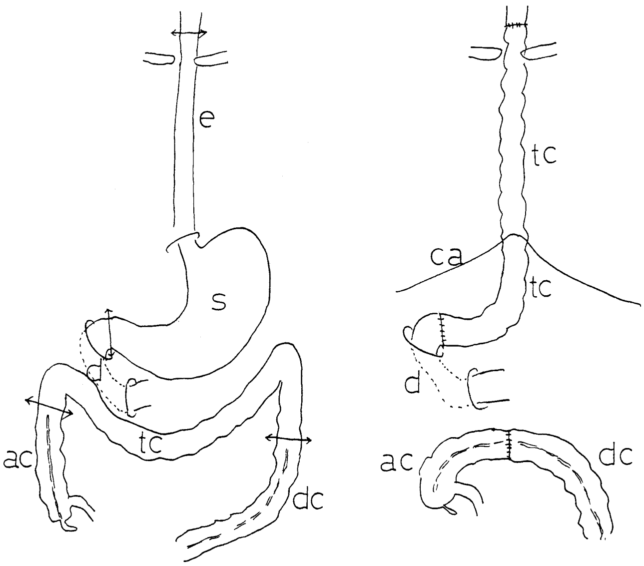

Fig. 2. Explanations of the operative scheme of radical esophagectomy and colonic replacement to show the location of the replaced colon. *e*, esophagus; *s*, stomach; *d*, duodenum; *ac*, ascending colon; *tc*, transverse colon; *dc*, descending colon; *ca*, costal arch

thoracoabdominal surface of patients at rest in the supine position after overnight fasting. The electrode locations expressed with *x-y* coordinates were similar to those described in previous reports, attaching 17 supraumbilical and 10 infraumbilical electrodes to the thoracoabdominal surface[3–5] (Fig. 1). These were the dished electroencephalographic electrodes, connected to a modified electroencephalographic amplifier (time constant = 5 s, high cut = 0.5 Hz, low cut = −6 dB/oct, high cut = −12 dB/oct) (Biotop 6R12-4, NEC-Sanei, Toyo, Japan). EGGs were stored in disks and analyzed by the maximal entropy (MEM) method (1 file = 128 points, sampled at 1 s). Ensemble means of seven fasting and seven postprandial spectra were calculated before and after eating two blocks of Calorie-mate (Otsuka Pharmaceutical, Tokushima, Japan; 1 kcal/block). Spectral frequencies were arbitrarily classified into the following five groups: a 1-cpm group (0–2.4 cpm), a 3-cpm group (2.5–4.9), a 6-cpm group (5.0–7.4), an 8-cpm group (7.5–9.9), and a 10-cpm group (10.0–12.9).[2–4] The fasting and postprandial maximal power (μV^2) in those averaged spectral groups were adopted as the representatives for drawing maps. Therefore, the maximal power at a given electrode position could be expressed as $Z_i = (X_i, Y_i)$, where Z is power or amplitude. It was assumed that X_o was the right thoracoabdominal edge, X_{max} was the left thoracoabdominal edge, Y_o was the horizontal symphysis line, and Y_{max} was the horizontal xiphoid line (Fig. 1). Thereafter, the usual contour map program for geographic purposes[6] was introduced and the maximal power foci (MPFs) of the five spectral groups were drawn. The isopower line intervals, corresponding to the contour or isoaltitude line, were 1/20 of the maximal power in each spectral group. Usually, just one maximal power focus (MPF) was found, although sometimes, two or three isopower MPFs were encountered in one spectral group.

Informed consent for recording EGGs was obtained from each colon replacement patient ($n = 6$) and control subject ($n = 15$). Because we had no paired preoperative control recordings for colon replacement, there having been no recent patients with indications for that operation, patients scheduled to undergo total gastrectomy ($n = 7$) and subtotal gastrectomy ($n = 8$) were employed as preoperative controls ($n = 15$).[3] The mean age of the 15 preoperative controls was 62 ± 2.0 years (range, 48–74 years) and the mean age of the 6 patients who underwent colon replacement was 73 ± 1.9 years (range, 65–77 years). The EGG recording was made 60 ± 17.9 months (range, 17–126 months) ($n = 6$) after the operation. We confirmed that none of the patients had suffered any serious complications by asking them to complete a questionnaire. Colonic replacement included radical esophagectomy, total gastrectomy, and interposition of the isolated transverse colon between

Table 1. Comparison of amplitude (power, μV^2) between the preoperative (pre, $n = 15$) and colonic replacement (cr, $n = 6$) groups

	1 (0–2.4 cpm)	3 (2.5–4.9 cpm)	6 (5.0–7.4 cpm)	8 (7.5–9.9 cpm)	10 (10.0–12.9 cpm)
pre					
f	169772 ± 33367	131671 ± 34969	23954 ± 5250[A]	18741 ± 4123[B]	18645 ± 3354[C]
p	100972 ± 18141	220318 ± 30817[D]	26002 ± 4386[E]	14826 ± 2261[F]	19448 ± 3434[G]
cr					
f	172376 ± 73671	79127 ± 19397	52451 ± 6474[a]	70534 ± 22567[b]	153199 ± 75482[c]
p	145844 ± 44559	125615 ± 14216[d]	47565 ± 7214[e]	135838 ± 91866[f]	69807 ± 17627[g]

cpm, cycles per minute; f, fasting; p, postprandial state
A-a, B-b, C-c, F-f, G-g: $P < 0.01$; D-d, E-e: $P < 0.05$

the remaining esophagus and the duodenum (all via the substernal route). Furthermore, the remaining ascending and descending colon was anastomosed after isolation of the transverse colon (Fig. 2). Five of the six patients were also subjected to ambulatory intraluminal pressure recording and analysis. We confirmed the epigastric colonic locations of their interposed colons by fluoroscopy after inserting solid-state sensors via the nose.[1] We compared the mean fasting and postprandial maximal powers in the five spectral groups, including the whole supraumbilical (1–17 channels) and infraumbilical (18–27 channels) powers in the preoperative controls and the colon replacement patients (Table 1). The mean fasting and postprandial maximal powers of the supraumbilical and infraumbilical channels were also compared. We speculated that the epigastric 3-cpm activities reflected the stomach EGG activities; that the thoracoabdominal 10-cpm activities reflected the small intestinal EGG activities; and that the infraumbilical 3- and 6-cpm activities reflected the colonic EGG activities.[2–4,7] Therefore, mean fasting and postprandial frequencies and instability factors in the five spectral groups, including the whole channels, were compared. The mean frequencies of the supraumbilical and infraumbilical channels were also compared. The instability factor was defined as: (standard deviation of spectral frequency)/(mean spectral frequency) in each spectral group.

Statistical analysis was done using Mann-Whitney's *U*-test and the mean and SE (standard error) were also calculated (Table 1). *P* values of less than 0.05 were considered significant.

Results

Figure 3 shows examples of colored topographic EGG maps of a preoperative control and a patient who underwent esophagectomy with colon replacement. The superimposed EGG maps clearly showed an epigastric concentration of 3-cpm MPFs in the preoperative controls, but not in the colon replacement patients. The distribution of MPFs of other frequencies, namely, 1, 6, 8, and 10 cpm, were similar in the preoperative controls and the colon replacement patients (Fig. 4).

The spectral peaks of 3-cpm activities (2.5–4.9 cpm) were constantly observed in a piled manner in running spectra, especially in the supraumbilical channels, in the preoperative controls but not in the colon replacement patients. Therefore, as expected, the fasting mean frequency (3.5 ± 0.09 cpm, mean ± SE, $n = 6$) and postprandial instability factor (0.19 ± 0.014) were significantly greater in the 3-cpm colon replacement group than in the preoperative controls (3.1 ± 0.05, $P < 0.01$ and 0.14 ± 0.013, $P < 0.05$, respectively, $n = 15$). Instead, clear peaks of about 10 cpm were constantly observed in a piled manner in running spectra, especially in the umbilical to infraumbilical channels in three of six colon replacement patients as in total gastrectomy.[3,7] Moreover, the fasting and postprandial amplitude of 10 cpm (10.0–12.9 cpm) was significantly greater in the colon replacement patients than in the preoperative controls ($P < 0.01$) (Table 1).

The maximal postprandial amplitude (power) of the 3-cpm group of colon replacement patients was significantly less than that of the preoperative controls ($P < 0.05$) (Table 1). In contrast, the amplitude of 6 cpm in the colon replacement group was significantly greater than that in the preoperative controls, both in the fasting and postprandial state ($P < 0.05$–0.01). Similarly, the fasting and postrandial 8- and 10-cpm amplitudes in colon replacement were significantly larger than those in the controls ($P < 0.01$) (Table 1).

The mean frequency was significantly higher in the 1-cpm colon replacement group in the fasting state (1.7 ± 0.08 cpm, $n = 6$) than in the preoperative controls (1.5 ± 0.05 cpm, $n = 15$) ($P < 0.05$). Similarly, it was significantly higher in the 3-cpm colon replacement group in the fasting state than in the preoperative controls ($P < 0.01$). There were no significant differences among the other frequency groups of 6, 8, and 10 cpm (Table 2). The postprandial instability factors in the

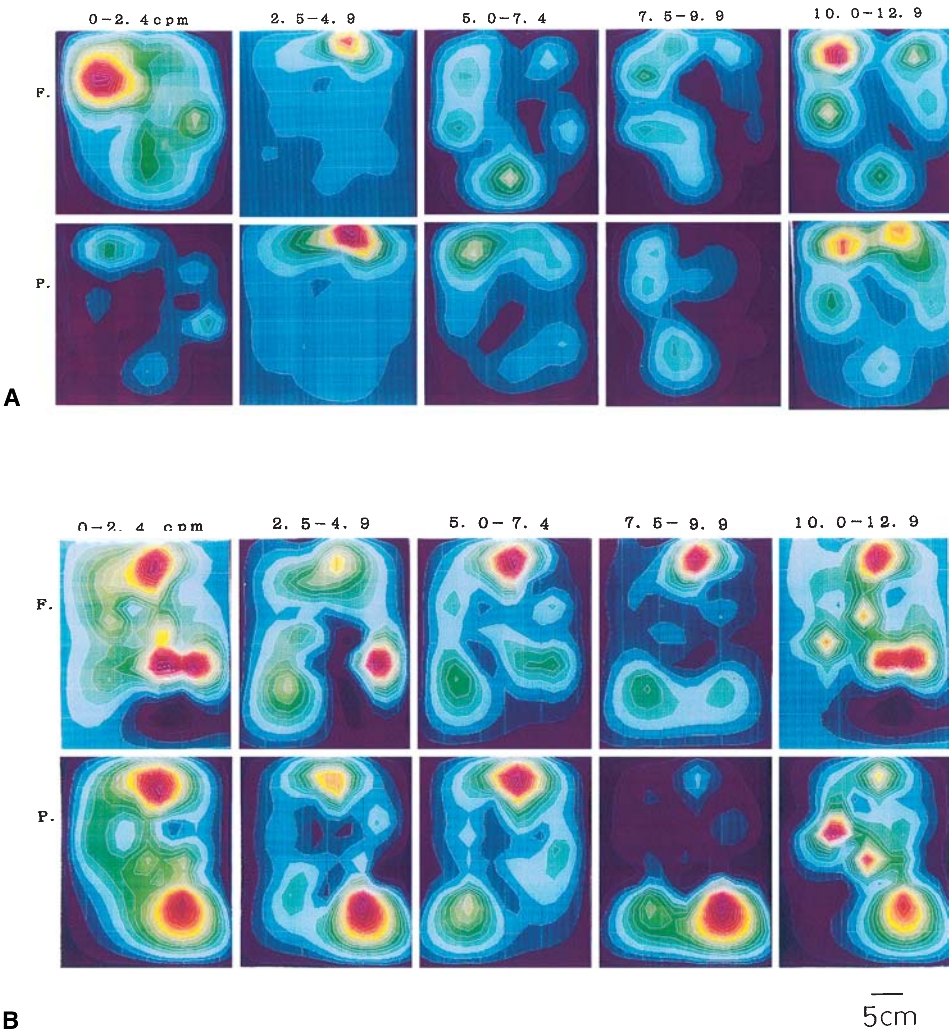

Fig. 3. Examples of isopower EGG maps from a preoperative control (**A**) and a patient with colonic replacement (**B**). The power becomes greater from blue to yellow to red. The power intervals (1/20 of maximal power) are different in each spectral group 2.5–4.9, 5.0–7.4, 7.5–9.9, and 10.0–12.9 cpm. In contrast to one maximal power focus (MPF) of epigastric 3-cpm in the preoperative control (**A**), the colon replacement shows a supraumbilical higher hill and an infraumbilical MPF of 3-cpm. The supraumbilical hill may reflect the replaced colonic activity and the infraumbilical MPF may reflect the anastomosed colon in its original location. Similarly, a supraumibilical MPF and a higher infraumbilical hill of 6-cpm may reflect the replaced colonic activity and the remaining anastomosed one, respectively. The bar at the bottom of the figure shows an indicator of 5 cm

Table 2. Comparison of frequency (cpm) between the preoperative (pre, $n = 15$) and colonic replacement (cr, $n = 6$) groups

	1 (0–2.4 cpm)	3 (2.5–4.9 cpm)	6 (5.0–7.4 cpm)	8 (7.5–9.9 cpm)	10 (10.0–12.9 cpm)
pre					
f	1.5 ± 0.05[A]	3.2 ± 0.06[B]	6.0 ± 0.07	8.7 ± 0.10	11.1 ± 0.07
p	1.5 ± 0.05	3.2 ± 0.04	6.0 ± 0.06	8.7 ± 0.08	11.1 ± 0.09
cr					
f	1.7 ± 0.08[a]	3.6 ± 0.10[b]	6.1 ± 0.20	8.6 ± 0.15	11.3 ± 0.15
p	1.5 ± 0.09	3.4 ± 0.14	6.0 ± 0.15	8.7 ± 0.10	11.3 ± 0.14

f, fasting; p, postprandial
A-a: $P < 0.05$; B-b: $P < 0.01$

3-cpm (0.19 ± 0.014) and 6-cpm (0.11 ± 0.004) colon replacement groups (including the supraumbilical and infraumbilical channels) were significantly greater than those in the preoperative controls (0.14 ± 0.013 and 0.09 ± 0.006, $P < 0.05$). In a separate comparison of supraumbilical and infraumbilical channels, the fasting (0.20 ± 0.015) and postprandial (0.19 ± 0.019) instability factors in the 3-cpm supraumbilical channels of the colon replacement group were significantly greater than those in the preoperative controls (fasting, 0.12 ± 0.014; postprandial, 0.10 ± 0.014; $P < 0.01$). Only the postprandial supraumbilical instability factor in the 6-cpm colon replacement group (0.11 ± 0.006) was significantly greater than that in the preoperative controls (0.08 ± 0.007, $P < 0.01$). Similarly, the postprandial infraumbilical instability factor in the 6-cpm colon re-

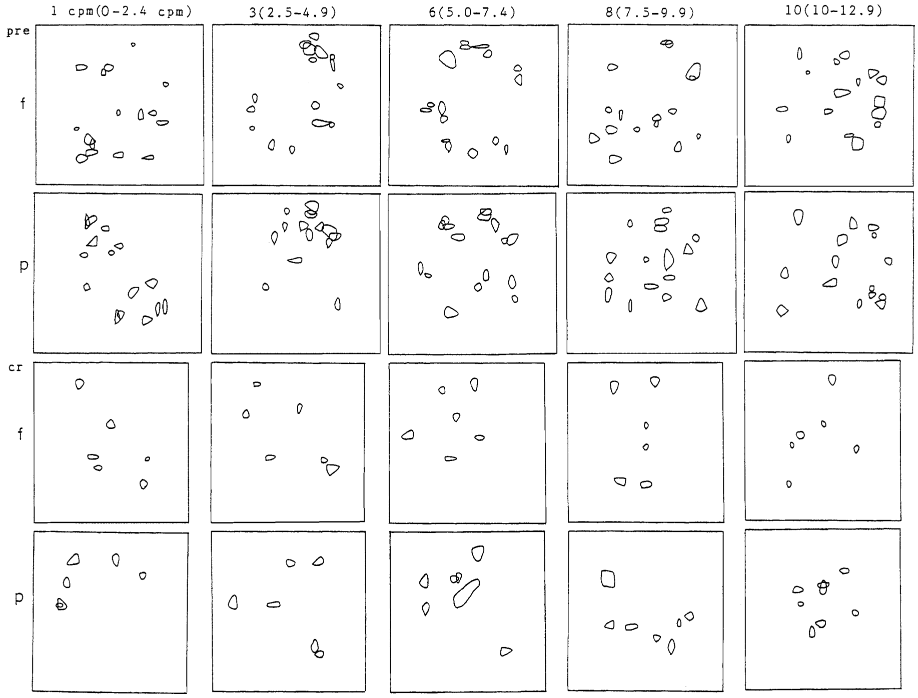

Fig. 4. The maps of superimposed maximal power foci of the preoperative controls (*pre*, upper two rows, $n = 15$) and colon replacement (*cr*, lower two rows, $n = 6$). Maximal power foci or areas are encircled by *lines*. From left to right are maps of the 1-cpm (0–2.4 cpm), 3-cpm (2.5–4.9), 6-cpm (5.0–7.4), 8-cpm (7.5–9.9), and 10-cpm groups (10.0–12.9). *f*, fasting; *p*, postprandial

placement group (0.11 ± 0.008) was significantly greater than that in the preoperative controls (0.10 ± 0.008, $P < 0.01$) (not shown in Table 2).

Discussion

It is well known that the colon shows complex electrical and mechanical activities. Spectral analysis reveals a wide range of spectral components; for example, less than 1 cpm mass propulsion or mass movement for defecation,[8] around 3–5 cpm,[8–11] and around 8–10 cpm.[8–12] Abdominal surface recordings of EGGs have shown that two spectral components, 2.5–3.5 cpm and 3.6–7.5 cpm, reflect colonic activities.[7,9,13,14] We obtained evidence that two similar spectral components in EGGs, of the 3-cpm group (2.5–4.9 cpm) and the 6-cpm group (5.0–7.4 cpm), reflected colonic activity, especially in an infraumbilical recording of 27 channel EGGs. According to our report, no 3- and 6-cpm infraumbilical MPFs were seen in patients who had undergone total colectomy.[3] We were able to further quantitatively characterize colonic activity in the EGGs in this study.

Isopower or topographic EGG maps gave similar results after colon replacement and total gastrectomy, although fewer 3-cpm MPFs were concentrated in the epigastrium of colon replacement.[3] When studying the distributions of 1-, 6-, 8-, and 10-cpm MPFs, it was difficult to find differences between the colonic replacement group and the preoperative controls or the subtotal gastrectomy group or the total colectomy group,[3] mainly because of the small sample sizes.

In the colon replacement group, the absence of the stomach in the epigastrium contributed to a significant amplitude (power) decrease ($P < 0.05$) in the 3-cpm group (2.5–4.9), similar to that after total gastrectomy or subtotal gastrectomy,[3,7] compared with preoperative controls. After total gastrectomy, weaker 3-cpm activity in the epigastrium is assumed to be derived from the colon.[7,13] Similarly, the lower 3-cpm activity recorded after colon replacement may be derived from the replaced colon located in the original stomach region. However, a power percentage increase of 3 cpm (2.6–3.5 cpm) was also reported after right hemicolectomy.[14]

In contrast to the 3-cpm group (2.5–4.9 cpm) activity, the amplitude of the 6-cpm (5.0–7.4 cpm) activity was significantly greater in the colon replacement group than in the preoperative controls. This could be because the true 6-cpm activity of the colon is greater than the apparent 6-cpm activity of the stomach. It is also possible that the replaced supraumbilical colon and the remaining anastomosed infraumbilical colon became closer after the stomach was removed, causing the EGG colonic activity to be more directly recorded, resulting in an amplitude increase. On the other hand, a 3.6–7.5 cpm power decrease was reported after right hemicolectomy.[14] The colon replacement, as well as the absence of the stomach and the direct anastomosis of the ascending and descending colon in the suprapubic area, may expose the infraumbilical small intestine to the abdominal wall more directly. Therefore, surface EGG recording may pick up the small intestinal activity of 8–10 cpm more directly, like after total gastrectomy[3,7,13] (Table 1).

The significantly higher frequencies in fasting 3-cpm activity in the colon replacement group (3.5 ± 0.09) than in the preoperative controls (3.1 ± 0.05) suggested that gastric and colonic activity may differ slightly in the 3-cpm group EGG activity (2.5–4.9 cpm). A constantly changing EGG wave[13] or inconsistent 3-cpm activity in running spectra seems a characteristic of colonic activity in the EGGs recorded on the abdominal surface.[7,13,14] As expected, the instability factors in the postprandial 3- and 6-cpm groups (0.19 ± 0.014 and 0.11 ± 0.004, respectively) were greater in the colon replacement group than in the preoperative controls (0.14 ± 0.013, $P < 0.05$ and 0.09 ± 0.006, $P < 0.01$).

The mean frequency in the fasting 1-cpm group (0–2.4 cpm) after colon replacement (1.7 ± 0.08) was significantly higher than that in the preoperative controls (1.5 ± 0.05, $P < 0.05$) (Table 2). As in the 3-cpm group activity, the EGG activity in the 1-cpm colon group[3,15] may not be constant, and the instability factors in the 1-cpm colon replacement group (fasting, 0.20 ± 0.024; postprandial, 0.21 ± 0.020) were greater than those of the preoperative controls (fasting, 0.19 ± 0.021; postprandial, 0.18 ± 0.015), although the differences were not significant. The 1-cpm EGG activities probably reflect the colonic ones.[3,15]

In contrast, the 6-cpm EGG activities of the control and colonic replacement groups were similar, as in the 8- and 10-cpm groups (Table 2, mean of the whole channel). The supraumibilical 6-cpm EGG activities of the colonic replacement group (fasting, 6.1 ± 0.15; postprandial, 6.0 ± 0.14; $n = 6$) were also similar to those of the preoperative control (fasting, 6.0 ± 0.06; postprandial, 5.9 ± 0.07; $n = 6$). The infraumbilical 6-cpm EGG activities were also similar in the colonic replacement group (fasting, 6.0 ± 0.21; postprandial, 6.0 ± 0.18, $n = 6$) and the preoperative controls (fasting, 6.0 ± 0.10; postprandial, 6.0 ± 0.07). These results suggest that the replaced colonic EGG activities have a similar frequency to the original colonic ones.

We recently obtained data indicating that EGG colonic activity contained a wide range of spectral components, other than the 3- and 6-cpm groups. We found that it contained 1- (0–2.4 cpm), 3- (2.5–4.9), 6- (2.0–7.4), 8- (7.5–9.9), and 10- (10.0–12.9) cpm groups by comparing the topographic EGG maps and videofluorograms of children with short bowel syndrome. The projected portrait of the colon on the thoraco-abdominal surface, which was obtained with the aid of video-fluorograms, was occupied by every 1-, 3-, 6-, 8-, and 10-cpm MPF.[4]

In conclusion, colonic EGG activity may contain 3- and 6-cpm spectral components, especially in the infraumbilical EGGs, as suggested by isopower or topographic EGGs.[2–4] Furthermore, the spectral amplitude and frequency of the EGGs of the stomach and the colon are significantly different. The replaced colonic spectral EGG activity had significantly higher frequency in the 3-cpm group and greater amplitude in the 6-cpm group than gastric spectral activity. However, the replaced colon behaves like the original colon in motor[1] and EGG activities, and seems to function well as a substitute for the esophagus without risk of serious complications.

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