Relationships between cecoileal reflux and ileal motor patterns in conscious pigs

G. Cuche, Charles-Henri Malbert

Relationships between cecoileal reflux and ileal motor patterns in conscious pigs

G. CUCHE AND C. H. MALBERT
Unité Flux Digestifs et Métabolisme Protéique, Station de Recherches Porcines, Institut National de la Recherche Agronomique, 35590 Saint-Gilles, France

Cuche, G., and C. H. Malbert. Relationships between cecoileal reflux and ileal motor patterns in conscious pigs. *Am. J. Physiol.* 274 (*Gastrointest. Liver Physiol.* 37): G35–G41, 1998.—Ileal infusion of cecocolonic contents, used to mimick reflux, enhanced terminal ileal motility, increasing the frequencies of prolonged propagated contractions (PPC) and discrete clustered contractions (DCC). Because the reflux rate in dogs and humans is marginal, the relationship of these motor patterns to reflux remained putative. In six conscious pigs, the ileal pH, used to indicate reflux event, was measured 10 and 5 cm proximal to the ileocecal sphincter (ICS). Ileal motility was evaluated with three strain gauges 15, 10, and 5 cm proximal to the ICS. Ileal pH dips were observed about eight times per hour in the fasting or fed state, and 46% of the pH dips were preceded by a retrograde contraction. During pH dips, frequency of ileal contractions not classified as PPC or DCC was significantly increased. Of the PPC 52% occurred immediately after the start of the dip and might act as a clearance mechanism because dips associated with PPC were of smaller amplitude and duration than those not associated with PPC. Most DCC also occurred during pH dips but their delay to the onset of the dip was longer. The pig presents frequent cecoileal reflux events associated with ileal motor patterns, some of them might facilitate reflux, whereas others act as a clearance mechanism.

prolonged propagated contractions; discrete clustered contractions; ileocecal sphincter

IN DOGS only 10% of the radioactivity infused in the colon flows back into the ileum, hence cecoileal reflux is confined (13). On the contrary, reflux amounts to 30–70% after division of external ligamentous attachments at the ileocolonic junction (13). This figure is close to that observed in intact horses (20) for which the extensive reflux rate is likely the consequence of a large cecum that accounts for 60% of the gut volume. However, the size and behavior of the horse make it difficult to use it as an experimental model to evaluate the mechanisms of reflux. Alternatively, the pig, also an animal with a large cecum, might be more suitable.

In dogs, after section of the external ileocolonic ligaments (13), ileal motility consists primarily of single, broad-based contractions (prolonged propagated contractions or PPC) or brief bursts of phasic contractions (discrete clustered contractions or DCC) that propagate aborad. These motor patterns are identical to those observed after ileal administration of short chain fatty acids (SCFA) (3, 9, 12). The relationship of these motor events to reflux has never been established, and it is not known whether they contribute to or are generated by reflux.

Assessment of the relationships between ileal reflux and motility requires a method to evaluate the occurrence of reflux with a time resolution close to that of motility recordings. In humans and animals, pH measurement is an excellent tool at the esophageal (1) or duodenal level (6, 15) because a pH gradient exists between the stomach and the esophagus or the stomach and the duodenum. In pigs, pH drops might also represent an adequate indicator for retrograde propulsion of cecal fluid into the distal ileum because the cecum contains a large amount of acidic compounds (SCFA; 20) synthesized after the fermentation of polysaccharides.

The aim of our study was *1*) to evaluate the frequency of cecoileal reflux episodes in intact pigs and *2*) to correlate their occurrence with ileal motor patterns.

MATERIALS AND METHODS

Surgery

Under general anesthesia and aseptic conditions, a lateral laparotomy was performed on six female Large White pigs (38 ± 1.5 kg). Briefly, pigs were preanesthetized with ketamine (5 mg/kg im). Suppression of the pharyngotracheal reflex was obtained by administration of halothane (5% vol/vol) via a face mask immediately before tracheal intubation. A venous cannula was inserted into the marginal vein of the ear to infuse Ringer-lactate during surgery. The pigs were mechanically ventilated by a Siemens SAL 9000 ventilator with a tidal volume of 15 ml/kg at a respiratory rate of 18 breaths/min. Halothane was introduced in the respiration circuit, and its amount was adjusted continuously (~3% vol/vol, 1 maximal alveolar concentration) to maintain a surgical level of anesthesia. Ventilation was also adjusted to obtain normocapnia (end-tidal carbon dioxide pressure at 35–45 mmHg). Normocapnia was measured using an infrared capnograph (Engström Eliza) with air sampling at the Y piece of the ventilator. Fractional inspired oxygen was changed between 20 and 100% using pulse oxymetry data supplied by a sensor (Ohmeda, pulse oxymeter) attached to the tail. Rectal temperature was maintained constant during surgery (38.5 ± 0.5°C) by a heating pad under the animal.

During the surgical procedure, the animals were fitted with three strain gauge force transducers (I1–I3; Vishay Measurement) located 5, 10, and 15 cm proximal to the ileocecal sphincter (ICS). Strain gauge wires were brought subcutaneously to exit between the shoulders. A T-shaped silicone cannula (OD 16 mm) was inserted 20 cm proximal to the ICS and exteriorized through the right flank (Fig. 1). Particular care was taken during the surgical procedure to avoid damaging the external ligaments because of their involvement in the ICS competence (13). A silicone tube (ID 5 mm, OD 10 mm) was implanted in the cecum and also brought subcutaneously between the shoulders. Animals were allowed 2 wk for recovery from the surgical procedure.

Motility and pH Recordings

Signals from the strain gauges were recorded on a four-channel chart recorder (Gould 4042) via half-bridge couplers

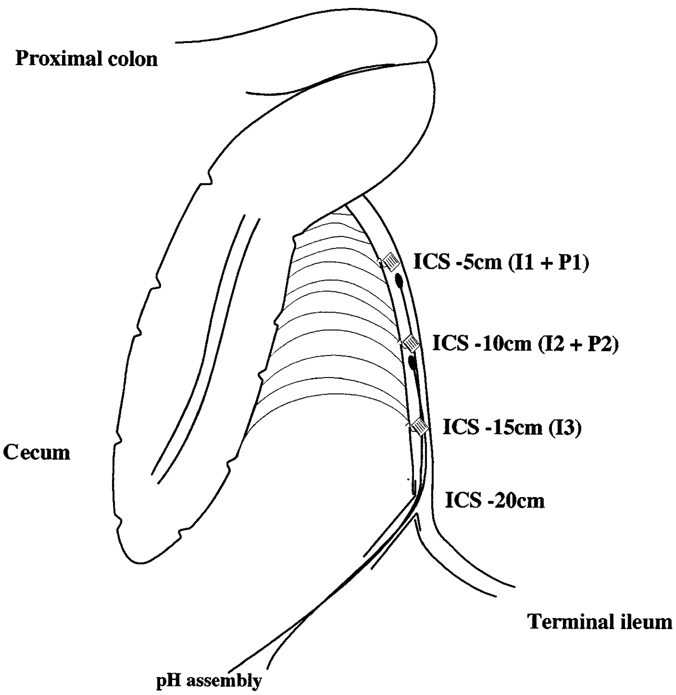

Fig. 1. Surgical preparation of animals. Ileal motility was recorded using 3 strain gauges (I1, I2, and I3). pH probes (P1 and P2) introduced extemporaneously in terminal ileum through a T-shaped cannula and located 5 and 10 cm proximal to the ileocecal sphincter (ICS) were used to detect cecoileal reflux events.

(1B31, Analog Devices) and digitized simultaneously (15 Hz) on a microcomputer (Macintosh II, Apple Computer) using an analog-to-digital card (NB MIO16, National Instruments) after low-pass filtration at 10 Hz. Data were stored on computer disks for later analysis.

Intraluminal ileal pH values at 5 (P1) and 10 (P2) cm proximal to the ICS were used as indicators of cecoileal reflux events (20). A bundle of two miniature Ag-AgCl pH electrodes (N9653, Ingold, 4 mm diam) was used to evaluate the length of terminal ileum exposed to cecocolonic fluid during reflux events. The pH electrodes were connected to pH meters (P501, Consort) with optical insulation to avoid cross-talk between pH signals. Electrodes were calibrated using standard buffer solutions of pH 4 and 7 before each study. The bandwidth of the pH signal was limited to that of motility, i.e., 10 Hz. The pH signals were digitized and stored on computer disks along with motility data.

Validation of pH Probe Technique for Reflux Assessment

To cancel a possible contact between the probe surface and the ileal mucosa that could generate false pH dips, pH probes were shielded using a miniature polyethylene wire cage (15). The wires (0.6 mm in diam) were fixed immediately above the sensitive part of the probe using heat shrinkable tubing. The whole assembly has an overall diameter of 5.2 mm and can be easily moved through the ileal cannula.

In addition to protecting the pH probes, we tested the existence of reflux by directly measuring the passage of cecocolonic fluids into the distal ileum. Twice in each animal, while the pH was not recorded, a miniature cotton swab enclosed in a polyethylene maze was carefully inserted in the ileal lumen at the level of the cannula. The swab was allowed to progress, propelled by the ileal contractions, so that its location was 10 cm proximal to the ICS. This took ~60 min. ^{99m}Tc-diethylenetriamine pentaacetic acid (DTPA, 5 MBq) in saline (30 ml) was infused in the cecum (5 ml/min) using the cecal tube; 15 min after this infusion, the swab was recovered by pulling a string attached to the polyethylene maze. The radioactivity present in the swab was measured using a gamma-counter (Mecaserto, SAIP, Malakoff, France) minus radioactivity decay. The presence of radioactivity within the swab will demonstrate the reality of reflux.

Estimation of Volume of Refluxate

The complex chemical composition together with the number of buffering systems present within the cecocolonic fluid make it impossible to relate in vivo the amount of cecal contents to the characteristics of a pH dip. To overcome this problem, we have mimicked in vitro the arrival of cecal contents into a known ileal volume while the pH was evaluated. Before euthanasia and under general anesthesia (halothane 3%, vol/vol), the ileum was ligated at each end and its contents were collected. The entire content of the cecum was also removed. The ileal fluid was immediately titrated with cecal fluids, by adding a known volume of cecal content to a known volume of ileal content while the pH was measured.

Experimental Protocol

Animals were fasted for at least 16 h. Water was freely available except during the experiments. One hour before the experiment, the pH electrode assembly was positioned extemporaneously in the distal ileum using a method similar to that used for esophageal pH monitoring in humans (10). The pH assembly was passed through the ICS until P1 recorded a sudden pH drop (ΔpH > 2) corresponding to its entry into the cecum. The assembly was then withdrawn 5 cm. Once positioned, the pH probe assembly was firmly secured to the cannula arm.

Recordings were performed during interdigestive and postprandial periods. After 2 h of recordings, during which time at least one ileal phase III was recorded (14), the animals were fed (1 kg of solid food: 40% carbohydrates, 17% proteins, <2% lipids, 41% water) and recordings were continued for 2 h more. This protocol was repeated five times for each animal with a 2-day interval. At the end of the experiments the animals were killed with an overdose of thiopental sodium.

Data Analysis

Analysis were performed using Malbert ADelaide (C. H. Malbert and Synectics Medical, Stockholm, Sweden). A pH dip was defined as a rapid decrease (≥0.3 pH/min) in pH, followed by a slower return to basal level. To qualify for a pH dip, the amplitude of the pH drop must be ≥0.2 pH and its duration <15 min. This rather restrictive time limit was selected arbitrarily to reject as a dip long-lasting changes in ileal pH due to modifications of ileal chyme chemical characteristics after a meal. Each dip was described using three parameters: *1*) pH value before the dip (basal), *2*) minimal pH value during the dip, and *3*) its duration. The amplitude of the pH dip was defined as "basal pH-minimal pH." The pH dip was considered as terminated when the pH regained initial pH ± SD. For analysis of ileal pH in relation to migrating motor complex (MMC) pattern only, original ileal pH data [x(i)] were normalized to match the mean durations of MMC phases. Normalization was performed by decimation followed by calculation of the mean pH value [y(i)] over the decimation period according to the formula

$$y(\mathrm{i}) = \frac{1}{m} \sum_{k=0}^{k=m-1} x[\mathrm{i}(m + k)] \quad \text{for i} = 0, 1, 2 \ldots \left(\frac{n}{m} - 1\right),$$

where n is the number of original pH data, m is the decimating factor, and n/m is the number of final pH data.

The amplitude of ileal waves was expressed as a percentage of the maximal amplitude recorded during a control phase III (16). Contractions were defined as phasic increases of amplitude >10%, lasting for >1 s. Once recognized by the software, ileal contractions were scanned visually and by an additional data processing module for PPC and DCC according to previously defined criteria (7). PPC were defined as high amplitude (>70%), phasic waves with a duration >12 s and propagating aborad over at least two channels within 4 s. The high amplitude threshold (70%) was adapted from that used during manometry experiments (7). Discrete clustered contractions were defined as sequences of phasic contractions of at least 1-min duration and propagating aborad over at least two channels within 4 s. Ileal contractions that did not fit PPC or DCC criteria were called unclassified contractions. These contractions comprised aborad or orad propagated and unpropagated contractions. For unclassified contractions, the time window allowed to accept propagation over adjacent recording points was 4 s.

The temporal relationship between the onset of ileal pH dip and the onset of ileal contractions was assessed using cross-correlation (15). Onset of contraction was calculated automatically by the software using recursive testing of the upstroke of the contraction against the calculated baseline ±3% of baseline variations over 1 min.

Data were expressed as means ± SE. Comparisons between means were achieved using analysis of variance (level of significance $P = 0.05$).

RESULTS

Direct Evaluation of Reflux

The radioactivity within the swab was significant after 15 min of contact with ileal juice: 1.2 ± 0.06 MBq were recovered in the swab, a value equal to ~20% of that administered in the cecum.

Ileal pH and Buffering Capability

The pH values of ileal and cecocolonic fluids sampled in anesthetized animals (7.4 ± 0.17 and 6.5 ± 0.12, respectively) were not significantly different from in vivo values obtained with miniature pH probes (7.4 ± 0.02 and 6.4 ± 0.09). In vitro, a pH drop of 0.2 amplitude was obtained by the addition of 0.3 ± 0.09 ml of cecocolonic fluids to 1 ml of ileal contents (Fig. 2). No change in the slope of the titration curve can be observed over the tested pH and volume ranges, indicating that ileal pH could be an excellent marker for detection of reflux episodes.

Characteristics of pH Dips

Acidification events of the ileum 5 cm proximal to the ICS occurred 8 ± 0.5 and 6 ± 0.4 times/h ($P < 0.05$) in interdigestive and postprandial periods, respectively. The individual characteristics of the pH dips changed after the meal (Table 1), with their duration being significantly longer: 82% of pH dips were detected in sequence at P1 and then at P2 7 ± 1.5 s later (a time necessary for fluids flowing back to cover the 5 cm between the two probes; Fig. 3). The pH dips recorded

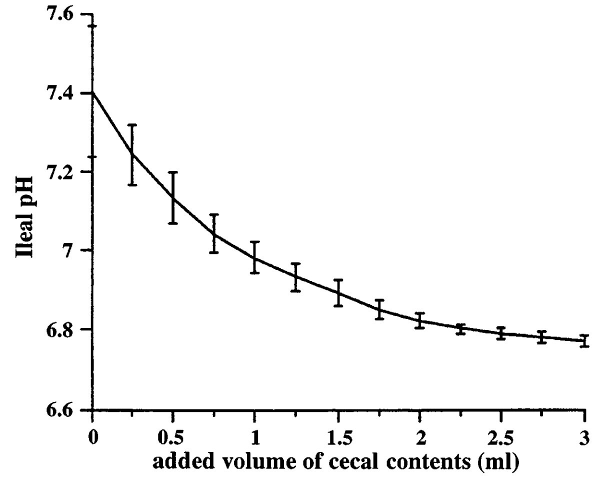

Fig. 2. Titration curve of ileal chyme by cecal fluid. Horizontal axis, volume of cecal fluid added to 1 ml of ileal content; vertical axis, pH of final mixture. Note absence of slope change over pH range tested, which included in vivo ileal pH.

at P2 had a smaller amplitude and duration than those detected at P1 (Table 1). Dips detected at P1 only (18%) had a reduced amplitude (0.4 ± 0.03 vs. 0.6 ± 0.02 pH, respectively, for nonpropagated vs. propagated dips; $P < 0.05$) but similar duration (237 ± 16.9 vs. 297 ± 18.6 s; $P > 0.05$). pH dips were never detected at P2 without prior detection at P1.

Relationships Between pH Dips and MMC Pattern

Ileal pH at P1 was significantly less during phase III than during phases I and II of the MMC (Fig. 4) because of a greater number of pH dips during phase III than during phases I and II (Table 2). Yet more frequently, there was no clear and constant relationship between pH dips and individual ileal phase III contractions. Ileal pH at P2 was not significantly modified in relation to MMC (7.6 ± 0.02, 7.6 ± 0.01, and 7.6 ± 0.02, during phase I, II, and III, respectively; $P > 0.05$).

Relationships Between pH Dips and Ileal Motility Patterns

Three different ileal motor patterns were observed in the interdigestive phase: *1*) nonclassified contractions (54% of total phasic contractions), *2*) DCC (44% of total phasic contractions), and *3*) PPC (<2%). In the postprandial period, PPC disappeared and nonclassified contractions (74% of total phasic contractions) or DCC (26% of

Table 1. *Characteristics of ileal pH dips recorded at P1 and P2 before and after meal*

	P1		P2	
	Fasted	Fed	Fasted	Fed
Amplitude, pH	0.6 ± 0.02	0.6 ± 0.03	0.4 ± 0.02	0.4 ± 0.03
Duration, s	262 ± 12.7	356 ± 27.0*	186 ± 9.9	243 ± 18.2*
Frequency, events/h	7.8 ± 0.47	6.2 ± 0.40*	6.5 ± 0.47	5.2 ± 0.40*

Values are means ± SE for 591 and 479 pH dips at P1 and P2, respectively. P1 and P2, pH probes at 5 (P1) and 10 (P2) cm proximal to ileocecal sphincter. *$P < 0.05$ compared with fasted state.

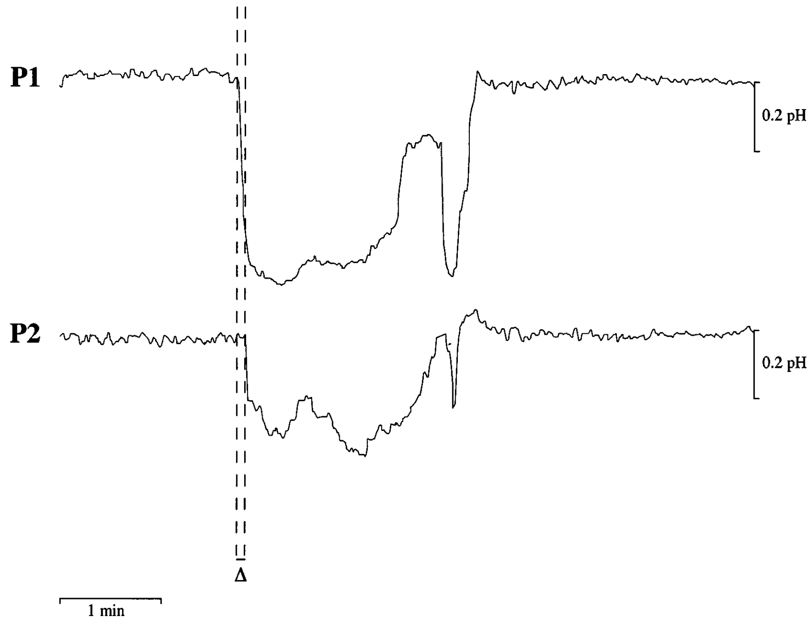

Fig. 3. Recordings of ileal pH at P1 and P2 during a pH dip. Decrease in pH occurred sequentially at P1 and then at P2, with 5-s delay (Δ). Amplitude of dip at the most proximal recording site (P2) was less than that observed at the distal site (P1).

total phasic contractions) were the only detectable motor patterns.

Ileal contractions occurring immediately before pH dips. In the interdigestive and digestive periods 46% of pH dips were preceded by a retrograde propagated contraction (Fig. 5). Cross-correlation analysis between the signals from I1 and P1 confirmed that the onset of the pH dip occurred after the onset of the retrograde contraction on the most distal recording location. This delay was significantly greater before than after the meal (2.1 ± 0.24 vs. 0.9 ± 0.26 s, respectively, in the interdigestive and postprandial periods; $P < 0.05$). pH values decreased more rapidly for pH dips preceded by a retrograde contraction (slope −5.0 ± 0.86 pH/min) than for those not associated with a retrograde contraction (−0.8 ± 0.04 pH/min). No other motor pattern was significantly more frequent before (within a 10-s time window) than during a pH dip.

Ileal contractions occurring during or after pH dips. In the interdigestive period but not postprandially, frequency but not amplitude of unclassified ileal contractions increased significantly during pH dip (Fig. 6). During the pH dips most ileal unclassified contractions (74%) were propagated in the orad-aborad direction at a mean velocity of 2.1 ± 0.09 cm/s.

During the interdigestive period 91% of the DCC occurred during a pH dip, and this value was halved (53%) in the postprandial period. These DCC were observed 128 ± 123.4 s after the onset of a pH dip. Individual characteristics of DCC recorded during a pH dip were not significantly different from those recorded in the absence of pH dips (amplitude 38 ± 1.5 vs. 35 ± 1.8%, duration 84 ± 8.5 vs. 77 ± 11.3 s, and frequency of contractions within DCC 9 ± 0.7 vs. 11 ± 1.2 contraction/min, respectively, when DCC occurred during or in the absence of pH dips; $P > 0.05$). In the interdigestive period pH dips temporally associated with DCC had a greater amplitude (0.9 ± 0.11 pH) and duration (351 ± 59.0 s) than those not associated with DCC (amplitude 0.6 ± 0.03 pH, duration 229 ± 24.3 s; $P < 0.05$). These differences were not observed in the postprandial period (amplitude 0.5 ± 0.08 vs. 0.6 ± 0.05 pH, duration 310 ± 38.0 vs. 344 ± 24.0 s, respectively, for dips associated and not associated with DCC; $P > 0.05$).

PPC were observed in the interdigestive period only with a frequency of 1.5 ± 0.24 per h. About one-half of them (52%) occurred during the initial pH decrease of the dip and a 4.6 ± 3.30 s delay was observed between the onset of the dip and the PPC (Fig. 7). Their

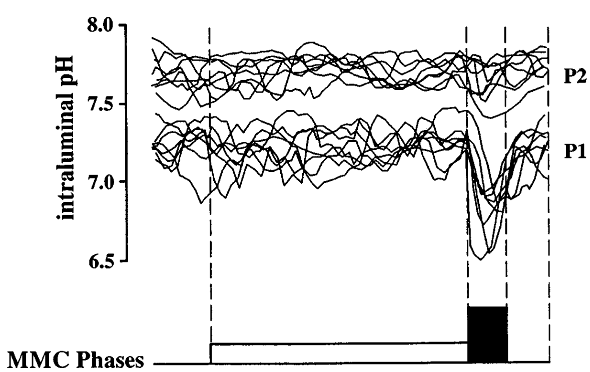

Fig. 4. Evolution of ileal pH in relation to migrating motor complex (MMC) pattern. pH data were normalized to match duration of MMC phases. There was a significant decrease in pH during phase III vs. phases I and II. These changes were absent 10 cm proximal to the ICS. Black box, phase III; white box, phase II.

Table 2. *Characteristics of ileal pH dips in relation to MMC phases*

	Phase I	Phase II	Phase III
Amplitude, pH	0.5 ± 0.06*	0.6 ± 0.02*	0.6 ± 0.06*
Duration, s	253 ± 52.8†	265 ± 18.9†	272 ± 27.0†
Frequency, events/h	7.7 ± 0.38‡	7.8 ± 0.39‡	11.8 ± 0.43§

Values are means ± SE. MMC, migrating motor complex. Values with different superscripts indicate a significant difference at $P < 0.05$.

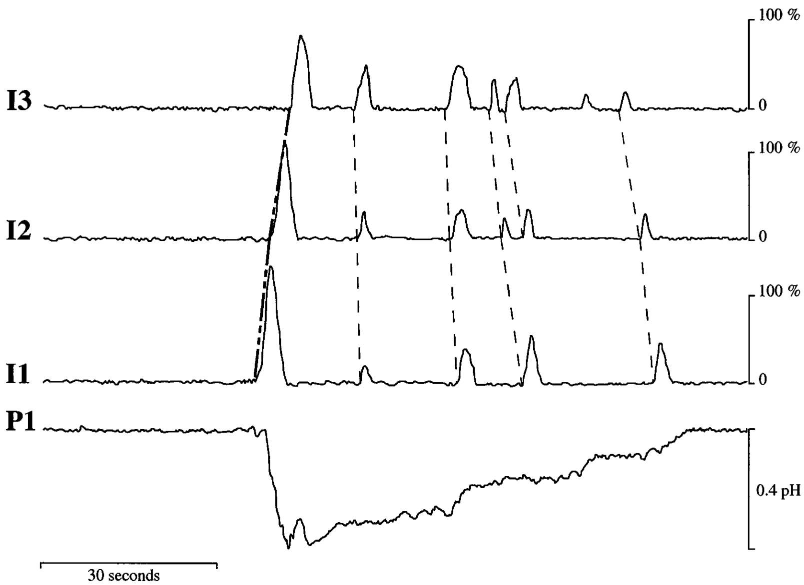

Fig. 5. Example of retrograde ileal contraction (heavy dotted line) occurring before onset of pH dip. A delay of ~2 s was observed between onset of pH dip and onset of contraction on the most distal strain gauge. Unclassified anterograde propagated contractions (light dotted lines) occurred frequently during reflux event.

amplitude (113 ± 7.9%) and duration (15.8 ± 0.80 s) did not differ from those not temporally related to pH dips (amplitude 112 ± 5.8%, duration 17.3 ± 1.16 s; $P > 0.05$). pH dips associated with a PPC were of significantly reduced amplitude and duration than those not related to a PPC (amplitude 0.4 ± 0.06 vs. 0.7 ± 0.06 pH, duration 118 ± 26.0 vs. 342 ± 53.6 s).

pH dips unrelated to ileal motor events. pH dips not associated with any ileal motor event were only observed 18 times in all animals. These infrequent dips were of greater amplitude (0.8 ± 0.09 pH) and duration (393 ± 69.0 s) than these related to nonclassified ileal contractions ($P < 0.05$).

DISCUSSION

This work demonstrates for the first time frequent cecoileal reflux episodes in intact pigs. These reflux events are temporally related to motility patterns of the terminal ileum. Some of these patterns facilitate reflux because they occurred before pH drop, whereas others are a consequence of the reflux because they followed or

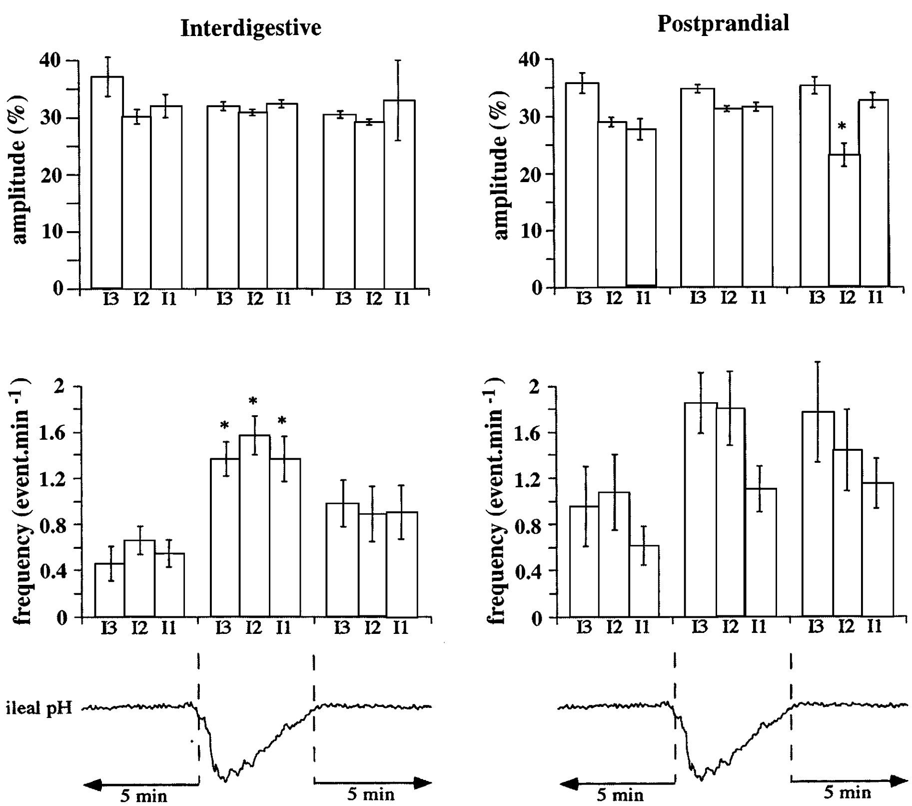

Fig. 6. Individual characteristics of nonclassified ileal contractions in relation to pH dips. During interdigestive phase only, the frequency of nonclassified ileal contractions was increased, whereas the pH was low. Frequency was reset to basal values on termination of pH dip. *Significant difference from 5-min period preceding pH dip: $P < 0.05$.

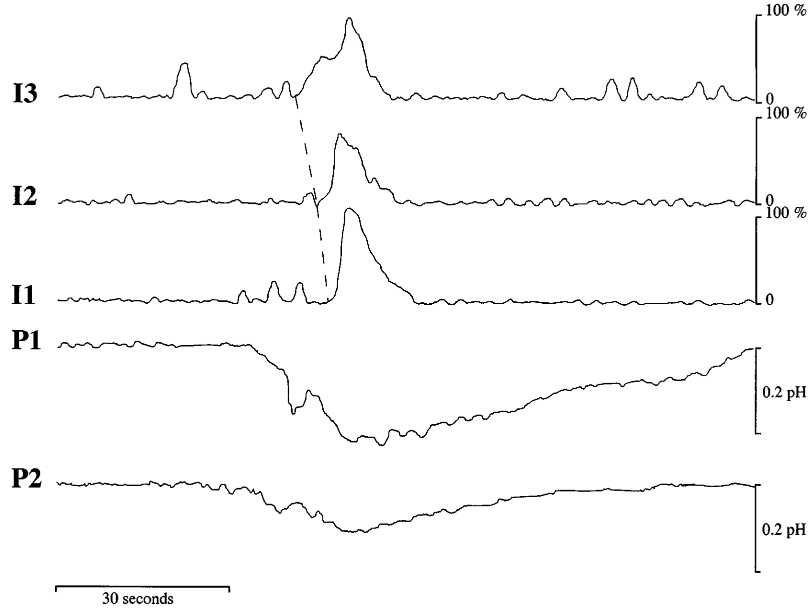

Fig. 7. Example of prolonged propagated contractions (PPC) occurring after onset of pH dips. pH started to recover to basal values when PPC was recorded on the most distal strain gauge.

occurred simultaneously with an acidification event at the terminal ileum.

The reliability of pH dips as indicators for cecoileal reflux events is supported by the following observations. Titration of ileal fluid by cecal contents demonstrated the low buffering capability of the ileal chyme within the pH range usually observed in vivo. Furthermore, it is unlikely that these pH dips resulted from temporary contacts between the pH probes and the ileal mucosa. First, a wire cage located around the tip of the electrodes significantly protects the glass from the mucosa (4). Second, the dissymmetrical shape of pH dips was similar to that observed during gastroesophageal reflux events (19). By comparison, the ileal pH drop is likely related to the arrival of cecal acidic fluids into the ileum. pH values remained low until the aboral transit of less acidic chyme (acid clearance). Third, most of the pH dips were detected in sequence 5 cm and then 10 cm proximal to the ICS and none at 10 cm alone. Fourth, the recovering of radioactivity in the terminal ileum after ^{99m}Tc-DTPA infusion in the cecum provides final support for assessing the reality of cecoileal reflux events.

About one-half of the reflux episodes were preceded by retrograde contractions propagated over the three recording locations at an average speed of 2.0 ± 0.10 cm/s. The delay observed between the reflux event and this set of contractions was compatible with a causal relationship between this motor event and the reflux episode. Furthermore, pH dips preceded by retrograde contractions have an initial slope significantly greater than those not preceded by this motor pattern. The existence of this motor pattern together with changes in the characteristics of pH dip are key agreements in favor of the hypothesis that ileal retrograde contractions trigger reflux. However, this motility pattern, although always associated with reflux, is not necessary to generate reflux event because they were not observed before 54% of the reflux episodes. This motor pattern was seldom observed in other species. A retrograde contraction on the ileum was present occasionally in humans (22) after colonic infusion of oleic acid. The physiological role of these retrograde contractions is still unknown but they might supply a limited amount of SCFA into the ileum. These compounds have a known trophic effect on the mucosa (5).

Multiple motor patterns were recorded during the reflux episode itself and therefore might be triggered by the reflux. Of the nonclassified contractions 74% were propagated oral to aboral during the reflux episode. Interdigestive reflux episodes unassociated with these contractions lasted longer, suggesting the involvement of these in the ileal clearance from acidic refluxate. Almost all DCC occurred during reflux episodes. Although DCC are a propulsive motor pattern (12) and might act as clearance mechanism, DCC-associated reflux events did not exhibit characteristics different from those of reflux events not associated with DCC. This was probably the consequence of the 2-min delay between the start of reflux episode and the onset of DCC. PPC were also predominantly observed during the reflux episode. PPC, as are DCC, are propulsive (12) but in contrast with DCC, PPC are associated with a reduced amplitude and duration of pH dips. This enhanced efficacy to clear the ileum from acidic refluxate is probably related to the rapid occurrence of PPC after the onset of pH dips (5 s). Hence, during the interdigestive phase only, PPC might represent an efficient pathway for ileal clearance. This is consistent with the presence of PPC predominantly on the last 20–30 cm of the ileum in humans (17).

SCFA could be considered a strong candidate for being the chemical signal whereby the ileum could "sense" reflux because SCFA infused at cecocolonic concentration in the terminal ileum stimulate the ileal motility, particularly DCC and PPC in humans (3, 9) and dogs (8, 11).

A temporal relationship between cecoileal reflux and MMC phases was expected. Indeed in pigs, unlike humans, phase III was classically recorded in the terminal ileum (14). However, the ileal pH decreased, and the frequency of cecoileal reflux episodes increased during phase III while ICS basal pressure was increased in dogs (18) and horses (20), hence generating a greater resistance to retrograde flow. This discrepancy could not be explained by any particular colonic motility pattern associated with ileal phase III because no temporal relationship between ileal phase III and colonic motor complexes could be evidenced in dogs (21) and rats (2).

In conclusion, cecoileal reflux events occurred about eight times per hour in pigs. The arrival of cecocolonic fluids into the ileum was preceded by retrograde contraction. DCC and PPC were observed during ileal content acidification episodes and might provide a clearance mechanism for the distal ileum.

Address reprint requests to C. H. Malbert.

Received 29 April 1997; accepted in final form 15 September 1997.

REFERENCES

1. **Dent, J., W. J. Dodds, R. H. Friedman, T. Sekiguchi, W. J. Hogan, R. C. Arndorfer, and D. J. Petrie.** Mechanism of gastroesophageal reflux in recumbent asymptomatic human subjects. *J. Clin. Invest.* 65: 256–267, 1980.
2. **Du, C.** Motricité du côlon chez le rat—nature et contrôle médullaire. In: *Laboratoire de Physiologie.* Toulouse, France: Institut National Polytechnique de Toulouse, 1986, p. 169.
3. **Fich, A., S. F. Phillips, N. S. Hakim, M. L. Brown, and A. R. Zinsmeister.** Stimulation of ileal emptying by short chain fatty acids. *Dig. Dis. Sci.* 34: 1516–1520, 1989.
4. **Fimmel, C. J., A. Etienne, T. Cilluffo, C. Von Ritter, T. Gasser, and J. P. Rey.** Long-term ambulatory gastric pH monitoring: validation of a new method and effect of H2 antagonists. *Gastroenterology* 88: 1842–1851, 1985.
5. **Frankel, W. L., W. Zhang, A. Singh, D. M. Klurfeld, S. Don, and T. Sakata.** Mediation of the trophic effects of short chain fatty acids on the rat jejunum and colon. *Gastroenterology* 106: 375–380, 1994.
6. **Houghton, L. A., N. W. Read, R. Heddle, M. Horowitz, P. J. Collins, and B. Chatterton.** Relationship of the motor activity of the antrum, pylorus and duodenum to gastric emptying of a solid-liquid mixed meal. *Gastroenterology* 94: 1276–1284, 1988.
7. **Kamath, P. S., M. T. Hoepfner, and S. F. Phillips.** Short chain fatty acids stimulate motility of the canine ileum. *Am. J. Physiol.* 253 (*Gastrointest. Liver Physiol.* 16): G427–G433, 1987.
8. **Kamath, P. S., and S. Phillips.** Initiation of motility in canine ileum by short chain fatty acids and inhibition by pharmacological agents. *Gut* 29: 941–948, 1988.
9. **Kamath, P. S., S. F. Phillips, and A. R. Zinsmeister.** Short chain fatty acids stimulate ileal motility in humans. *Gastroenterology* 95: 1496–1502, 1988.
10. **Klauser, A. G., N. E. Schindlbeck, and S. A. Müller-Lissner.** Esophageal 24-hour pH monitoring: is prior manometry necessary for correct positioning of the electrode? *Am. J. Gastroenterol.* 85: 1463–1467, 1990.
11. **Kohler, L. W., R. Heddle, B. W. Miedema, S. F. Phillips, and K. A. Kelly.** Response of canine ileocolonic sphincter to intraluminal acetic acid and colonic distension. *Dig. Dis. Sci.* 36: 1594–1600, 1991.
12. **Kruis, W., F. Azpiroz, and S. Phillips.** Contractile patterns and transit of fluid in canine terminal ileum. *Am. J. Physiol.* 249 (*Gastrointest. Liver Physiol.* 12): G264–G270, 1985.
13. **Kumar, D., S. F. Phillips, and M. L. Brown.** Reflux from ileum to colon in the dog: role of external ligamentous attachments. *Dig. Dis. Sci.* 33: 345–352, 1988.
14. **Laplace, J. P.** Organisation de la motricité de l'intestin grèle chez le porc et influence de l'alimentation. *Ann. Zootech.* 27: 377–408, 1978.
15. **Malbert, C. H., and Y. Ruckebusch.** Duodenal pH dips as an index of transpyloric flow in conscious dogs. *Gastroenterology* 105: 755–763, 1993.
16. **Mathis, C., and C. H. Malbert.** Gastric but not duodenal motor effects of oral erythromycin are dose related. *Neurogastroenterol. Motil.* 7: 47–54, 1995.
17. **Quigley, E. M. M., T. J. Borody, S. F. Phillips, R. L. Wienbeck, and A. Haddad.** Motility of the terminal ileum and ileocecal sphincter in healthy humans. *Gastroenterology* 87: 857–866, 1984.
18. **Quigley, E. M. M., S. F. Phillips, J. Dent, and B. M. Taylor.** Myoelectric activity and intraluminal pressure of the canine ileocolonic sphincter. *Gastroenterology* 85: 1054–1062, 1983.
19. **Richter, J. E.** Gastro-oesophageal disease. In: *An Illustrated Guide to Gastrointestinal Motility,* edited by D. Kumar and D. Wingate. London: Churchill Communications Europe, 1993, p. 496–521.
20. **Roger, T., C. H. Malbert, and Y. Ruckebusch.** Functional role of the equine ileocecal sphincter. *J. Gastrointest. Motil.* 2: 224–229, 1990.
21. **Siegle, M. L., and H. J. Ehrlein.** Interdigestive contractile patterns of the ileum in dogs. *Am. J. Physiol.* 253 (*Gastrointest. Liver Physiol.* 16): G452–G460, 1987.
22. **Spiller, R. C., M. L. Brown, and S. F. Phillips.** Decreased fluid tolerance, accelerated transit, and abnormal motility of the human colon induced by oleic acid. *Gastroenterology* 91: 100–107, 1986.