Spectral analysis of colonic intraluminal pressure in patients who received a colonic replacement following radical esophagectomy

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Abstract

The aim of this study was to evaluate the motor activity of the interposed colonic segment in patients who had received a colonic replacement following radical esophagectomy using spectral analysis and a 24 hr activity graph. The 24-hr ambulatory pressure waves were recorded in the replaced colon after esophagectomy (n=8) using a solid-state manometric catheter (MicroDigitrapper, Synetics). Motility and spectral analyses of the intraluminal pressure waves were performed by Multigram and Gastrosoft (Synetics). It was revealed that after a meal the 3 cpm (cycles per minute) component of the motility index increased but the 12–15 cpm component decreased. The diurnal rhythm showed that colonic motility was high in the daytime and low during sleep. In contrast, duodenal motility was relatively high even during sleep. The motility index increased as the postoperative period increased. The motility of the replaced colon was higher during the daytime and after meals. The higher motility after meals was characterized by an increase in the 3 cpm component. These motor characteristics may help the function of the replaced colon as a substitute for the esophagus.

Key words: esophagectomy, colonic replacement, motility, spectral analysis

Introduction

Colonic replacement following radical esophagectomy is a well established procedure when both esophageal and stomach cancers are simultaneously found or esophageal cancer has infiltrated into the stomach, as well as in the case of esophageal cancer when gastrectomy was performed previously. The colonic replacement seems to give a good quality of life (QOL) to such patients (Jones et al., 1971; Clark et al., 1976; Corazziari et al., 1977; Benages et al., 1981; Moreno-Osset et al., 1986; Isolauri et al., 1987; Watanabe et al., 1997; Watanabe et al., 2000). In an attempt to determine why this colonic replacement method gives such a good QOL, we...
investigated its motility by recording and spectrally analyzing the intraluminal pressure waves in the replaced colon. The replaced colon showed signs of good motor activity and functioned as a good substitute for the esophagus and the stomach.

### Materials and Methods

Eight men, 45–77 years old (67.4 ± 3.63, mean ± SE) who had undergone an esophagectomy and colonic replacement were studied. Their postoperative period was 1 to 76 months (> 6 years) (45.1 ± 14.03 months). The transverse colon was resected and used to replace the esophagus and was innervated by its original autonomic nerves running along with the associated vascular system. Four cases had retained a remnant stomach, that is the replaced colonic segment was anastomosed with the remnant stomach and in one case, the sensor tip was in the remnant stomach. The age and postoperative duration of these four patients was 63.5 ± 6.65 years old and 9.8 ± 6.16 month. In the other 4 cases there was no remnant stomach and the replaced colon was directly anastomosed with the duodenum, such that in 3 cases the sensor tip was in the duodenum. The age and postoperative duration was 71.3 ± 2.66 years old and 60.3 ± 19.53 months. All were free from cancer recurrence and without serious symptoms or complications. They needed no further dilatation for obstruction after the operation. Their postsurgical symptoms, such as belching, dysphagia, bile regurgitation, breaking wind, abdominal discomfort, constipation, and diarrhea are tabulated in Table 1.

A manometric catheter containing 6 solid-state sensors (6 channels) was inserted after more than 5 hr of fasting, via the nose under fluoroscopic control, into the interposed colonic segment. Figure 1 is a schematic drawing showing the replaced colonic segment, anastomosed duodenum and esophagus, and the sensor locations. A 24 hr ambulatory study was performed by means of a MicroDigitrapper 4Mb (sampling at 4 Hz, Synetics) and the subject took meals and water as usual. Data were loaded into a computer and analyzed with Multigram and Electrogastrogram software (Gastrosoft, Synetics). After the entire data obtained for each subject was condensed into graphical form (Fig. 2, upper graph) with the software, a one hour analysis before each meal and a two hour analysis after each meal were usually done with the software for motility analysis (Figs. 2, 3). The Multigram software for motility analysis (threshold, 10 mmHg and duration, over 1 sec) gives a condensed graph which illustrates the contraction frequency at a glance for a subject over a 24 hr period (Fig. 2, upper graph), as well as details of contraction frequency per minute, mean amplitude, mean duration, mean area and motility index (defined as \( \ln (\frac{\text{area}}{\text{min}}) \), where area = mmHg X sec). Each data set was printed out for analysis of propagated contractions (threshold, 10 mmHg, duration, 5–40 sec) and for calculating their conduction velocity from the difference in peaks. According to the Nyquist sampling theorem (\( \Delta t = 1/2f \), where \( \Delta t \) is sampling period in sec and \( f \) is Nyquist frequency and maximally reproducible signal frequency in Hz), a sampling rate of 4 Hz (0.25 sec) can reproduce the digitized signal up to 2 Hz (120 cpm). Therefore, a sampling rate of 4 Hz was deemed to be satisfactory for reproduction and for FFT (fast Fourier transform) analysis to get the power spectra for both pressure and electrical signals (e.g., electrogastrogram) up to 120 cpm. The amplitude units of the ordinate are either in mmHg\(^2\) or \( \mu \text{V}^2\), but they are both
Motility of replaced colon

Table 1 Profiles for the 8 male patients, giving age (years old, yo), postoperative months (months, pom), the % content of 3 cpm (2.4-3.7 cpm), 0-2.4, 3.7-10, and 10.0-15.0 and motility index (MI) before (f) and after meal (pr)

<table>
<thead>
<tr>
<th>yo</th>
<th>pom</th>
<th>3 cpm</th>
<th>0-2.4</th>
<th>3.7-10.0</th>
<th>10.0-12.0</th>
<th>MI</th>
<th>symptoms</th>
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<tr>
<td>1.</td>
<td>45</td>
<td>f</td>
<td>2.1 ± 0.8</td>
<td>94.8 ± 1.6</td>
<td>3.1 ± 1.2</td>
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<td>3.3 ± 0.3</td>
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<td></td>
<td></td>
<td>pr</td>
<td>1.4 ± 0.5</td>
<td>93.4 ± 2.1</td>
<td>5.3 ± 1.7</td>
<td>0</td>
<td>3.1 ± 0.3</td>
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<td>2.</td>
<td>75</td>
<td>f</td>
<td>1.1 ± 0.4</td>
<td>94.7 ± 1.1</td>
<td>2.8 ± 0.7</td>
<td>1.4 ± 0.5</td>
<td>3.9 ± 0.2</td>
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<tr>
<td></td>
<td></td>
<td>pr</td>
<td>1.1 ± 0.5</td>
<td>97.6 ± 0.7</td>
<td>1.4 ± 0.5</td>
<td>0</td>
<td>P&lt;0.05</td>
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<td>3.</td>
<td>71</td>
<td>f</td>
<td>3.0 ± 0.6</td>
<td>87.6 ± 2.7</td>
<td>4.0 ± 1.1</td>
<td>5.4 ± 1.6</td>
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<tr>
<td></td>
<td></td>
<td>pr</td>
<td>4.6 ± 1.0</td>
<td>91.7 ± 1.9</td>
<td>3.1 ± 1.0</td>
<td>0.6 ± 0.3</td>
<td>5.3 ± 0.2</td>
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<td>4.</td>
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<td>f</td>
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<td>95.1 ± 1.1</td>
<td>1.7 ± 0.6</td>
<td>1.7 ± 0.7</td>
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<td>12.2 ± 2.4</td>
<td>57.3 ± 6.3</td>
<td>30.5 ± 4.3</td>
<td>0</td>
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<td>77</td>
<td>f</td>
<td>4.9 ± 1.8</td>
<td>69.2 ± 2.2</td>
<td>3.3 ± 0.8</td>
<td>24.3 ± 5.8</td>
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<td>16.9 ± 2.6</td>
<td>78.1 ± 2.9</td>
<td>3.3 ± 0.8</td>
<td>1.7 ± 0.8</td>
<td>4.9 ± 0.2</td>
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<tr>
<td>6.</td>
<td>65</td>
<td>f</td>
<td>2.0 ± 0.5</td>
<td>69.1 ± 2.9</td>
<td>6.7 ± 0.9</td>
<td>20.9 ± 2.6</td>
<td>4.9 ± 0.2</td>
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<td>6.9 ± 1.2</td>
<td>81.3 ± 2.4</td>
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<td>5.5 ± 0.1</td>
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<td>6.7 ± 2.1</td>
<td>55.4 ± 1.7</td>
<td>15.0 ± 3.7</td>
<td>23.0 ± 5.4</td>
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<td>29.0 ± 7.2</td>
<td>5.5 ± 1.9</td>
<td>6.5 ± 0.2</td>
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<td>8.</td>
<td>74</td>
<td>f</td>
<td>3.8 ± 0.7</td>
<td>92.5 ± 1.6</td>
<td>2.8 ± 0.9</td>
<td>1.0 ± 0.5</td>
<td>4.1 ± 0.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>pr</td>
<td>4.4 ± 1.0</td>
<td>94.5 ± 1.2</td>
<td>1.1 ± 0.4</td>
<td>0</td>
<td>5.3 ± 0.2</td>
</tr>
</tbody>
</table>

Cases 1–4 had a residual stomach, while cases 5–8 were without a residual stomach. n=10-24, (channel or sensor number, 1–6) X (meal frequency, 2–4.) Symptoms: 1:dysphagia; 2: bile regurgitation; 3: frequent breaking wind; 4: abdominal discomfort; 5: frequent belching, constipation (c) and diarrhea (d). Laxative was given to treat constipation.

normalized as dB. Therefore, the intraluminal pressure waves were spectrally analysed with the Electrogastrrogram software by FFT to obtain the frequency information regarding the motility. It provided percentages for the 3 cpm component (2.4–3.7 cpm), the 0–2.4 cpm component (corresponding to bradygastria in the usual electrogastrrogram, EGG), the 3.7–10.0 cpm component (corresponding to tachygastria in EGG), and the 10.0–15.0 cpm component (corresponding to duodeno-respiratory activity in EGG). Informed consent was obtained from all patients. Mean and standard error (SE) was calculated and P values of less than 0.05 when using the Student’s t-test were considered to be significant.

Results

Motor activity after meals and diurnal changes

Figure 2 shows an example of overnight recording of the motor activity in the replaced colon (ch1–3) and the duodenum (ch4–ch6) (upper graph) and a running spectral array of ch2 (lower left) and ch4 (lower right) by FFT after the morning meal (thick bars under the abscissa frequency scale). The ch2 motor activity is quiet during sleep and that of ch4 is still active during sleep (during thick bar in the upper graph in Fig. 2). The running spectral array of ch2
Fig. 1. A schematic drawing showing the positions of the solid-state sensors (1-6) for recording the motor activity of the replaced colon. The anastomosed cervical esophagus and duodenum are also shown. Inter-sensor lengths are indicated on either side. The manometric catheter containing the sensors was inserted via the nose into the interposed colonic segment under fluoroscopic control.

shows that a 3 cpm component is present as well as a 0–2.4 cpm component (lower left side of the graph). The lower right side array shows a relatively dominant 3 cpm and 10.0–15.0 cpm component of ch2. The 3 cpm percentage (%) component increased after a meal in 6 out of 8 cases and increased significantly in 4 cases (Table 1, P<0.05–0.01). The 3 cpm % content increased after a meal in 2 out of 4 cases who had a remnant stomach, and in one case it increased significantly after a meal (Table 1, P<0.01). In contrast, in all 4 cases there was an increased 3 cpm % content after a meal in 2 out of 4 cases who had a remnant stomach, and in one case it increased significantly after a meal (Table 1, P<0.05–0.01). But the mean 3 cpm % content after a meal was not significantly different and was similar in the two groups, i.e., both with (n=4) and without (n=4) remnant stomach. The 0–2.4 cpm % component decreased significantly after a meal (P<0.001) in one case with the remnant stomach, but increased significantly (P<0.01) in one case without the remnant stomach (Table 1). The 3.7–10 cpm component increased significantly after a meal (P<0.001) in one case with the residual stomach. The 10–15 cpm % component decreased significantly after a meal in 3 cases with the remnant stomach and in 3 cases without the residual stomach (P<0.05–0.01) (Table 1).
Motility of replaced colon

Fig. 2. An example of a condensed chart recording of the overnight pressure waves in both the replaced colon (channels 1-3) and duodenum (channels 4-6) (upper graph) and a running spectrum from one subject after FFT which was recorded after a morning meal (lower graphs). The longer thick bar in the abscissa time scale shows the sleeping time (between 22:00 and 06:00 hrs). The shorter thick bar (around 11:00 hrs) indicates the time that was spectrally analyzed and the spectral arrays for ch2 (left) and ch4 (right) are shown in the lower graphs.

The motility index significantly increased in 3 cases with the remnant stomach and in 3 cases without the remnant stomach (P<0.01) (Table 1 and Fig. 3). Figure 3 shows the motility index for 24 hours, the same case as in Fig. 2. The motility index during sleep decreased in ch1, ch2 and ch3, which were thought to be recording from the replaced colonic segment, whereas the motility indices of ch4, ch5 and ch6 which were thought to be recording from the duodenum did not change so much during sleep (Fig. 3). The dominant frequencies of ch4, ch5 and ch6 were between 10–12 cpm while those of ch1, ch2, and ch3 were lower during sleep. Similar tendencies were seen in other cases. Significant differences of mean motility indices between the duodenum and the replaced colon and when the subjects were awake or asleep are shown in Fig. 4.
Fig. 3. The 24-hr motility indices for the same subject as recorded in Fig. 2. The indices for channels 1, 2 and 3 (ch1, ch2 and ch3) decreased relatively during sleep (indicated by the black bar under the abscissa time scale), while those of channel 4, 5 and 6 were relatively high during sleep. The recordings for ch1, ch2 and ch3 are from the replaced colon, while those from ch4, ch5 and ch6 are from the duodenum.

Propagated contractions

Propagated contractions were usually observed after eating and awakening in the morning in addition to non-propagating segmental contractions of lower amplitudes. However, the propagated contractions did not propagate across the colono-gastric or colono-duodenal junctions. They were found 24.7% after eating and 16.5% after awakening in the morning. Mean contraction number was 0.58/hr (0–32/person/overnight) and amounted to 97 in all 8 subjects. Their mean amplitude, duration, and conduction velocity was 102.6 ± 84.7 mmHg, 7.0 ± 7.38 sec, and 0.61 ± 0.52 mm/sec, respectively. Their mean frequency after eating for an hour was 1.0/hr (0–11) and that after awakening for an hour was 2.0/hr (0–7).

Motility and postoperative months

The motility index (ordinate, Y) increased with the length of the postoperative period (abscissa, X), $Y = 1.46X + 48.7 (r=0.68, P<0.05)$. 
Motility of replaced colon

Fig. 4. Diurnal changes of the mean motility indices of the duodenum (upper dotted line) and the replaced colon (lower solid line) (mean ± SE). Each point shows the mean of the motility indices for all channels from the sensors located in the duodenum (usually channels 4 to 6, with n=5-7, from 3 subjects) or from those in the replaced colon (usually channels 1-3, with n=26-37 from all 8 subjects). The usual sleep time (22:00-06:00 hrs), is indicated by the thick bar. D; dinner, B; breakfast, L; lunch. Significant differences between the motility indices of the duodenum and colon are indicated as either x (P<0.05), xx (P<0.01) or xxx (P<0.001). Significant differences with time for the colon are indicated by the lower thin lines and larger filled circles (o, P<0.05, oo, P<0.01, ooo, P<0.001), while those for the duodenum are indicated by the upper thin lines and circles. Significant falls in motility indices during sleep were not seen in the duodenum except between the dinner peak and 23:00 hrs. Significant increases in mean motility index as a result of dinner was seen both for the colon and duodenum. But a significant increase of the mean motility index as a result of lunch was only seen for the colon.

Discussion

The replaced transverse colon is reported to show either no sign of motor activity or only some peristaltic activity (Othersen and Clatworthy, 1967; Sieber and Sieber, 1968; Miller et al., 1975; Clark et al., 1976; Isolauri et al., 1987; Rogers et al., 1987). A swallowed bolus is reported to travel the replaced transverse colon as a result of the bolus weight itself and not due to contraction or by acid induced peristalsis (Jones et al., 1971; Corazziari et al., 1977; Bonagas et al., 1981; Moreno-Osset et al., 1986). However, it is well known that the colon shows signs of complex electrical and mechanical activity (Sarne, 1989). The myo-electrical activity and spike activity of the colon contains a wide range of spectral components, with a lower frequency of 2-
4 cpm and a higher frequency of 6–12 cpm. Spiking activity includes short spike bursts (SSB) and long spike bursts (LSB) (Taylor et al., 1975; Snape et al., 1979; Stoddard et al., 1979; Bueno et al., 1980; Schang et al., 1983; Sarna et al., 1980; Sarna et al., 1981). Spectral analysis of pressure showed less than 1 cpm mass propulsion or mass movement for defecation (Taylor et al., 1975; Naruducci et al., 1987), around 3–5 cpm (Stoddard et al., 1979; Narducci et al., 1987), and around 8–10 cpm (Taylor et al., 1975; Snape et al., 1979; Stoddard et al., 1979; Sarna et al., 1980). All forms of motor activity similar to that described in the normal colon above were observed in this study of the replaced transverse colon during ambulatory overnight recordings. Similarly, in abdominal surface recordings of EGGs, two spectral components, 2.5–3.5 cpm and 3.6–7.5 cpm, are reported to reflect colonic activity (Taylor et al., 1975; Pezzola et al., 1989; Riezzo et al., 1994). We also obtained evidence that two similar components in EGGs, the 3 cpm group (2.5–4.9) and the 6 cpm group (2.0–7.4), reflected colonic activity, especially in intraumbilical recordings (Homma et al., 1999; Homma et al., 2003).

An increase in colonic motor activity after eating is well known as a colonic response to eating (CRE), especially in the rectosigmoid segment (Misiewicz, 1984). Electromyographic analysis revealed that the number of long spike bursts (LSB) and migrating LSB increased after feeding (Frexinos et al., 1985) and LSB of 2.7–3.3 cpm were observed in the rectosigmoid junction (Dapoigny et al., 1988). A manometric study also showed that segmental and migrating contractions increased after feeding (Moreno-Osset et al., 1989). The mechanism of CRE is thought to be mediated by neural reflexes and by gastrointestinal hormones. Afferent neural receptors may be present in the stomach (Sun et al., 1982; Wiley et al., 1988) or in the duodenum (Sun et al., 1982). The replaced transverse colon in this study is innervated by perivascular nerves. Our observation of a postprandial increase of 3 cpm % content in pressure waves in the replaced colonic segment seems to indicate the presence of mechanical and or chemical receptors in the replaced colonic segment itself, or in the duodenum, and probably in the remnant denervated stomach itself. But the significant postprandial increase in 3 cpm % content was seen only in one patient out of four having a remnant stomach. Therefore, chemical receptors and certain gastric hormones in the remnant stomach seem to be too low to produce CRE. A bolus of food in the replaced colonic segment as a substitute for the esophagus seems to stimulate mechanical or chemical receptors of the colonic wall and induce non-migrating or migrating colonic motor activity. However, the mean postoperative duration of the subject group without remnant stomach (60.3 ± 19.53 month, n=4) was significantly longer than that with remnant stomach (9.8 ± 6.16 month, n=4) (P<0.05). We have shown that the motility index improved with longer postoperative periods.

Diurnal changes in colonic motility are also known with a decrease during sleep and an increase after eating and awakening (Frexinos et al., 1987; Narducci et al., 1987; Dapoigny et al., 1988; Soffer et al., 1988). Similar observations have been reported for small bowel motility in the duodenum and jejunum (Soffer et al., 1993). However, the decrease in motility during sleep and the increase on awakening of the duodenum is much less than that observed in this study of the replaced colon. The mechanism involved in the diurnal changes in colonic motility has not been elucidated. Diurnal changes in colonic motility are also seen in the replaced colonic segment. This suggests that basic diurnal rhythms may be present in the hypothalamic diurnal
center, mainly in the suprachiasmatic nucleus, and that the autonomic innervation transmits these changes even in the replaced transverse colon via the intact perivascular nerves or via hormones in the blood supply.

Not all patients needed dilatation to relieve swallowing disorders due to narrowing of the esophago-colonic, colono-gastric or colono-duodenal junctions after the main operation. As for other symptoms, bile regurgitation was found in all patients without the remnant stomach but in no patient with a remnant stomach. The remnant stomach seems to work as a barrier to bile regurgitation.

References


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