Electrical and contractile activities of the human rectosigmoid*

SUSHIL SARNA,† P LATIMER, D CAMPBELL, and W E WATERFALL

From the Departments of Surgery and Physiology, The Medical College of Wisconsin, Milwaukee, Department of Psychiatry, Temple University, Philadelphia, and Departments of Surgery and Psychiatry, McMaster University, Hamilton, Ontario, Canada

SUMMARY Electrical and mechanical activities were recorded from the rectosigmoid of normal subjects using an intraluminal recording tube with two sets of bipolar electrodes and strain gauges. Four distinct types of electrical activities were recorded. (1) Electrical control activity (ECA). This activity varied in amplitude and frequency over time and the control waves were not phase-locked. The means of dominant frequency components in the lower and higher frequency ranges were 3.86±0.18 SD and 10.41±0.46 SD c/min, respectively. The overall dominant frequency component was mostly in the lower frequency range of 2.0–9.0 c/min. (2) Discrete electrical response activity (DERA). This activity appeared as short duration bursts (<10 s) of response potentials whose repetition rate was in the total colonic electrical control activity frequency range of 2.0–13.0 c/min. The mean duration of this activity was 2.24±1.30 SD s. (3) Continuous electrical response activity (CERA). This activity appeared as long duration bursts (>10 s) of response potentials which were not related to electrical control activity. Its mean duration was 14.78±3.68 SD s. This activity generally did not propagate. (4) Contractile electrical complex (CEC). This activity appeared as oscillations in the frequency range of 25–40 c/min and was not related to electrical control activity. This activity propagated, sometimes proximally and sometimes distally. Its mean duration was 18.87±9.22 SD s. The latter three types of electrical activities were all associated with different types of contractions. These contractions, however, did not always occlude the lumen. Colonic electrical control activity controls the appearance of discrete electrical response activity in time and space. The mechanism of generation of continuous electrical response activity and contractile electrical complex is not yet known.

The smooth muscle layers of the stomach and the small intestine show two types of electrical activities, the electrical control activity and the electrical response activity. The electrical control activity controls the appearance, in time and space, of electrical response activity, when the latter is present. The electrical response activity occurs only on a part of the control wave cycle – that is, during the depolarised phase – and is directly associated with rhythmic or phasic contractions.

Our postoperative colonic serosal recordings from patients undergoing cholecystectomy have shown the presence of four distinct types of electrical activities in the ascending, transverse, descending, and the proximal sigmoid colon. These four electrical activities were called the electrical control activity (ECA), the discrete electrical response activity (DERA), the continuous electrical response activity (CERA), and the contractile electrical complex (CEC). The first two of these activities are similar to the two electrical activities in the stomach and the small intestine.

The procedure of intraoperative implantation of electrodes in our previous study, however, did not allow us an easy access to the rectosigmoid. Furthermore, it is difficult to record simultaneously the colonic electrical and contractile activities in the postoperative state to define the relationship...
between them. This study was therefore undertaken to record the electrical and mechanical activities simultaneously from the rectosigmoid using intraluminal recording methods, to define the characteristics of these activities in this region, and to show the relationship between the electrical and mechanical events in the colon. An abstract of this work has appeared elsewhere.3

Methods

The 17 subjects (age 18–60 years, mean 30±14 years; seven men, 10 women) chosen for this study had no known disorder of the gastrointestinal tract. Specifically, they had no complaints of abdominal pain, constipation, or diarrhoea and were not taking any medication. The subjects' diet was restricted to fluids after 6 pm on the day before the experiment. They were given an enema (sodium phosphate-biphosphate compound; Fleet-Frosst) at noon on the day of the experiment that started at 4 pm. Each subject gave informed consent.

A recording tube with two sets of bipolar electrodes and two strain gauges were used to record the electrical and mechanical activities, respectively (Fig. 1). The distance between the electrode-strain gauge pairs was 4-0 cm. The tube was positioned through a sigmoidoscope so that the electrode strain gauge pairs were 10–30 cm from the anal margin. Little or no air insufflation was required. There was no retention of cleansing enema in any of the subjects, observed at sigmoidoscopy.

Respiration was recorded by a Beckman pneumogram placed around the patient's chest. All recordings were made on a Beckman recorder with lower and upper cut off frequencies set at 0-16 and 30 Hz, respectively, for electrical recordings and dc and 30 Hz for strain gauge recordings. The signals were also recorded on a Hewlett-Packard FM tape recorder (model 3968A) for later computer analysis.

This report is part of a larger study in which we have evaluated the effect of mental stress, meal, and neostigmine on colonic electrical and contractile activities. This paper describes the basic characteristics of colonic electrical and contractile activities and the relationship between them during the control period. A 30 minute period was allowed for the adaptation of colon to recording tube insertion. Two two-minute segments of data, one from 30–32 minutes and the other from 35–37 minutes from the beginning, were chosen from both the electrodes for computer analysis of electrical control activity. The electrical control activity was analysed using the Fast Fourier transform method as described before.4 The frequency analysis was done on one minute segments of data called blocks. There were thus a total of 136 blocks of data for the 17 subjects from both electrodes.

Fig. 1 (a) Intraluminal recording tube with electrodes and strain gauges. (b) Electrical and mechanical activities of rectosigmoid. E1 and E2 were 4 cm apart, while SG1 and SG2 were approximately at same level as E1 and E2, respectively. Each tick at top represents one second.
The electrical signals were sampled at 10 Hz for analysis of electrical control activity as described before. Each block of data for this analysis thus consisted of 600 data points representing a one minute period. Four hundred and twenty-four zeros were added to it to form 1024 points for the Fast Fourier transform analysis.

The criteria for the selection of significant frequency components in electrical control activity was the same as described before. The strongest frequency component in the total colonic electrical control activity frequency range of 2.0–13.0 c/min was first identified. Additional frequency components were considered to be present if their peaks were at least 25% in strength of the largest peak. The peak at respiration frequency, if any, was rejected. The peaks in the lower frequency range of 2.0–9.0 c/min were labelled as LP1, LP2, LP3, and LP4 and in the higher frequency range as HP1 and HP2 in the decreasing order of their magnitudes, respectively.

The durations of discrete electrical response activity, continuous electrical response activity, contractile electrical complex, and their associated contractions and their propagation were determined visually over the 10 minute recording period in each of the 17 subjects. The frequency analysis of response potentials in both the discrete electrical response activity and the continuous electrical response activity was done using a sampling rate of 100 Hz over a period of 10.24 seconds as described earlier.

Like all other intraluminal recording devices, our recording tube recorded only those contractions which constricted the lumen to at least the size of the diameter of the recording device. In our case, the diameter of the recording tube was 8 mm. The contractions that constricted the lumen to this size were called lumen occluding contractions.

Results

Four distinct types of electrical activities were recorded from the human rectosigmoid using intraluminal electrodes. (1) Electrical control activity (2) Discrete electrical response activity (3) Continuous electrical response activity and (4) Contractile electrical complex. These were similar to those that have been reported for the rest of the colon using serosal electrodes. The last three activities were associated with contractions of colonic muscle as recorded by intraluminal strain gauges.

ELECTRICAL CONTROL ACTIVITY

Electrical control activity was present in the rectosigmoid in all blocks of data recorded from all subjects. It was irregular in amplitude and time, varying in frequency as shown in Fig. 1(b). These characteristics are similar to those that have been reported earlier for electrical control activity in the ascending, transverse, descending, and the proximal sigmoid colon using serosal electrodes. The control waves were not phase-locked at the adjacent electrode sites 4 cm apart in any of the subjects.

Figure 2 shows the power spectrum plots of the first minute of electrical signals in Fig. 1(b). The signal at E1 had only one significant frequency component at 5.8 c/min. There is only one significant frequency component at 5.8 c/min. (b) Power spectrum of the corresponding one minute of electrical control activity at E2 in Fig. 1(b). This block of electrical control activity had three frequency components in the lower frequency range of 2.3, 5.8, and 7.0 c/min in the decreasing order of their magnitudes. In addition, a frequency component of 10.5 c/min was also present in the higher frequency range.
component at 5·8 c/min (LP1). The electrical control activity signal at E2 had three frequency components 2·3 c/min, 5·8 c/min, and 7·0 c/min in the lower frequency range of 2·0–9·0 c/min. These were called LP1, LP2, and LP3 in the decreasing order of their strength. The electrical control activity signal at E2 also had one frequency component at 10·5 c/min in the higher frequency range of 9·0–13·0 c/min. This was called HP1. The overall dominant frequency component defined as one that has the largest signal strength in the total colonic electrical control activity frequency range of 2·0–13·0 c/min was at 2·3 c/min at E2.

In general, up to four frequency components (LP1, LP2, LP3, and LP4 in the decreasing order of their strength) were observed in the lower frequency range of 2·0–9·0 c/min and up to 2 (HP1 and HP2 in the decreasing order of their strength) in the higher frequency range of 9·0–13·0 c/min. The mean frequencies of LP1, LP2, LP3, LP4, HP1, and HP2 are given in the Table. The overall dominant frequency component was in the lower frequency range in 92·6±15·3% of blocks.

**Discrete electrical response activity**

This activity appeared as short duration (<10 s) bursts of response potentials as shown in Fig. 3. The tracing at E1 shows one burst of continuous electrical response activity (continuous electrical response activity see later) and three bursts of discrete electrical response activity. The onset of continuous electrical response activity is indicated by a double arrow, while the onsets of discrete electrical response activity bursts are indicated by single arrows. The difference between the two is that the continuous electrical response activity consisted of response potentials that were continuously present over one or more control wave cycles whereas the discrete electrical response activity bursts lasted for only a part of control wave cycle. The contractions associated with continuous electrical response activity and discrete electrical

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**Table Colonic ECA frequency components**

<table>
<thead>
<tr>
<th></th>
<th>Mean ± SD (c/min)</th>
<th>% Presence</th>
</tr>
</thead>
<tbody>
<tr>
<td>LP1</td>
<td>3·86±0·18</td>
<td>97·0±9·4</td>
</tr>
<tr>
<td>LP2</td>
<td>4·90±0·82</td>
<td>73·5±16·4</td>
</tr>
<tr>
<td>LP3</td>
<td>5·87±1·41</td>
<td>42·6±15·3</td>
</tr>
<tr>
<td>LP4</td>
<td>6·62±1·38</td>
<td>14·7±12·8</td>
</tr>
<tr>
<td>HP1</td>
<td>10·41±0·46</td>
<td>33·0±31·8</td>
</tr>
<tr>
<td>HP2</td>
<td>11·28±1·27</td>
<td>7·3±11·7</td>
</tr>
</tbody>
</table>

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*Fig. 3* Tracing showing the occurrence of continuous electrical response activity and discrete electrical response activity bursts. The onsets of these two types of activities are shown by double and single arrows, respectively. The continuous electrical response activity burst at E1 was associated with a tonic lumen occluding contraction at SG1 of approximately the same duration. The three discrete electrical response activity bursts at E1 were associated with rhythmic contractions at SG1. The discrete electrical response activity burst at E2 was also associated with a contraction at SG2. Each tick at the top represents one second.
response activity bursts were of approximately the same duration as the corresponding bursts. The contractions associated with continuous electrical response activity were of long duration whereas those associated with discrete electrical response activity were of the rhythmic or phasic type. The discrete electrical response activity burst at E2 was also associated with a small amplitude contraction at SG2.

There was no fixed temporal or spatial pattern of occurrence of discrete electrical response activity bursts. The response potentials sometimes occurred as a single burst and sometimes as a train of a few bursts on consecutive control wave cycles. The mean duration of discrete electrical response activity bursts was 2·2±1·2 SD s (n=130).

The discrete electrical response activity bursts were accompanied by lumen occluding contractions in 44% of cases. When discrete electrical response activity bursts occurred as a train, the dominant frequency component in the power spectrum of electrical control activity corresponded to the repetition rate of bursts indicating that the appearance of discrete electrical response activity in the rectosigmoid is controlled by electrical control activity as in the rest of the colon.²

CONTINUOUS ELECTRICAL RESPONSE ACTIVITY
This activity appeared as long duration (>10 s) bursts of response potentials which continued over one or more control wave cycles as shown in Figs. 3 and 4. The duration of continuous electrical response activity bursts or their repetition rate was not related to electrical control activity. The frequency content of continuous electrical response activity as determined by the Fast Fourier transform method was in the range of 0·9–10·0 Hz which was the same as that of discrete electrical response activity. This agrees with the frequency content of these activities recorded with serosal electrodes from the rest of the colon.² The duration of continuous electrical response activity varied from 10–28 s with a mean of 14·7±3·6 SD s (n=35). In three out of 35 occurrences, the continuous electrical response activity appeared concurrently at both the electrodes. In two cases, the time lag of onset was proximal, and in one case it was distal. Figure 4 shows the distal time lag between the onsets of continuous electrical response activities at E1 and E2. The onset of corresponding contractions at SG1 and SG2 also showed a distal time lag. This activity was associated with a sustained colonic muscle contraction as shown in Figs. 3 and 4. The duration of contractions was approximately the same as that of the continuous electrical response activity burst (mean 15·4±4·1 SD s). This activity was associated with a lumen occluding contraction in only 60·0% of its occurrences.

CONTRACTILE ELECTRICAL COMPLEX
The contractile electrical complex appeared as bursts of electrical oscillations in the frequency range of 25–40 c/min as shown in Fig. 5. This figure shows four bursts of contractile electrical complexes at electrodes E1 and E2. Both bursts at E1 and the second burst at E2 are associated with tonic contractions. The duration of each contraction was approximately the same as the duration of contractile electrical complex bursts (mean 17·1±8·6 SD s). The duration of contractile electrical complex bursts varied from 8 to 84 s with a mean of 18·8±9·2 s (n=83).

The contractile electrical complex bursts were not always associated with lumen occluding contractions, as is shown in Fig. 6 where the first burst of contractile electrical complex at E2 is associated with a lumen occluding contraction, whereas the second burst at the same electrode and with the same sensitivity is not associated with such a contraction. The second burst was recorded five minutes after the first one. The contractile electrical
Tracing showing two distally propagated bursts of contractile electrical complexes at electrodes E1 and E2. Both bursts at E1 and second burst at E2 are associated with tonic lumen-occluding contractions. The onsets of contractile electrical complexes and contractions are indicated by arrows. Each tick at top represents one second.

complex burst at E1 was also not associated with a lumen occluding contraction. The contractile electrical complex was associated with lumen occluding contractions in 55% of its occurrences.

The contractile electrical complex bursts occurred concurrently at both the electrodes in 32.1% of the cases (Fig. 6(a)). When so, the time of onset of contractile electrical complex at the two electrodes showed a distal lag in 71.4% of cases, a proximal lag in 17.8% of cases, and it appeared simultaneously at the two electrodes in the remaining 10.7% of cases. In Fig. 5, both bursts of contractile electrical complexes

(a) Two tracings showing contractile electrical complexes and associated contractions from same subject, five minutes apart. Contractile electrical complex at E2 in (a) was associated with tonic lumen-occluding contraction, while later occurrence of contractile electrical complex at same electrode and with same sensitivity was not associated with lumen-occluding contraction. Furthermore, during second occurrence in (b), the contractile electrical complex occurred only at electrode E2, while, during first occurrence, contractile electrical complex bursts occurred concurrently at both electrodes and showed a proximal time lag. Contractile electrical complex at E1 was, however, not associated with lumen-occluding contraction.
complex at the two electrodes occurred with a distal time lag, whereas in Fig. 6(a) the contractile electrical complex bursts occurred with proximal time lag. The velocity of propagation of contractile electrical complex was 1.26±0.6 cm/s (n=6) in the proximal direction and 1.73±1.1 cm/s (n=21) in the distal direction. When the contractile electrical complex bursts occurred concurrently at the two electrodes, the individual oscillations of contractile electrical complex were not phase-locked. On other occasions, contractile electrical complex bursts occurred on only one electrode at a time as shown in Fig. 6(b).

Discussion

Four distinct types of electrical activities are present in the human rectosigmoid as in the rest of the colon. The characteristics of electrical control activity in the rectosigmoid are similar to those that have been reported for the rest of the colon using serosal electrodes — that is, it is time varying in frequency and amplitude but continuously present. The mean frequencies of electrical control activity in the rectosigmoid in the lower and higher frequency ranges recorded with intraluminal electrodes are comparable with those recorded from the human colon postoperatively with serosal electrodes. This confirms our earlier observation that colonic electrical control activity frequency is not significantly altered in the convalescent period after laparotomy. This study shows that the rectosigmoid electrical control activity has the characteristics of electrical control activity in the distal segment where the overall dominant frequency is usually in the lower frequency range and the control waves are not phase-locked. The presence of multiple frequency components whose frequency and amplitude vary from minute to minute signifies that the colonic electrical control activity is non-sinusoidal in waveshape and time-varying in frequency and amplitude.

The remaining three types of electrical activities are all associated with contractions of colonic muscle. The discrete electrical response activity generally occurred as isolated short duration bursts of response potentials. If these occurred in a train, their repetition rate was in the total colonic electrical control activity frequency range of 2.0–13.0 c/min. Bueno et al have also observed the repetition rate of these bursts to a maximum of about 13/min in human rectosigmoid. The lack of coordination of discrete electrical response activity at adjacent electrodes is explained by the phase-unlocked electrical control activity at these electrodes. The cycle to cycle variation of electrical control activity frequency content explains the lack of periodicity in the repetition rate of discrete electrical response activity.

The discrete electrical response activity of the colon is similar to the electrical response activity of the stomach and small intestine. The term discrete was added to distinguish it from continuous electrical response activity in the colon.

The continuous electrical response activity was so called because it occurred as a continuous burst of response potentials over one or more control wave cycles, as opposed to discrete electrical response activity, which occurred as a discrete burst of response potentials over a part of the control wave cycle. The repetition rate of discrete electrical response activity is controlled by electrical control activity, whereas continuous electrical response activity occurs independently of electrical control activity. Bueno et al have also reported the presence of two types of response potential bursts in the human colon. They called them short duration when the bursts were of duration 1.5–3.5 s and long duration bursts when the duration was 17 to 21 s. These roughly correspond to discrete electrical response activity and continuous electrical response activity in our recordings. Bueno et al, however, used a lower cut-off frequency of 1.6 Hz and would have thus filtered out electrical control activity and contractile electrical complex.

The difference between continuous electrical response activity and contractile electrical complex is that the latter occurs as electrical oscillations in the frequency range of 25–40 c/min, whereas the continuous electrical response activity consists of a burst of response potentials at a frequency of 0.9–10 Hz. They were both, however, associated with sustained contractions whose durations were approximately the same as the duration of corresponding bursts of continuous electrical response activity or contractile electrical complex.

Another major difference between the continuous electrical response activity and the contractile electrical complex is that the contractile electrical complex bursts propagate in the proximal or the distal direction much more often than the continuous electrical response activity bursts. Neither continuous electrical response activity nor contractile electrical complex is controlled by electrical control activity in its appearance in time and space.

The contractile electrical complex was so called because the electrical complex (oscillations at 25–40 c/min) were associated directly with contractile activity as opposed to electrical control activity, which is not directly associated with contractions but controls the appearance in time and space of
Colonic motility

discrete electrical response activity, which, in turn, is associated with contractions. Another major difference between contractile electrical complex and electrical control activity is that contractile electrical complex occurs intermittently in bursts, whereas electrical control activity is omnipresent. The contractile electrical complex burst has frequencies in the range of 25–40 c/min, whereas the colonic electrical control activity has frequency components in the range of 2.0–13.0 c/min.

Other investigators have also recorded colonic electrical activities using the intraluminal recording methods but did not report the presence of contractile electrical complex. This could be due to the sensitivity of the recording method. We have observed the presence of contractile electrical complex in the colon with both the serosal and the intraluminal recording methods. Kirk and Duthie have also recorded an electrical activity at 22±5 c/min in vitro from human colon. They showed that this activity was associated with a tonic contraction and thus may be similar to the contractile electrical complex we recorded in vivo. Christensen et al and El-Sharkawy et al have also reported similar activities in the cat and dog colon in vitro using monopolar electrodes.

Our intraluminal strain gauges, like other intraluminal recording methods, would record those contractions that constrict the lumen at least to the size of the diameter of the recording tube. In this regard, we found that all three contractile electrical activities were not always associated with lumen occluding contractions. This may either be due to weak contractions or due to the contractions not occurring simultaneously all around the circumference. Brodribb et al have also reported a lack of 1:1 relationship between response potentials recorded with serosal electrodes and contractions recorded intraluminally with perfused tubes from conscious monkeys. They found that lumen-occluding contractions that would raise the intraluminal pressure at the recording site occurred in less than half the cases where circular muscle contractions were recorded with strain gauges. Couturier et al have also reported that the response potentials recorded with intraluminal electrodes are not always associated with contractions recorded with perfused tubes.

This study shows that the colon has three types of contractions, the rhythmic or the phasic type associated with discrete electrical response activity and controlled in their appearance in time and space by electrical control activity, the tonic type associated with continuous electrical response activity which generally do not propagate, and the tonic type associated with contractile electrical complex which propagate in both directions. The origin and nature of contractile electrical complexes is not known. These complexes seem to be the major propagatory activity in the colon and thus may largely be responsible for the transport of contents.

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S Sarna, P Latimer, D Campbell and W E Waterfall

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