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# The effect of whole-gut lavage on colon motility and gastrocolic response in a monkey

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*The effects of thorough colon lavage on fasting electrical control and response activities, as well as on muscular contractions, were recorded from the right, transverse, mid, and left colon of four conditioned monkeys. The gastrocolic response of monkeys to feeding is most prominent in the right and transverse colon in both duration and frequency of contractions. The response is reduced in midcolon and is just discernible in the left colon in fasted but otherwise unprepared animals. After lavage of the colon, a gastrocolic response to feeding is vigorously present throughout the colon. The removal of colonic content by lavage also leads to an increase in the duration of the gastrocolic response. These experimental observations are consistent with the results noted in humans in similar although less systematic experiments. Although the mechanism is unknown, the presence of stool in the lumen appears to blunt the contractile gastrocolic response of the colon to feeding.*

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The GASTROCOLIC RESPONSE is initiated by ingestion of food, occurs after a lag period of 15 to 30 minutes, and results in a significant increase in frequency and amplitude of contractions in the colon that persists for 40 to 120 minutes. In previous studies of non-human primates, a prominent gastrocolic response has been noted in the right colon (RC), but a significant gastrocolic response has not been seen in the left colon (LC).[1,2] In contrast, in humans, a gastrocolic response has been reported to occur in the LC.[3-8]

Although the possible effects of material in the colon lumen on this physiologic response have not been previously studied directly, a review of relevant reports in the literature indicates that the presence and duration of gastrocolic response of the LC seem to be influenced by the presence or absence of fecal matter in the lumen of the LC. In those studies in which clearance of fecal matter from the colon was attempted, the reported gastrocolic response was of longer duration than in studies in which colon mechanical cleansing preparation was omitted. To determine the possible influence of colon lumen content on motility and specifically on the gastrocolic response, we have investigated the effects of a high-volume cleansing lavage on colon electrical and contractile events in both the fasting and fed states.

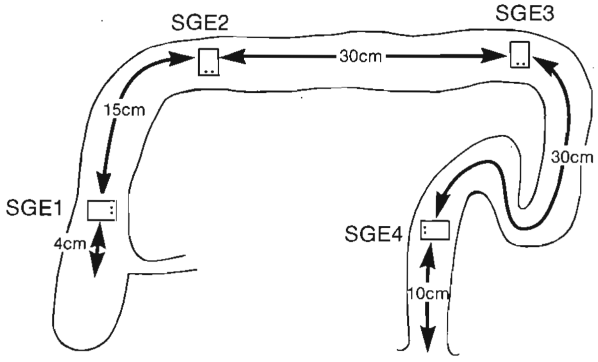

**Fig. 1.** Diagram of placement of strain-gauge electrode (SGE) units.

## METHODS

Four Macaca arctoides (stump-tail monkeys) weighing 6 to 8 kg were conditioned to sit in primate chairs

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**Table I.** ECA of the subhuman primate colon

| | | *RC* | | | *TC* | | |
|---|---|---|---|---|---|---|---|
| *Experimental state* | *Frequency range* | *Dominant frequency (CPM)* | *Relative tenancy (%)* | *Power density* | *Dominant frequency (CPM)* | *Relative tenancy (%)* | *Power density* |
| Prelavage fasting | Lower | 4.1 ± 0.3 | 96.5 | 8.8 ± 0.1 | 3.9 ± 0.2 | 100 | 8.9 ± 0.1 |
| | Higher | 14.7 ± 1.0 | 20.6 | 5.8 ± 0.5 | 12.8 ± .9 | 12.4 | 6.1 ± 0.6 |
| Prelavage fed | Lower | 4.1 ± 0.3 | 99.1 | 8.8 ± 0.1 | 3.9 ± 0.2 | 99.1 | 9.1 ± 0.1 |
| | Higher | 15.5 ± 1.1 | 16.4 | 7.7 ± 0.4 | 13.0 ± 1.8 | 4.2 | 6.7 ± 1.2 |
| Postlavage fasting | Lower | 4.6 ± 0.3 | 100 | 9.0 ± 0.1 | 4.0 ± 0.4 | 100 | 9.1 ± 0.1 |
| | Higher | 10.7 ± 0.9 | 5.0 | 7.8 ± 0.6 | 13.2 ± 1.6 | 5.4 | 6.0 ± 1.1 |
| Postlavage fed | Lower | 4.3 ± 0.3 | 99.1 | 9.1 ± 0.1 | 3.8 ± 0.4 | 95.8 | 9.0 ± 0.1 |
| | Higher | 10.8 ± 1.4 | 5.8 | 8.1 ± 0.9 | 11.7 ± 0.2 | 10.8 | 8.4 ± 0.3 |

and were transported to the recording laboratory on a daily basis whether or not recordings were made. After conditioning had been completed, a laparotomy was performed (ketamine, 10 mg/kg intramuscular preanesthetic; pentobarbitol, 20 mg/kg intravenous general anesthetic). Units consisting of a strain-gauge transducer (Micro measurements No. EA-06-031DE-120, Option SE) and a bipolar silver electrode potted together in silicone rubber were sutured to the serosal surface of the colon and oriented to respond maximally to the circular muscle as previously reported from this laboratory.[1]

Four sites were chosen for implantation of the strain-gauge electrode units: the RC, 5 cm distal to the ileocecal junction; transverse colon (TC), 15 cm distal to the RC; midcolon (MC), 30 cm distal to the TC; and the LC, 10 cm proximal to the peritoneal reflection and approximately 30 cm distal to MC (Fig. 1). Two weeks were allowed for postoperative recovery after implantation of the strain-gauge electrode units. The sensitivity of the strain-gauge transducers was then set to respond with a full scale deflection of the pen recorder to stimulation by 0.2 mg/kg of subcutaneous bethanechol.

In each experiment, animals fasted overnight. Basal recordings were obtained for 60 minutes; the animals were then fed 150 gm of monkey chow and water, and recording continued for an additional 90 minutes. The following day, the bowel was lavaged by a method modified from that of Davis et al.[9] The lavage solution was composed of 25 mmol of NaCL, 40 mmol of $Na_2SO_4$, 10 mmol of KCL, 20 mmol of $NaHCO_3$,and 59 gm/L of polyethylene glycol–4000 and was infused through a nasogastric tube at a rate of 25 ml/kg/hr for a period of 6 hours. Blood samples were drawn before and after lavage to determine serum electrolyte levels.

During pilot studies of the lavage technique, it was found that the serum concentrations of potassium and calcium were reduced about 1 mEq/L and 0.5 mEq/L, respectively, by lavage alone. Simultaneous intravenous infusion of 5% dextrose in Ringer's lactated solution at a rate of 100 ml/hr prevented these alterations of electrolyte concentration and was used during lavage in all of the experiments we report.

On the day after lavage, recordings of responses of fasting and fed colonic motility were made again as described above. The animals then returned to a standard monkey chow diet with fruit supplements for at least 3 days before repeating the experimental cycle. Each animal had four cycles of recordings; the group of animals thus yielded 16 sets of experimental observations.

Recordings of colonic electrical activity and contractile responses were made on an eight-channel recorder (Beckman RM dynograph, Fullerton, Calif.) with the signal simultaneously recorded on tape (Hewlett-Packard 3968A Hewlett-Packard, Palo Alto, Calif.). Contractions were recorded by the strain gauge from DC to 30 Hz and reported as the number of contractions per 10 minutes. Electrical activity was recorded between 0.16 and 30 Hz. Electrical control activity (ECA) is reported as the frequency per minute. ECA analysis was performed on a Nova 4X computer (Data General Corp. Westboro, Mass.) by fast-Fourier transform. The signal was low-pass filtered at 1 Hz and sampled at 2 Hz; a total of 128 data points, representing 64 seconds, were used in each block for frequency analysis.[10-12] A total of 80 blocks per animal were analyzed in each of the four experimental states (prelavage, postlavage, fed, and fasted). Electrical response activity (ERA) is reported as the incidence of electrical spikes superimposed on ECA/10 min. A total of 600 minutes of recordings in each animal were analyzed manually for correlation of contractions with ERA.

Preliminary analyses showed no significant interanimal or interexperiment variations. All data were then

| *MC* | | | *LC* | | |
|---|---|---|---|---|---|
| *Dominant frequency (CPM)* | *Relative tenancy (%)* | *Power density* | *Dominant frequency (CPM)* | *Relative tenancy (%)* | *Power density* |
| 3.6 ± 0.5 | 100 | 9.1 ± 0.1 | 3.8 ± 0.5 | 88.0 | 8.9 ± 0.1 |
| 15.5 ± 1.2 | 10.9 | 7.4 ± 0.8 | 13.5 ± 0.8 | 41.5 | 8.3 ± 0.3 |
| 3.4 ± 0.2 | 99.0 | 9.1 ± 0.1 | 4.2 ± 0.3 | 91.1 | 8.9 ± 0.1 |
| 14.4 ± 0.8 | 11.0 | 7.1 ± 1.2 | 13.6 ± 0.9 | 26.0 | 7.7 ± 0.3 |
| 3.9 ± 0.4 | 99.1 | 9.0 ± 0.1 | 4.6 ± 0.3 | 100 | 9.0 ± 0.1 |
| 11.0 ± 0.8 | 3.7 | 6.0 ± 1.2 | 13.2 ± 1.0 | 7.6 | 7.1 ± 0.9 |
| 4.0 ± 0.2 | 100 | 9.1 ± 0.1 | 4.0 ± 0.3 | 90.8 | 8.9 ± 0.1 |
| 9.4 ± 0.8 | 2.3 | 7.0 ± 0.1 | 12.2 ± 0.4 | 22.2 | 8.2 ± 0.2 |

pooled for further analysis. Statistical significance was assessed with the paired *t* test and analysis of variance. Data are expressed as grand means ± standard error. *P* values of <0.05 were considered to represent a significant difference between data sets.

## RESULTS

ECA frequency did not differ between the four experimental states. The dominant ECA frequency was about 4 cycles per minute (CPM) and was in the lower range (2 to 9 CPM) as determined by power density and relative tenancy (percentage of time such frequency was present) (Table I). ECA was also present in the higher range of 9 to 18 CPM but at a lower power and tenancy. ECA in both frequency ranges could be present simultaneously; when this occurred, the frequency in the lower range was dominant.

ERA was found to correlate with contractions of the colon on a 1:1 basis (Table II; Fig. 2). Because of the high degree of correspondence between ERA recorded by the implanted electrode and physical contraction of the circular muscle of the colon wall recorded by the strain gauge, only contraction frequency data will be further presented. Clearance of colon lumen content by lavage did not influence the frequency of fasting contraction of the colon (Table III).

Feeding in the basal (prelavage) state was followed by an increase in contraction frequency (gastrocolic response) in RC and TC (Figs. 3 and 4, *solid line*), beginning within 20 minutes and remaining increased for the remainder of the 90 minute period of observation. In MC an increase in contraction frequency was also seen within 20 minutes, but the initial burst of activity subsequently decreased (Fig. 5, *solid line*). The LC responded to a meal with a modest increase in contraction frequency, but the response was not significantly increased over the frequency of fasting basal contractions (Fig. 6, *solid line*).

**Table II.** Correspondence between ERA and contractions of the colon circular muscle (events/10 min)

| | *Frequency* | *Correlation coefficient* | *p Value* |
|---|---|---|---|
| RC | | | |
| ERA | 10.3 ± 0.7 | 0.996 | <0.001 |
| Contractions | 10.2 ± 0.7 | | |
| TC | | | |
| ERA | 12.7 ± 0.7 | 0.993 | <0.001 |
| Contractions | 12.6 ± 0.7 | | |
| MC | | | |
| ERA | 9.8 ± 0.4 | 0.988 | <0.001 |
| Contractions | 9.7 ± 0.4 | | |
| LC | | | |
| ERA | 10.3 ± 0.4 | 0.997 | <0.001 |
| Contractions | 10.2 ± 0.4 | | |

In the postlavage state, feeding resulted in increased contractile activity (gastrocolic response) within 20 minutes at all recordings sites, and contractions remained increased for the duration of post feeding observations (Figs. 3 to 6, *dashed line*). Post lavage feeding responses also were significantly greater than prelavage feeding responses for the last two 10 minute recording periods in RC (Fig. 3) and the last 10 minute observation period in TC (Fig. 4), but for much longer periods in MC and LC (Figs. 5 and 6).

## DISCUSSION

Two frequency ranges of ECA are present in the monkey: 2 to 9 and 9 to 18 CPM. This observation is in general agreement with our observations in humans (unpublished) and with the report in humans by Sarna et al.,[11] who showed colonic ECA ranges of 2 to 9 and 9 to 13 CPM. Our results differ from the observations of Taylor et al.,[13, 14] who reported human colonic ECA in the ranges of 2.5 to 4 and 6 to 10 CPM.

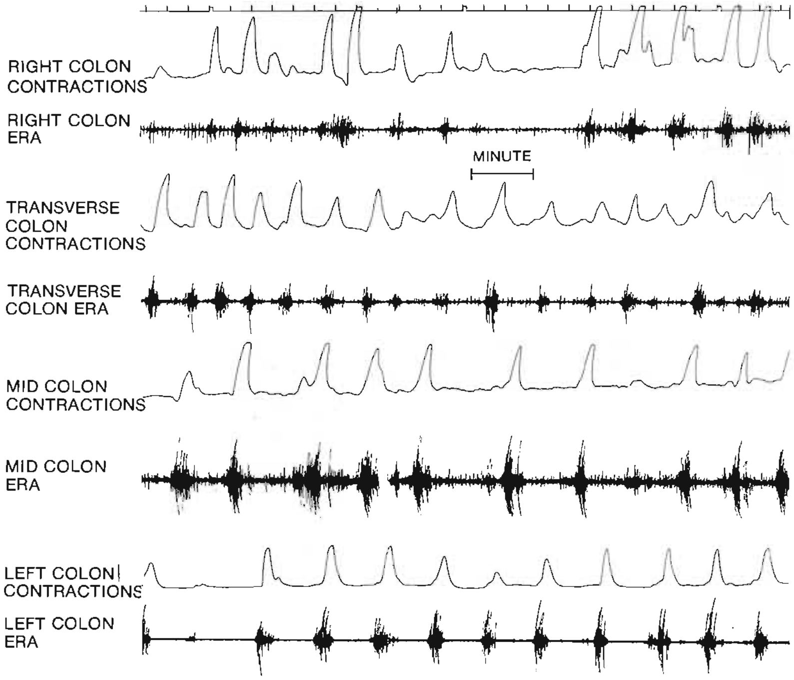

**Fig. 2.** Recording shows the 1:1 correspondence between ERA and contractions in the colon. Contractions were recorded by the strain gauge; electrical signals were recorded by the bipolar electrode.

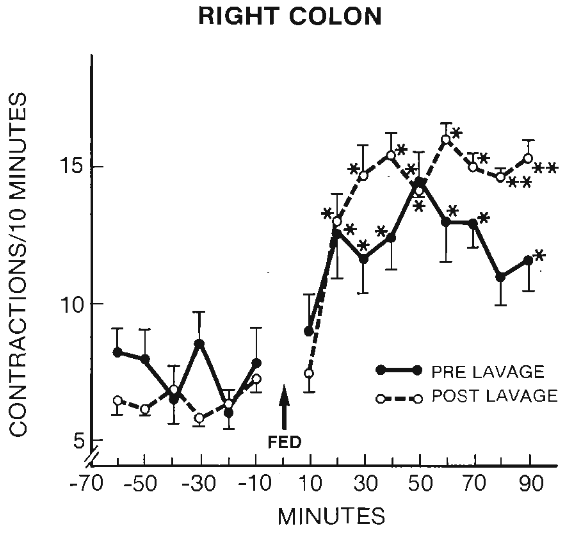

**Fig. 3.** Frequency of circular muscle contractions in the RC during fasting and in response to feeding (mean ± SE). An *asterisk* indicates $p < .05$ for comparisons of feeding to fasting; *double asterisk* indicates $p < .05$ for comparisons of both prelavage to postlavage and feeding to fasting.

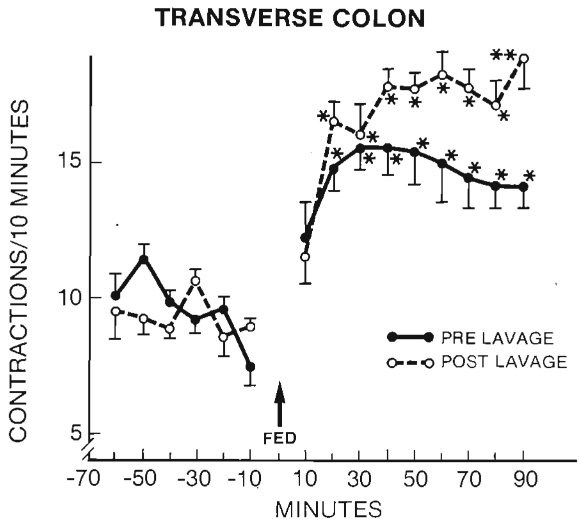

**Fig. 4.** Frequency of circular muscle contraction in the TC during fasting and in response to feeding (mean ± SE). An *asterisk* indicates $p < .05$ to compare feeding to fasting; *double asterisk* indicates $p < .05$ to compare both prelavage with postlavage and feeding with fasting.

ECA frequency in the monkey did not change with feeding, lavage, or feeding plus lavage in our experiments. The dominant ECA frequency throughout the monkey colon remained in the lower frequency range, exhibiting a mean frequency of approximately 4.0 CPM. This observation is in contrast to the report by Sarna[11] in humans, in which the RC and LC had dominant frequencies in the lower range, but the

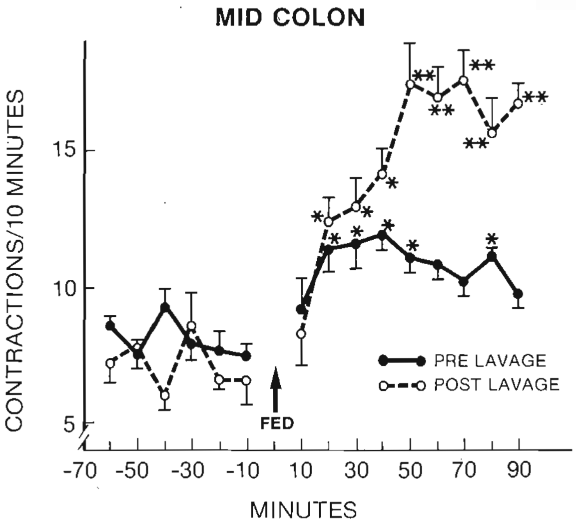

**Fig. 5.** Frequency of circular muscle contractions in the MC during fasting and in response to feeding (mean ± SE). An *asterisk* indicates $p < .05$ for comparisons of feeding to fasting; *double asterisk* indicates $p < .05$ for comparisons of both prelavage to post lavage and feeding to fasting.

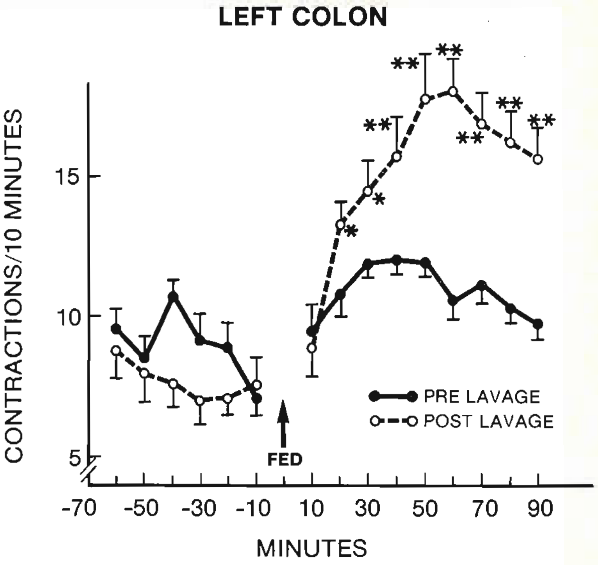

**Fig. 6.** Frequency of circular muscle contractions in the LC during fasting and in response to feeding (mean ± SE). An *asterisk* indicates $p < .05$ comparing feeding to fasting; *double asterisk* indicates $p < .05$ for comparisons both of prelavage to postlavage and feeding to fasting.

**Table III.** Frequency of fasting colon contractions (contractions/10 min)

| | *Prelavage* | *Postlavage* | *p Value* |
|---|---|---|---|
| RC | 7.5 ± 0.9 | 6.4 ± 0.4 | NS |
| TC | 9.6 ± 0.4 | 9.4 ± 0.4 | NS |
| MC | 8.1 ± 0.5 | 7.1 ± 0.6 | NS |
| LC | 9.1 ± 0.6 | 7.5 ± 0.7 | NS |

transverse and midcolon exhibited dominant frequencies in a higher range.

The gastrocolic responses of the proximal colon seen in these experiments confirm our previous observations.[2, 15, 16] Ingestion of food initiates a response characterized by increased ERA, which is pronounced in the proximal colon in fasted but unlavaged animals, and is muted or absent in the distal colon. After lavage the response to feeding is not greatly different from that of the prelavage state in RC and TC. However, after lavage responses in MC and LC are markedly increased in both frequency and duration. The gastrocolic response frequency in the lavaged and presumably empty LC was approximately that of the RC and increased more than 50% compared with the unlavaged colon. The gastrocolic response also persisted in the lavaged LC for more than 90 minutes.

The observation of a gastrocolic response in RC and TC, usually without lavage or other special preparation, may be because these parts of the colon contain little fecal matter after an overnight fast, while the more distal colon always has formed stool present in the lumen (observations made at operation during these and other experiments). Our observation that the presence of stool in the LC lumen of monkeys apparently dampens the gastrocolic response was unexpected, and we do not have a ready explanation for this event.

In studies in humans, the duration of the gastrocolic response reported in the LC has varied from 30 to more than 90 minutes. Those studies that reported longer durations of increased postprandial motility had been done in patients in whom preparation of the colon was used in some manner to remove fecal matter. Chowdhury and Lorber[4] and Schang and Devroede[17] used enemas of saline solution to "clean" the colon and reported a gastrocolic response of the LC lasting 80 to 90 minutes after feeding. Kirwan and Smith[6] used catharsis to remove colon fecal content and found that LC motility was significantly increased for the duration of their postprandial study (90 minutes).

In contrast, human investigations in which the colon was not cleansed showed that the postprandial increase in LC motility was shorter, varying from 15 to 50 minutes. Battle et al.[3] found that ERA increased postprandially, reaching a peak at 30 minutes, and then returned to fasting values by 50 minutes. Leoning-Baucke and Anuras[7] reported that the frequency of contractions of the LC increased significantly after the beginning of a meal but returned to fasting levels shortly after the meal had been completed. Kerlin et al.[5] saw an increase in the motor response of the rectosigmoid colon (25 cm from the anus), but at a site just 5 cm more distal there was no response to a meal. The motility of the RC was also studied by this group and was found to increase its activity significantly postprandially, with the increase in motility greater in the second hour. The gastrocolic responses recorded in humans in whom fecal matter remains in the colon lumen are similar to those in fasted but unlavaged monkeys. In some manner the presence of stool in the colon lumen decreases the contractions usually initiated as a part of the gastrocolic response. Since the urge to defecate often follows a meal, this inhibition of contractions must play a role in normal defecation, a role that remains be be elucidated.

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