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Resolution of Postoperative Ileus in Humans

ROBERT E. CONDON, M.D. VERNE E. COWLES, B.S. WILLIAM J. SCHULTE, M.D.
CONSTANTINE T. FRANTZIDES, M.D. JAMES L. MAHONEY, M.D. SUSHIL K. SARNA, PH.D.

From the Department of Surgery and the Vince Lombardi Cancer Clinic, The Medical College of Wisconsin, and the Surgical Research Section, Zablocki VA Medical Center, Milwaukee, Wisconsin

Bipolar electrodes were placed in the ascending and descending colon of 13 patients during laparotomy. The magnitude of their operations varied from exploratory laparotomy to total gastrectomy. The magnitude and length of the operations performed did not correlate positively with the duration of postoperative ileus. Signals were recorded for up to 4 hours daily for up to 8 days after operation during periods of rest and, in some patients, after administration of epidural or parenteral morphine sulfate. Power spectrum analyses of electrical control activity (ECA) showed dominant frequencies in both lower (2–9 cpm) and higher (9–14 cpm) ranges. During postoperative recovery, the mean ECA frequencies in right and left colon were relatively constant, but a variety of dominant ECA frequency relationships were observed. The modal pattern in the right colon was a shift in the dominant frequency from the higher to the lower range as recovery progressed, while the modal pattern in the left colon was persistent dominance of ECA in the higher frequency range. Electrical response activity (ERA) initially was comprised of only random, disorganized single bursts but became progressively more complex through the initial 3 postoperative days with the appearance of more organized bursts and clusters, some of which propagated very slowly (about 5 cm/min) both orad and aborad. ERA recovery culminated, typically on the third or fourth postoperative day, with the return of long bursts of continuous ERA, some of which propagated at a higher velocity (about 80 cm/min) and exclusively in the aborad direction and which were accompanied by passage of flatus or by defecation.

POSTOPERATIVE ILEUS is a form of temporary bowel motor dysfunction that regularly follows operative procedures in the abdomen and on its contents or adjacent tissues, and occurs after operations remote from the abdomen, particularly those involving the brain.

The discoordination of bowel motor function during postoperative ileus prevents consumption of an oral diet immediately after operation and is responsible for some morbidity and for prolongation of postoperative recovery and hospital stay.

We have previously reported our experimental observations in monkeys of early postoperative recovery of bowel function. We first demonstrated that postoperative ileus was most persistent in the left colon compared to other bowel segments,[1] and that recovery of motor function occurred about the third day after an abdominal operation. We then showed that the timing and pattern of recovery of coordinated colonic motor function after operation was not influenced either by the magnitude or by the length of the operative procedure.[2,3] Morphine, a stimulant of motor activity in normal bowel, was shown also to stimulate the colon during postoperative ileus, whereas other commonly used anodynes, such as meperidine and codeine, were less active in this regard.[4,5]

Understanding of colon motor function in man is limited, primarily because under usual conditions studies are restricted to those segments of the colon that can be easily intubated per anum. Further, serial observations of motor function from the same colon site over a period of days cannot reliably be accomplished by repetitive intubation of the lumen. Such longitudinal studies are possible only with implanted electrodes; only a few such studies have been done,[6–9] none of which provide data from the first postoperative day onward.

We now report our observations in 13 patients of the relationship of operative magnitude and duration to the duration of postoperative ileus, and the changes in elec-

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Reprint requests: Robert E. Condon, M.D., Ausman Foundation Professor and Chairman, Department of Surgery, The Medical College of Wisconsin, 8700 West Wisconsin Avenue, Milwaukee, WI 53226.

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TABLE 1. *Data of Patients Having Colon Motility Recordings*

Patient ID	Diagnosis	Operation	Operation Length (hr)	Operation Magnitude*	Day Ileus Clears
#1 19 F	Traumatic paraplegia	Colostomy closure	1.7	2	4
#2 32 M	Familial pancreatitis	Pancreatojejunostomy	3.2	3	4
#3 82 F	Failed Angelchik	Fundoplication	1.8	3	3
#4 62 F	Failed Nissen	Fundoplication	2.3	3	3
#5 56 M	Reflux esophagitis	Fundoplication	3.2	3	3
#6 60 M	Cholelithiasis	Cholecystectomy	1.7	2	4
#7 63 M	Renal artery stenosis	Angioplasty	3.3	3	3
#8 64 F	Epigastric mass	Exploratory lap; biopsy	0.8	1	4
#9 28 M	Chronic gastric atony	Total gastrectomy	5.7	4	2
#10 36 F	Small bowel obstruction	Exploratory laparotomy	4.2	1	3
#11 72 F	Rectal prolapse	Rectopexy	3.3	3	3
#12 17 M	Reflux esophagitis	Fundoplication	1.8	3	4
#13 84 F	Diverticulitis	Anterior resection	4.5	3	2

* Arbitrary scale, range 1–4.

trical control activity (ECA) and electrical response activity (ERA) during recovery from postoperative ileus. ECA is a recurring depolarization of intestinal smooth muscle. ERA is an intermittent high frequency discharge superimposed on the depolarization of ECA and associated with muscle contraction.

Material

The study group was comprised of seven women and six men, ranging in age from 17 to 84 years, who were having elective abdominal operations. The diagnoses treated and operations conducted are recorded in Table 1. The experiments were reviewed and approved by the Human Research Review Committee of the Medical College of Wisconsin, and all patients gave informed consent to participate.

Anesthetic management was that chosen by the assigned anesthesiologist. Continuous epidural technic was elected in four patients; the epidural catheter was utilized in these patients for administration of morphine for up to 72 hours after operation. Postoperative patient management was not constrained, except that nasogastric tubes were not used.

Electrodes were fashioned from 0.3 mm O.D., Teflon®-coated, stainless steel wire (Medwire Corp., Mt. Vernon, NY) using the technic reported by Sarna and colleagues.[8,9] Electrodes were inserted through the anterior taenia into the circular muscle of the colon. Two electrodes were placed at each recording site, 2–4 mm apart, thus forming a bipolar electrode.

Three electrode pairs were placed in ascending (N = 10) and descending (N = 12) colon, each pair being 3 or 5 cm apart. In the ascending colon, the distal electrode pair was placed at the hepatic flexure; in the left colon, the proximal electrode pair was placed at the descending-sigmoid junction. The ends of each electrode pair were withdrawn through a needle in the flank and fixed to the skin. At the completion of postoperative observations, the electrodes were withdrawn by traction; there were no complications related to electrode placement or withdrawal.

Beginning on the first postoperative day and continuing daily until the patient had recovered from postoperative ileus, and in three patients for 1–3 days thereafter, recordings were made continuously daily for a period of 2–4 hours. Respiration was monitored by a pneumograph and recorded simultaneously with the signals from the bowel. The opportunity was taken in seven of our patients to record the effects of morphine, which had been ordered for pain relief; the morphine doses varied from 3–15 mg IM, 2–8 mg IV, and 5–9 mg epidural.

Recordings were made on a polygraph (Model 7, Grass Instrument Co., Quincy, MA) with lower and upper cutoff frequencies set at 0.04 and 35 Hz. Recordings were also made simultaneously on a magnetic FM tape recorder (Model 3968A, Hewlett-Packard Corp., San Diego, CA).

TABLE 2. *Characteristics of Electrical Response Activity During Recovery from Postoperative Ileus in Humans (N = 11)*

ERA Activity Class	Individual Burst Duration (sec)	Duration of Cluster (min)	Appears Day (mode)	Propagation Characteristics: Direction	Velocity (cm/min)	Segments Involved
DERA (short burst)	2.3 ± 0.1	4.9 ± 0.7	2	Both	2.4 ± 0.05	L only
DERA (longer burst)	4.4 ± 0.2	6.3 ± 6.3	3	Both	1.9 ± 0.5	L only
CERA (shorter burst)	12.2 ± 1.0	5.5 ± 0.8	3	Both	81 ± 11	R & L
CERA (longer burst)	20.1 ± 2.7	0.34 ± 0.05	4	Aborad only	80 ± 11	R & L

After visual inspection of the paper recordings, 80–120 representative minutes of each daily taped record were selected for further analysis. Movement artifacts were deleted, but otherwise the segments analyzed were continuous. The taped records were low-pass filtered below 0.3 Hz and band-pass filtered between 1–10 Hz to segregate ECA and ERA, respectively, at each recording electrode.

For analysis of ECA, the tape-recorded signals from each bipolar electrode were low-pass filtered at 1 Hz and sampled at 2 Hz. A total of 80–120 blocks of data from each electrode were analyzed each day; there were 128 data points, representing 64 seconds, contained in each block of data. Each block was subjected to fast-Fourier transformation using a computer (Nova 4X, Data General Corp., Southboro, MA) to determine the power spectrum.[8] The resolution of the fast-Fourier transformation program was 0.47 cpm. The power spectrum so produced is a display of the relative strength of each frequency component of a complex signal, normalized so that the strongest frequency has a magnitude of 10. Frequency peaks representing respiration were discarded. We then determined in each data block the frequencies with a magnitude of 9 and 10 occurring in the power spectrum and summed all such occurrences of each frequency during the entire recording analyzed to determine the overall power spectrum incidence of ECA being exhibited at each electrode by each patient on each day. Analysis of the ECA power spectra have been completed in six of the patients reported.

ERA was analyzed by rerecording all signals between 1–10 Hz (band-pass filtered) from the same 80–120 minutes of the original taped record used for the ECA analysis. The resultant filtered signals were then rerecorded on paper and used, together with the raw record, for initial visual analysis. Response activity was segregated into classes on the basis of whether the activity was random or grouped, the duration of individual ERA bursts, the overall duration of clusters of bursts, whether the bursts or clusters propagated, and the direction and velocity of propagation (Table 2). Propagation was defined as the sequential appearance at three electrodes with a constant velocity between electrodes of an ERA burst. Clusters were identified as repetitive ERA bursts of similar character occurring for a minimum duration of 2 minutes. ERA analysis has been completed in 11 of the 13 patients reported.

TABLE 3. *Colonic Electrical Control Activity During Recovery from Postoperative Ileus (cpm ± S.E.)*

	Colon Site Recorded: Frequency Range			
	Right Colon*		Left Colon*	
	Lower	Higher	Lower	Higher
Postoperative day				
1	5.8 ± 0.4	12.5 ± 0.3	7.4 ± 0.3	11.4 ± 0.2
2	5.9 ± 0.6	11.6 ± 0.5	3.7 ± 0.5	11.2 ± 0.5
3	5.2 ± 0.6	11.6 ± 0.4	4.7 ± 0.4	11.9 ± 0.4
4	4.9 ± 0.5	11.6 ± 0.5	4.9 ± 0.7	11.3 ± 0.5
5	6.5 ± 0.6	12.7 ± 0.4	8.5 ± 0.5	11.8 ± 0.8
6	4.2 ± 0.5	11.9 ± 0.5	4.8 ± 0.9	11.2 ± 0.5

* N = 6.

Results

Clinical Recovery from Ileus

Ileus cleared, as recorded in Table 1, on the third postoperative day (mean = 3.2 days; mode = 3 days). The correlation coefficient for length of operation *versus* duration of ileus is strongly negative (r = −0.9), as is the correlation coefficient for magnitude of operation *versus* duration of postoperative ileus (r = −0.8).

Electrical Control Activity

ECA was present throughout all recordings made from the first postoperative day onward. Although omnipresent, ECA amplitude waxed and waned, particularly during quiescent periods. Some electrodes recorded a dominant ECA frequency in the lower range of 2–9 cpm, typically with a power spectrum peak at 3–4 cpm, while other electrodes had ECA frequency dominance in the higher range of 9–14 cpm and peak power at frequencies of 11–12

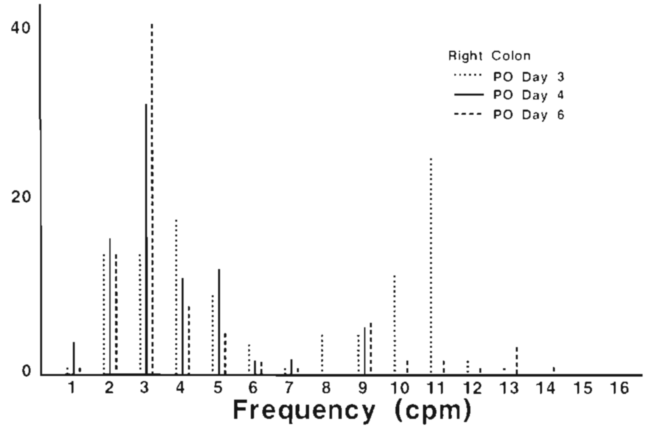

FIG. 1. ECA in the right colon shows a bimodal distribution of frequencies in both the lower and higher ranges on the third postoperative day (dots), but shifts to the lower range on the fourth postoperative day (solid) and subsequently (dashes). The vertical scale expresses the relative power spectrum incidence of the various ECA frequencies. Shifting of the dominant ECA frequency was the most common pattern noted in the right colon after operation.

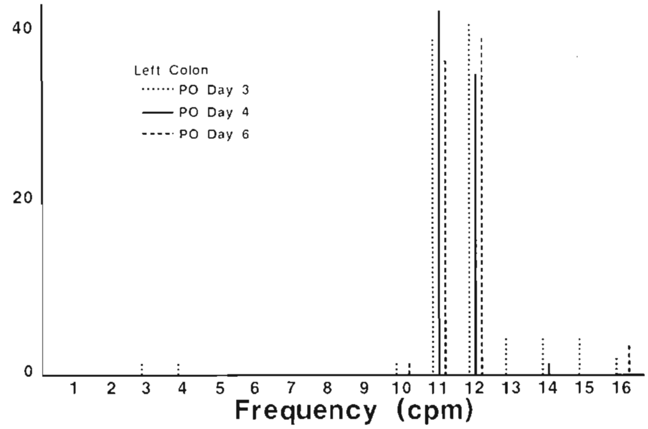

FIG. 2. ECA in the left colon shows dominance of frequencies in the higher range throughout postoperative recovery. This was the modal pattern of ECA activity in the left colon after operation. Contrast with Figure 1. Vertical scale as in Figure 1.

cpm. Mean ECA frequency in both the lower and higher ranges was nearly constant in both the right and left colon throughout recovery from postoperative ileus (Table 3). Inspection of the ECA recordings indicated that ECA was phase unlocked most of the time, particularly so during postoperative days 1 and 2, but detailed analyses remain to be done. Propagation of discrete electrical response activity (DERA, in which each ERA burst occurs on its corresponding ECA), implying at least intermittent phase-locking of ECA, was observed occasionally on postoperative day 2, and then progressively more frequently as recovery progressed. However, phase unlocked ECA was still the more common state, even after complete clinical recovery from ileus.

Between the lower and higher ECA frequency ranges, a variety of relationships were observed during postoperative recovery. In the right colon, the modal pattern was a progressive shift from the higher to the lower dominant ECA frequencies as recovery from ileus progressed (Fig. 1). The next most common pattern was ECA constantly dominant in the lower frequency range. But dominant ECA frequencies persistently in the higher range were recorded from two right colon electrodes, and shifts back and forth between the lower and higher frequency ranges were recorded from three other electrodes throughout the period of postoperative observation.

In the left colon, there was less variability in ECA. The modal pattern was persistent dominance of higher frequency ECA (Fig. 2). But, in three instances, ECA dominance was persistently in the lower frequency range, and in three other instances a pattern of shifting between the higher and lower ECA frequency ranges was observed at one left colon recording site after operation.

Electrical Response Activity

Typical ERA tracings are displayed in Figure 3. ERA on postoperative day 1 consisted only of random bursts of short duration DERA in all patients. On the second postoperative day, three patients began exhibiting clusters of short DERA bursts; in one patient, this response activity propagated in both the orad and aborad directions. Short burst DERA was present in all patients on the third postoperative day. On this day, ERA also became progressively more complex; discrete ERA having a longer burst duration appeared in most patients and propagated bidirec-

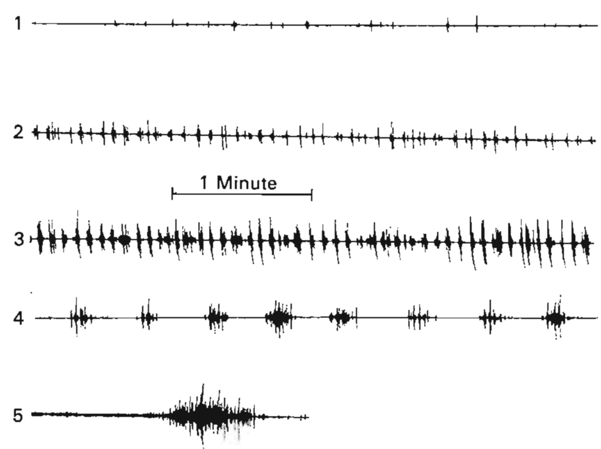

FIG. 3. Types of ERA recorded after operation. Line 1 shows random single bursts of short duration that were present on the first postoperative day. Line 2 shows short burst discrete ERA occurring in a cluster; this type of ERA appeared as early as the second postoperative day. Line 3 shows longer burst discrete ERA in a cluster of repetitive depolarizations; this type of ERA appeared on the third postoperative day. Line 4 shows a cluster of ERA exhibiting bursts that are longer than the ECA cycle; this activity appeared on the third or fourth postoperative day. Line 5 shows a very long burst of ERA, first appearing on the fourth postoperative day.

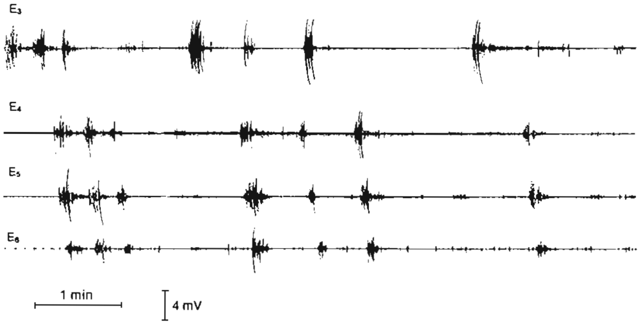

FIG. 4. Continuous ERA bursts that propagate from the right colon (electrode E3) to the left colon (electrodes E4–E6). This type of ERA was associated with passage of flatus.

tionally in the left colon (Table 2). Continuous electrical response activity (CERA, in which the burst discharge duration is longer than an ECA cycle and which is not controlled by ECA) also appeared on postoperative day 3 in most patients, and sometimes propagated bidirectionally (Fig. 4). CERA with a relatively long burst duration appeared on the fourth postoperative day; this ERA always migrated aborally (Fig. 5). Aborally propagated CERA of either shorter or longer burst duration was associated with the initial postoperative passage of flatus and stool. This type of response activity appeared initially on postoperative day 3 in three patients, on postoperative day 4 in five additional patients, and on postoperative day 5 in the remaining three patients.

Morphine Responses

Administration of intravenous morphine failed to evoke a consistent response on the first postoperative day, but thereafter both intravenous and intramuscular morphine always resulted in a ERA response (Fig. 6) lasting at least for 5 minutes, and which usually was of longer duration

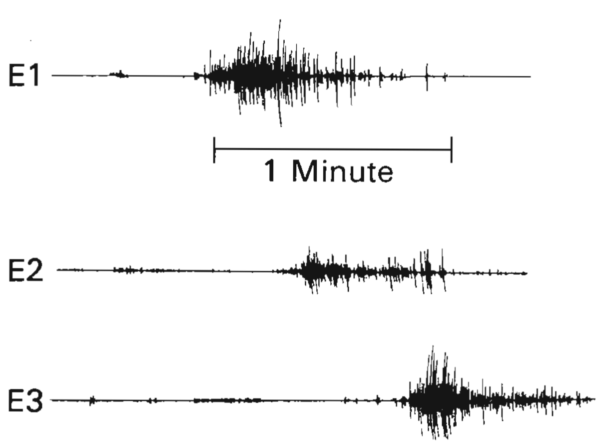

FIG. 5. Continuous long duration ERA burst propagating aborally. This ERA was seen in both the right and left colon, but was more common on the left side, and was associated with the passage of stool.

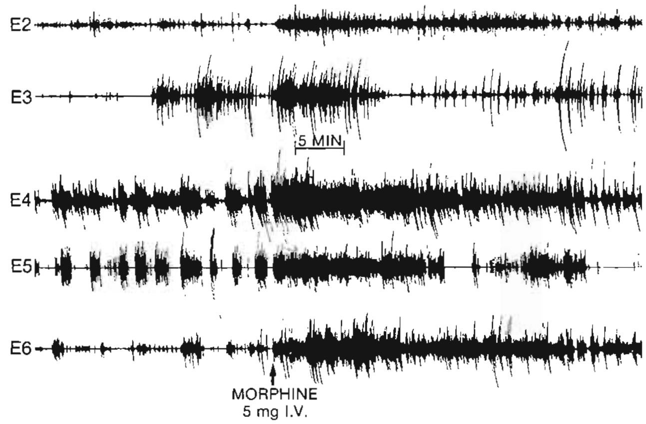

FIG. 6. The response to morphine (5 mg intravenously, at arrow) is a prolonged burst of both discrete and continuous ERA that is of longer duration in the left colon. Electrodes E2 and E3 are in ascending colon; electrodes E4–E6 are in left colon. This record has been condensed (compare Figures 3–5) in order to exhibit more of the ERA response induced by morphine. The condensed record appears to exhibit nearly continuous ERA, but both discrete and continuous ERA are present in the original record.

in the left colon compared to the right. Epidural morphine never produced ERA stimulation. Following intravenous or intramuscular morphine, once the effects of morphine stimulation abated, the colon returned to its former state. Administration of morphine did not induce ERA propagation, was not associated with passage of flatus or defecation, and did not alter the time to clinical recovery from postoperative ileus.

Discussion

The magnitude and length of an operation do not appear to be major factors influencing the duration of postoperative ileus. Indeed, in our patients, the correlation coefficients for both of these variables were negative, indicating that longer and more complex operations were associated with a shorter duration of ileus after operation. This observation in patients is similar to data we have derived from experiments in subhuman primates.[3]

Recovery from postoperative ileus appears, from our limited observations, to involve changes in both ECA and ERA. ECA was present in the earliest postoperative recordings. During quiescent periods, ECA amplitude waxed and waned, but ECA was never absent. This observation confirms the report of Sarna and associates.[8] Our finding differs from that of Couturier and associates,[10] Snape and coworkers,[11] and Taylor and colleagues,[9,12] who found ECA to be absent for part of the time in their recordings from various colon segments. The most probable explanation of the divergence between our observations and those of some other investigators is that methodologic difficulties led to their failure to identify the omnipresent ECA.

In both the right and left colon, there are two ranges of ECA frequencies. In the lower range, the mean frequency lies between 4.2–6.5 cpm in the right colon, and between 3.7–8.5 cpm in the left colon. In the higher range, the mean ECA frequencies were between 11.6–12.7 cpm in the right colon and 11.2–11.9 cpm in the left colon. These observations confirm those of Sarna and colleagues,[8] who also found similar ranges of ECA frequencies in the intra-abdominal colon. Taylor and associates also have reported ECA frequencies of 3 and 10 cpm in their patients after operation, values that are in reasonable agreement with our observations.[6,12]

The right and left colon behave differently in terms of ECA frequency during recovery from postoperative ileus. In the right colon, the most frequent ECA pattern was a shift from a bimodal expression of control potentials involving both the lower and higher frequency ranges to dominance of the lower 3–4 cpm frequencies as ileus resolved and oral alimentation was resumed. But there was considerable variation in the ECA patterns observed in the right colon after operation; dominance of the lower frequencies throughout the postoperative period was found almost as often as the shifting pattern. In the left colon, the higher 9–14 cpm frequencies dominated ECA throughout recovery from ileus, although there also was some variation, particularly in recordings from electrodes implanted in the more proximal portions of this side of the colon. The importance of shifting ECA during the early postoperative period is that it would prevent even temporary phase-locking of control potentials. Phase-locking occurs when individual ECA generators are coordinated with each other so they are discharging at the same frequency and with a fixed time lag between them. The presence of two frequency ranges of ECA, and the shifts in the dominant ECA frequency observed in some patients during recovery from ileus, is evidence that there are multiple ECA generators in the colon.

Random DERA was uniformly present in recordings made on the first postoperative day. Return of ERA progressed from short to longer single bursts, often in clusters lasting several minutes. Then relatively short, continuous ERA bursts, also occurring in clusters, appeared in both right and left colon, with occasional bidirectional propagation of these ERA in the left colon. Recovery from postoperative ileus culminated with aborally migrating longer, continuous bursts (CERA), appearing as early as the third postoperative day, and associated with clinical recovery from ileus as evidenced by passage of flatus and stool and subsequent ability to consume a diet.

Both the short and longer single bursts of response activity seen in our patients resemble the DERA reported by Sarna and colleagues[9] in that ERA occurs on each ECA, the ERA burst is of short duration (<10 sec), and has a maximal repetition rate which is that of the ECA frequency, about 11/min. This type of ERA also is similar to the short spike burst activity observed by Bueno and associates.[7,13] These workers defined short spike bursts as lasting 3.1 ± 0.4 seconds with a frequency of 10.6 ± 0.3 bursts/min.

The longer, more continuous bursts of ERA seen in our patients, which marked clinical recovery from ileus, fit the definition of CERA reported by Sarna,[9] in which individual oscillations were in the frequency range of 0.9–10 Hz and persisted for 15–300 seconds. This type of ERA is also similar to the long spike burst activity reported by Bueno and coworkers,[7,13] defined as bursts lasting 10.3 ± 3.6 seconds, occurring in isolation or rhythmically recurring at a rate of 3/min, or propagated at a speed of 3.9 ± 1.6 cm/sec or at a faster speed of 9.3 ± 2.4 cm/sec.

The ERA that followed administration of intravenous or intramuscular morphine in our patients shows that colonic smooth muscle opioid receptors can be stimulated to respond with a burst of ERA as early as the second postoperative day. But morphine-induced ERA was never seen to propagate, and administration of morphine did not alter the duration of postoperative ileus.

The pattern of recovery from postoperative ileus is very similar in both monkeys and man. Both ECA and ERA return to normal over the initial 3–4 days after operation. ECA, although constantly present, does show shifts in frequency in some patients, particularly in the right colon, but with eventual stabilization of the dominant ECA frequency in the lower range in the right colon and in the higher range in the left colon. ERA shows progressively more complex activity, beginning with random bursts, evolving through increasingly longer bursts, and culminating in coordinated aborally propagated discharges. A more complete understanding of colonic smooth muscle myogenic controls and responses, and of the effects of neural and humoral factors on colon motor function, is essential prior to future pharmacologic explorations to manipulate ileus in man. The similarity of recovery from ileus in monkeys and man indicates that monkeys are an excellent experimental model of human colonic function, particularly useful for screening studies regarding the effects of drugs and other interventions that may influence the course of postoperative ileus.

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Discussion

DR. R. SCOTT JONES (Charlottesville, Virginia): Dr. Condon, I thoroughly enjoyed this excellent presentation and the manuscript.

The study of the regulation of gastrointestinal motility has developed progressively during the last couple of decades, but more recently because of improvements in technology and electronic recording devices a number of advances have occurred. I think that the paper today represents the presentation of significant new information about the regulation of colon motility and is particularly important because the observations were made in human subjects.

The pacesetter potential or basic electrical rhythm has been observed for a number of years. It occurs in the stomach with the origin up in the lesser curvature and progresses aborally with a certain rate. There is also a characteristic of the small bowel, and this is new information concerning the colon in man.

I would like to make a couple of comments and ask clarification about a couple of variables.

First of all, Dr. Condon, I think it would help if you would make some comment to relate and let us understand the relationship between this electrical activity that you measured and the mechanical events that occur in the bowel. That is, can you relate this to motility or can you relate it to some other measurements such as transit?

There were several variables in this study that cannot be controlled in a clinical study like this, and I wonder if you would comment on those. First of all, some of your operations, particularly the fundoplications and certainly the total gastrectomy, probably perturbed the vagus nerve and vagal function. Would you comment on that and whether you could analyze that from your study.

Now, the vagus influences the right colon predominantly but not so much the left. You might want to comment on that.

The other issue is the question of morphine. Some of the patients got morphine and some did not; I was wondering if you could analyze the subsets of patients to observe the influence of morphine more carefully. The third variable I would like to ask about is the question of when the patients began to resume oral intake. You were doing your studies, and your measurements of oral intake were not a control variable. Is it possible that some of the observations that you recorded were the result of oral intake of fluid and solids? In other words, are we observing a feeding response rather than spontaneous recovery?

I think this was an excellent study, well presented and well prepared. I think that the group from Dr. Condon's department is certainly to be congratulated on this excellent work.

DR. JOAQUIN S. ALDRETE (Birmingham, Alabama): Really the two main reasons why patients cannot leave the hospital earlier, and this has become an important issue in these days of cost containment, are: number one, pain and, number two, the fact that gastrointestinal motility is not re-established soon enough. Hence, the efforts of Dr. Condon in elucidating this problem and ultimately accelerating or making possible that a patient undergoing, let's say, a cholecystectomy could go home in 2 or 3 days. It is likely that serious attempts to investigate the problems of impaired gastrointestinal motility in the immediate postoperative period will shorten the hospitalization period in many patients.

It is also to be commended that once Dr. Sarna, the coauthor of this paper and a well known electrophysiologist of the gastrointestinal tract, becomes associated with surgeons like Dr. Condon, basic research methods are applied to pertinent clinical situations.

We have studied extensively, in fact, we presented 4 years ago to this association our work on, postoperative changes in the electrical activity of the stomach. Some of the difficulties we found were similar to those found in the colon by Dr. Condon. I have some specific questions:

First, is what you are referring to as the ERA, the electrical response activity, the same thing as the fast wave or the spike potentials, which are recognized as perhaps the most likely event that triggers or initiates contraction?

Second, Dr. Jones already alluded to it; all the experts agree that the presence of electrical activity does not mean that there is contraction, which is what produces the re-establishment of colonic motility. Establishing this correlation between electrical activity and contraction of the smooth muscle is the big problem encountered by everybody studying this problem. Thus, my question is: did you do any motility studies?

I think that the spectrum analysis, the fast Fourier method, is the way to go, but you end up with a tremendous amount of data and several patterns, as you showed in both the fast wave and in the slow wave, since a very precise, statistical method is required to establish statistically valid differences in the trends observed. My second question is: Have you analyzed the data obtained, using statistically valid methods? In our studies on the gastric electrical activity, we used correlation coefficients and confidence bands methods: however, we could not really establish a statistically valid difference in the electrical patterns observed.

Finally, are you doing any work using surface electrodes that would obviate the need to insert the wires directly into the colon? Dr. Dick Shepherd in our department and I have been working with this method; there are still many technical problems to be resolved, and a sophisticated system of filters is required to differentiate the electrical signals originated by the colon, small bowel, and the stomach. But if one could accurately record the electrical activity of the gastrointestinal tract with "patch-type" electrodes applied to the skin, these important studies could be done more extensively.

I think this is an important paper. I think we will see more clinical applications in the future from studies of the electrical activity of the colon. I acknowledge that it is a very difficult field in which to work and be able to come up with clean definitive conclusions. Ultimately, I think, important contributions that will accelerate the recovery of patients after an operation will come out of these studies, like the one presented by Dr. Condon.

DR. ROBERT E. CONDON (Closing discussion): I want to thank Drs. Jones and Aldrete for their incisive and insightful comments and questions.

Both asked about the relationship between electrical events and contraction. There are a variety of ways to measure contraction, and most of them are not very good. In particular, getting observations in humans becomes very difficult. Intraluminal perfused catheters and balloons do not work in the colon because the colon is not closed under resting conditions. It is a chambered organ. Under those circumstances, you cannot tell, in fact, whether the things that you measure originated at the location of the transducer or somewhere upstream or downstream. A number of studies have been done using suction electrodes passed intraluminally. The problem with those is that you cannot accurately take them out and put them back in the same site, nor can you keep them in over a prolonged period of time.

The only way, quite honestly, to get reliable repetitive data about contractions over time is to sew a strain gauge to the surface of the bowel. You can readily do that in experimental animals, but there is no way yet to do that readily in humans. Therefore, we make a number of assumptions about humans based on our extensive background in animal work, which indicates that electrical response activity always correlates with contraction. It is a one-to-one phenomenon, with the exceptions being so infinitesimally small as to be statistically capable of being ignored. Whenever you see electrical response activity, a contraction is occurring.

We have one observation in a patient about the identity of ERA and contractions. The data were obtained not in the colon but in the stomach in a postoperative patient and indicate that is true. If you observe contractions in a barium-filled stomach under fluoroscopy and correlate that with a tracing, you can see that electrical response activity or spike waves do correlate with contraction.

Dr. Jones asked if there was any difference between operations in the upper abdomen and in other sites in terms of the responses that we saw. There was none. The locus of the operation also did not appear to influence the pattern of recovery, but you have got to remember that our data are based on a relatively small number of patients observed to date.

Were there any subsets among the patients in terms of their response to morphine? There were none. The only difference in morphine response was when morphine was administered epidurally; we did not see a bowel response even though eventually there was a slow rise in the concentration of morphine measurable in blood. Obviously, when it was given intravenously or intramuscularly, the serum morphine content rose much more rapidly, and those routes of administration also brought about an ERA response in the colon from the second postoperative day onward in all patients with no differences between upper and lower abdominal operations and no differences between right and left colon.

When was oral intake resumed? Oral intake was resumed when continuous electrical response activity appeared in the record, and usually the electrodes were pulled out the following day. We were not regularly observing feeding responses, Dr. Jones, although we did leave the electrodes in place in one patient for three subsequent days, and we do believe that there is a gastrocolic response of the left colon, but we obviously need a lot more data. One patient is not going to answer that particular question.

Dr. Aldrete asked me if ERA means spike potentials. Yes, there is a sort of problem in semantics in this growing field. I utilized the terminology introduced by my co-investigator, Sushil Sarna. There are other terminologies that grew out of other areas of motility investigation, but we both believe this particular terminology is most accurate and most likely to apply to all kinds of motility investigations in all kinds of bowel segments.

Have we done statistical analyses or correlations of the fast Fourier transformation program? I am not sure, Joaquin, exactly what the thrust of your question is. Is there a difference in determining the dominant frequency? Is that a statistically reliable determination? Yes, it is. The accuracy of reproduction of the fast Fourier transform program is 0.47 cycles per minute. The standard error of that determination is no more than twice the sensitivity of cycle determination; thus, when you are looking at a change from something in the range of 11 or 12 cycles down to a range of 3 or 4 cycles, that clearly is a statistically reliable difference.

We have done no work at all with surface electrodes. Their major advantage, obviously, is that they are noninvasive. The major disadvantage is that when used as a bipolar system, they encompass a lot of noise. Remember that a bipolar electrode reads all of the electrical events occurring between the two poles of the electrode, and even when they are placed relatively closely together on the surface of the abdomen, surface electrodes read a lot of noise and require a great deal of electronic manipulation. After we have done enough internal observations in man, we may be able to identify the most critical events, and then we may be able to find a place for the use of surface electrodes to tell us when, for instance, CERA has returned and it is time to eat.