Myoelectric activity of the ileum, cecum, proximal loop of the ascending colon, and spiral colon in cows with naturally occurring cecal dilatation-dislocation

Christine Kunz-Kirchhofer, Dr med vet; Esther Schelling, Dr med vet, PhD; Sylvie Probst, Dr med vet; Monika Brechbühl, Dr med vet; Adrian Steiner, Dr med vet, MS, Dr habil; Mireille Meylan, Dr med vet, PhD, Dr habil

Objective—To analyze myoelectric activity of the ileum, cecum, proximal loop of the ascending colon (PLAC), and spiral colon in cows with naturally occurring cecal dilatation-dislocation (CDD) and compare findings with those in healthy cows.

Animals—8 CDD-affected and 6 healthy control cows.

Procedures—Immediately after diagnosis, CDD-affected cows underwent surgery; control cows underwent a similar surgical procedure. Before completion of surgery, 8 bipolar silver electrodes were implanted in the ileum (n = 2), cecum (1), PLAC (1), and spiral colon (4) of each cow. Beginning the day after surgery, intestinal myoelectric activity was recorded daily (8-hour period) for 4 days; data were analyzed by use of specialized software programs. Quantitative variables of myoelectric activity were compared between groups.

Results—Cows of both groups recovered without complications after surgery. In control cows, physiologic myoelectric activity was recorded in all intestinal segments on all days after surgery. Apparently normal myoelectric activity was evident in the ileum of CDD-affected cows on the first day after surgery, but myoelectric activity patterns in the cecum, PLAC, and spiral colon were variable with no organized cyclic myoelectric patterns, incomplete or normally organized migrating myoelectric complexes, and slow normalization over time.

Conclusions and Clinical Relevance—After surgery for CDD, normal myoelectric patterns were disrupted in the large intestine of cows, especially in the spiral colon. Clinical recovery with effective transit of ingesta occurred before normalization of myoelectric activity in the large intestine. Therapeutic protocols for restoration or normalization of spiral colon motility should be developed for treatment of CDD-affected cattle. (Am J Vet Res 2010;71:304–313)

Cecal dilatation-dislocation, a common and economically important abdominal disorder that affects mainly dairy cattle, has been described in numerous clinical reports1–3 from Europe and North America. In an epidemiologic study4 in Switzerland, the prevalences for CDD and left abomasal displacement were similar (0.05% at the individual cow level). Clinical signs of CDD include a moderately reduced general condition, a pronounced decrease in milk yield, reduced appetite, decreased to absent ruminal motility, and mild signs of colic, frequently without alterations in heart and respiratory rates and rectal temperature. More specific signs of the disease include positive results of succussion or percussion during auscultation in the right flank area combined with detection of a dilated cecum during rectal palpation. Rectal palpation findings provide a conclusive clinical diagnosis in 95% of cases.1 Various approaches, including surgical and medical methods, have been described for treatment of CDD in cattle.1–10 The prognosis is generally considered to be fair, but recurrence rates as high as 10% during the first week after surgery have been reported.1,11,12 Despite the considerable amount of information available regarding clinical aspects of CDD, the pathogenesis of the disease is poorly understood. Hence, it remains

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From the Clinic for Ruminants, Vetsuisse-Faculty, University of Berne, 3012 Berne, Switzerland (Kunz-Kirchhofer, Probst, Brechbühl, Steiner, Meylan); and the Swiss Tropical and Public Health Institute, University of Basel, 4002 Basel, Switzerland (Schelling). Dr Probst’s present address is Veterinary Practice Krebs, 1073 Mollie-Margot, Switzerland.
Address correspondence to Dr. Meylan (mireille.meylan@knp.unibe.ch).

Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
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<tr>
<td>bcMMC</td>
<td>Bovine colonic migrating myoelectric complex</td>
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<tr>
<td>CDD</td>
<td>Cecal dilatation-dislocation</td>
</tr>
<tr>
<td>MMC</td>
<td>Migrating myoelectric complex</td>
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<tr>
<td>PLAC</td>
<td>Proximal loop of the ascending colon</td>
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difficult to propose adequate medical treatment for replacement or support of surgical correction of the condition.

Atony or dysmotility of the cecum itself, leading to accumulation of gas and ingesta followed by dilatation and secondary displacement, has been reported to be of primary relevance in the pathogenesis of CDD. However, myoelectric activity was not reduced but increased in the cecum and PLAC of cows with delayed recovery or recurrence after surgery for CDD, compared with findings in cows with uneventful recovery after CDD and healthy control cows that underwent a similar surgical procedure. The pattern of myoelectric activity in the cecum and PLAC of the cows with delayed recovery or relapse after CDD was strikingly similar to that recorded orad to the site of obstruction caused by a cannula implanted in the distal portion of the PLAC of an otherwise healthy cow in another study. Therefore, it was hypothesized that the primary motility disturbance leading to CDD may be located not in the cecum itself but more distally in the digestive tract—that is, in the spiral colon. To verify this assumption, investigation of the myoelectric activity of the spiral colon in cows with naturally occurring CDD was warranted. To date, it has not been possible to induce the disease experimentally; therefore, such investigations have to be conducted in cows after surgical correction of naturally occurring CDD. Affected cattle can be appropriately instrumented during surgical correction of the condition, and relapse can be used as a model for the development of the disease. The physiologic patterns of myoelectric activity in the spiral colon of healthy cattle have been described in detail and can be used as a basis for comparison.

The purpose of the study reported here was to analyze the myoelectric activity of the ileum, cecum, PLAC, and spiral colon of cows after surgery to treat naturally occurring CDD and to compare those data with findings obtained from healthy control cows that underwent a similar surgical procedure. We hypothesized that myoelectric patterns recorded during the recovery period after surgery in CDD-affected cows would be significantly different from those recorded in control cows. Furthermore, we postulated that myoelectric activity recorded in cows with delayed recovery or recurrence of the disease would differ from activities recorded in control cows and in cows with CDD that recovered uneventfully after surgery. If dysfunction of the spiral colon in cows with CDD was detected during the postoperative period, this would open a new field of investigations on the effect of motility-modulating drugs (eg, bethanechol) on spiral colon motility and possibly lead to new therapeutic approaches for medical treatment or postoperative management of cattle with CDD.

Materials and Methods

Cows, housing, and animal care—Fourteen cows of the common dairy breeds in Switzerland were included in the study. Group 1 consisted of 8 cows (6 Red Holstein, Simmental, or Simmental-Red Holstein crossbreeds; 1 Holstein Friesian; and 1 Brown Swiss) with naturally occurring CDD that were admitted to our clinic for surgical correction of the disease. Ages of these cows ranged from 2.5 to 5 years and weights ranged from 520 to 661 kg. At the time of referral to the clinic, the cows’ daily milk yield had decreased to 1 to 10 L from 20 to 33 L. Cows with concomitant diseases in addition to CDD were not included in the study. The control group (group 2) was comprised of 6 healthy dairy cows (Simmental-Red Holstein crossbreeds) of similar ages (range, 3.5 to 5 years) and weights (range, 510 to 635 kg); daily milk yields of these cows ranged from 6.2 to 16.7 L.

The cows were housed in tie stalls on straw bedding. They were fed an individually calculated ration of hay and concentrate (determined on the basis of body weight and milk yield), had free access to water at all times, and were milked twice daily. The cows’ general condition, heart and respiratory rates, rectal temperature, appetite, gastrointestinal peristalsis, presence or absence of dilated intestinal loops detected during rectal examination, fecal output and consistency, and milk yield were monitored and recorded daily.

The project was approved by the Swiss Committee for Animal Care and Protection. Written informed consent was obtained for all client-owned cows (group 1). Cows in group 2 were purchased specifically for use in the project.

Surgical procedure, electrical implants, and postoperative care—Cows in group 1 underwent surgery immediately after confirmation of the diagnosis of CDD. The only preoperative treatment at the clinic consisted of IV administration of fluids as needed. For drainage and repositioning of the cecum, routine laparotomy with regional anesthesia (distal paravertebral nerve block achieved via infiltration of 2% lidocaine hydrochloride) was performed in standing cows. The position of the cecum, PLAC, and spiral colon in the abdomen prior to exteriorization of the cecum as well as the quantity and quality (consistency) of the contents evacuated through the enterotomy at the cecal apex were recorded. After closure of the enterotomy site and final exploration of the abdominal cavity, 8 bipolar polytetrafluoroethylene-coated chromel electrodes (0.127 mm in diameter and denuded over the most apical 3 mm) were implanted in the ileum (2 bipolar electrodes), the cecal body (1 bipolar electrode), the PLAC (1 bipolar electrode), and the spiral colon (2 electrodes in each of 2 locations [ie, 4 bipolar electrodes]; Figure 1). The denuded tips of the electrodes were introduced in the muscular layer of the intestine through a 12-gauge needle, and the electrode wires were sutured to the intestinal wall with polyglyconate 4-0 suture as described. The electrode wires penetrated the peritoneum and the abdominal muscles and exited the abdominal cavity between the transverse processes of the second and third lumbar vertebrae. The abdominal wall was closed routinely after implantation of the electrodes. Before suturing the skin, a reference electrode was implanted SC. For each cow in group 2, feed was withheld for 24 hours before the same surgical procedure as described for group 1 was performed. For all cows, the day of surgery was designated as day 0.

For cows in both groups, postoperative care included administration of cefotaxime (1 mg/kg SC, q 24 h for 5 days, starting 1 to 2 hours before surgery) and treatment with 3 L of fresh ruminal fluid with 20 L of...
The recorded signals were analyzed visually for each location separately at compression rates of 30, 100, 1,000, and 3,000 and at maximal compression by use of a commercial software program. First, the myoelectric tracings were evaluated for presence or absence of cyclic myoelectric activity organized in MMC in the ileum, cecum, and PLAC or in bcMMC in the spiral colon. If recurring cyclic activity was present, the next step was to determine whether the complete set of phases (I to III) of the MMC or the bcMMC was identifiable.

If complete MMC or bcMMC patterns were present, the registered quantitative data included the duration of the MMC or bcMMC and the duration of each individual activity phase in seconds. For phases I and II in all intestinal segments under investigation as well as for phase III of the MMC in the ileum, PLAC, and cecum, spike frequency (number of spikes/min) and spike duration (in seconds) were determined. Phase III of the bcMMC, characterized by its typical organization in continuous spike bursts of increasing and decreasing amplitude called spindles, consists of several regular spindles and a final spindle of longer duration and irregular shape. For this phase of the bcMMC, the duration of phase III, the number and the mean duration of regular spindles, and the duration of the final irregular spindle were recorded. If constant spiking activity was not organized in distinct cycles or phases, spike frequency (number of spikes/min) and spike duration (in seconds) were determined for the entire duration of the daily recording.

For spike analysis in all intestinal segments, the minimal duration of a spike was set at 0.5 seconds and maximal duration was set at 20 seconds. A spike was considered separated when it started at least 0.2 seconds after the preceding spike. These analyses of the intensity of spiking activity were done by use of a custom-designed software. All results generated with this program were controlled visually to ensure validity of the results as described.

If present, 4 MMCs in the proximal intestinal segments recorded each day were analyzed. In the spiral colon, 2 bcMMCs were recorded each day and analyzed.

**Statistical analysis**—Data from cows with organized cyclic activity (MMC and bcMMC) were analyzed and compared between groups 1 and 2 and among days. Results from each intestinal segment were analyzed separately. In locations where 2 bipolar electrodes had been implanted, the means of the 2 values for the ileum and the 2 values for each of the 2 spiral colon locations were used when the results of both electrodes were interpretable; otherwise, only the results of functional electrodes were considered. For the spiral colon, preliminary statistical evaluation of the data did not reveal any significant differences between the 2 implantation sites, which was in accordance with previous results. Thus, the values obtained from the 4 bipolar electrodes in the spiral colon were pooled for further analyses.

The durations of the MMC and bcMMC, the durations of the individual phases, the number of spikes per minute, and spike duration as well as the number and duration of spindles in phase III of the bcMMC were compared between the 2 groups by use of the Wilcoxon rank sum test. Differences among days within groups were tested with the Friedman test. Variables of spiking activity (spike frequency and duration) obtained from group 1 cows with constant irregular spiking activity were tested with the Friedman test. Variables of spiking activity (spike frequency and duration) obtained from group 1 cows with constant irregular spiking activity

**Figure 1**—Diagram to illustrate the placement of 8 bipolar electrodes used to record myoelectric activity in the intestinal tract of cows. A = ileum (2 bipolar electrodes). B = Cecum (1 bipolar electrode). C = PLAC (1 bipolar electrode). D = Proximal location in the spiral colon (second outermost centrifugal loop [2 bipolar electrodes]). E = Distal location in the spiral colon (third outermost centrifugal loop [2 bipolar electrodes]). (Adapted from Meylan M, Eicher R, Rothlisberger J, et al. Myoelectric activity of the spiral colon in dairy cows. Am J Vet Res 2002;63:78–85. Reprinted with permission.)
that resembled phase II activity but without organized cyclic patterns were compared with results for phase II activity in the same intestinal segments in group 1 cows with complete or incomplete MMC or bcMMC patterns by use of the Wilcoxon rank sum test. A value of $P < 0.05$ was considered significant, and analyses were done by use of computer software.

Results
Cows and clinical findings—All 8 cows with naturally occurring CDD were from dairy herds that were maintained under similar management and feeding regimens. Prior to admission to the clinic, the duration of clinical signs of CDD in group 1 cows was 8 to 96 hours. The general condition of all cows in group 1 was considered reduced from normal. Six cows had been completely off feed prior to referral, and 2 cows had still consumed approximately 50% of the offered ration. Other clinical signs included markedly reduced or absent defecation (4 cows) and slightly high heart rate (2 cows); however, respiratory rate and rectal temperature were within reference limits. Succussion during auscultation of the right flank area yielded positive results in 7 cows and auscultatory percussion yielded positive results in 5 cows. In all cows, the diagnosis of CDD was confirmed via rectal palpation. Each cow in group 2 was confirmed to be healthy on the basis of findings of a complete physical examination. A CBC and serum biochemical analyses were performed for all cows in groups 1 and 2; no clinically relevant abnormalities were detected in any cow.

Surgical findings, electrical implants, and short-term recovery—Observation of the abdominal cavity during surgery revealed that the cecal tip was directed toward the pelvic cavity in 6 cows in group 1 and retroflexion of the cecum was present in the other 2 cows. The amount of cecal contents evacuated during surgery in group 1 cows ranged from 10 to 40 L. The contents were mostly liquid, sometimes with masses of dry ingesta, or soft in consistency. The cecal wall did not have obvious signs of compromise (e.g., blue discoloration or fibrin exudation) in any cow in group 1. In all cows of group 1, the tone of the cecal wall was considered decreased and the spiral colon was moderately to severely dilated with liquid contents and gas.

Electrode implantation was completed uneventfully in most instances. All cows in group 1 stood quietly during the procedure, whereas the healthy control cows moved frequently, which rendered the implantation of electrodes more difficult.

During the postoperative period, monitoring of clinical variables revealed that the group 1 cows recovered uneventfully after surgery for CDD. In 1 cow (cow 6), defeca-
tion did not occur on day 1; via rectal palpation, the spiral colon was severely distended on day 1 and mildly distended on day 2. No abnormal findings were noted upon rectal examination on days 3 and 4. In another cow (cow 7), the spiral colon was slightly dilated on day 1 and auscultatory percussion in the right flank area yielded positive results on days 1 and 2. These abnormalities were not present on days 3 and 4. None of the cows in group 1 fulfilled the clinical criteria defined for delayed recovery or recurrence of CDD. Among all 8 group 1 cows, the amount of feces excreted ranged from 0 to 19 kg on day 1; the amount ranged from 22 to 32 kg on day 4. The consistency of feces changed from fluid to soft within the first 4 postoperative days in all cows in group 1. No complications developed during or after surgery in any control cow (group 2); all control cows recovered well from surgery.

Recording of myoelectric activity—On day 1 after surgery, myoelectric activity was recorded from 63 of 64 electrode sites in group 1 cows and from 40 of 48 electrode sites in group 2 cows. Electrode functioning remained similar during the following days. In group 2, artifacts superimposed on the myoelectric tracings complicated data analysis because some values could not be determined; such data loss was apparent for the cecum (data from 3/24 recording days was missing) and PLAC (data from 11/24 recording days was missing), in which only 1 bipolar electrode had been implanted. In the ileum (2 electrodes implanted) and the spiral colon (4 bipolar electrodes [2 at each of 2 locations]), measurements were obtained from all cows and all sites at all times.

MMC and bcMMC patterns—Whereas myoelectric activity in the intestinal tract of the control cows (group 2) was organized in distinct MMC and bcMMC patterns in all examined segments on day 1 and thereafter, MMC patterns were identifiable only in the ileum of group 1 cows in the immediate postoperative period. Spiking activity was detected in the large intestine of all cows treated for CDD, but it was not always organized in complete recurring cycles (Figure 2).

With regard to the ileum, complete MMC patterns were detected in 7 of 8 cows in group 1 on days 1, 2, and 4 and in 8 cows on day 3. All cows in group 2 had apparently normal ileal MMC patterns on days 1 through 4 (Figure 3). With regard to the cecum, complete MMC patterns were present in only 1 of 8 cows in group 1 on days 1, 2, and 3 and in 2 cows on day 4. Myoelectric activity was organized in recurrent cycles, but MMC patterns were incomplete with only phases I and II and no phase III of maximal spiking activity on 2 days in each of 3 cows (in 2 cows on days 1 and 4 and in 1 cow on days 2 and 3). In the remaining tracings from cows of group 1, there was no recognizable pattern or periodicity in the myoelectric activity of the cecum. All cows in group 2 had apparently normal cecal MMC patterns on days 1 through 4.

In the PLAC, complete MMC patterns were present in 2 cows in group 1 on days 1 through 4. An increasing number of cows (from 1 cow on day 1 to 3 cows on day 4) had incomplete cyclic patterns (phases I and II but no phase III). Cyclic myoelectric patterns were not detected in the PLAC of the remaining cows in group 1 (ie, 5 cows on day 1, 4 cows on days 2 and 3, and 3 cows on day 4). In cows in group 2, normally organized cyclic activity was evident on all 4 days; however, the poor quality of the tracings (as a result of many superimposed artifacts) impaired detailed data analysis in almost 50% of recordings.

In group 1, apparently normal bcMMC patterns in the spiral colon were detected in 1 cow on day 1, 3 cows on days 2 and 3, and 4 cows on day 4 (Figure 3). The number of cows that had cycles of only phases I and II ranged from 1 to 3 cows on different days, whereas the number of cows without cyclic activity decreased from 6 cows on day 1 to 2 cows on day 4. In control cows, distinct bcMMC patterns were identified on days 1 through 4.

No association was evident between the specific clinical variables which were expected to be abnormal in cases of relapse of CDD (decreased or absent fecal output, dry feces, or dilated loops of intestine upon rectal palpation; data not shown) and the myoelectric patterns observed on any particular day or in any particular intestinal segment. Therefore, these clinical variables were not analyzed further.

Myoelectric activity without cyclic organization in group 1 cows—In group 1 cows, 2 distinct types of spike patterns were detected in intestinal segments without cyclic activity (Figure 2). The first type consisted of continuous irregular spiking activity that resembled phase II of the MMC or bcMMC. Irregularly arranged spikes of variable amplitude were evident; the spike frequency was 1.0 to 4.9 spikes/min, and spike duration was 1.2 to 2.7 seconds. The second type of spiking activity consisted of regularly recurring spikes of constant amplitude (spike frequency, 3.1 to 9.9 spikes/min; spike duration, 1.3 to 2.5 seconds).

The first type (irregular) of spiking activity was detected in the ileum of 1 cow on day 2 and in the cecum of 4 cows on day 1, 5 cows on days 2 and 3, and 3 cows on day 4. In the PLAC, this irregular pattern was evident in 4 cows on day 1, 3 cows on day 2, and 2 cows on days 3 and 4. In the spiral colon, this pattern was present in 5 cows on day 1, 1 cow on days 2 and 3, and 2 cows on day 4.

The second type (constant regular) of spiking activity was recorded from the cecum and PLAC of 1 cow (cow 6) on day 1, 1 cow (cow 7) on day 2, and 1 cow (cow 4) on days 3 and 4. The same regular pattern was detected in the spiral colon of cow 6 on day 1 and cow 4 on days 2 and 3. Only these 3 cows had this noncyclic regular pattern of spiking activity in the large intestine. On days 1 and 2, cows 6 and 7 had severe to moderate dilatation of the spiral colon (determined via rectal palpation), but no abnormal clinical features were identified in association with this regular type of spiking activity in cow 4.

Statistical analysis of spiking activity variables—Only data obtained from cows with organized cyclic myoelectric patterns were used for statistical comparisons between groups. Therefore, the number of values available varied among days and electrode sites.

In the ileum, the duration of the MMC on day 3 was significantly lower in group 1 cows than it was in
group 2 cows, as was the duration of phase II. For phase I, the number of spikes per minute was significantly lower in cows treated for CDD, compared with control cows on all recording days. Likewise, spike duration in group 1 cows was lower than that in group 2 cows on all days (although the difference was not significant on day 1). Significant differences between groups for phase II variables were few and limited to single recording days. There were no significant differences in phase III variables between groups. Comparison among days within groups revealed several significant differences over days, especially in group 2; however, no patterns of change toward longer or shorter MMC or increased or decreased intensity of spiking activity could be identified (Table 1).

The duration of the cecal MMC appeared to be longer in group 1 than in group 2 on day 1, whereas it was shorter on days 2 through 4, but significant differences between groups were restricted to days 2 and 4. The duration of phase I followed a similar pattern (significant differences between groups on days 1, 3, and 4). The number of spikes per minute during phase III was higher in group 1 than in group 2 on days 1 through 4, but the difference was significant only on days 1 and 3. Several other variables (spike duration in all phases and duration of phase II) differed significantly between groups on single days. Significant differences in various variables among days within groups were detected, but no specific patterns of changes over time were identified (data not shown).

In the PLAC, the duration of the MMC in group 1 cows was significantly shorter than that in control cows on days 2 through 4. These differences appeared to be caused by increasing MMC duration over time in group

<table>
<thead>
<tr>
<th>Day 1</th>
<th>Day 2</th>
<th>Day 3</th>
<th>Day 4</th>
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<tbody>
<tr>
<td>Group 1</td>
<td>Group 2</td>
<td>Group 1</td>
<td>Group 2</td>
</tr>
<tr>
<td>Duration of the MMC (s)</td>
<td>3,484–5,286</td>
<td>3,292–5,477</td>
<td>3,046–5,071</td>
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<td>Phase I of the MMC</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Duration (s)</td>
<td>719–2,439*</td>
<td>331–1,024*</td>
<td>542–1,561</td>
</tr>
<tr>
<td>No. of spikes/min</td>
<td>0.1–0.8*</td>
<td>0.6–1.7*</td>
<td>0.2–0.8*</td>
</tr>
<tr>
<td>Spike duration (s)</td>
<td>0.6–1.3</td>
<td>1.1–1.4*</td>
<td>0.5–1.2</td>
</tr>
<tr>
<td>Phase II of the MMC</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Duration (s)</td>
<td>1,597–3,803</td>
<td>1,960–4,168</td>
<td>1,513–4,130</td>
</tr>
<tr>
<td>No. of spikes/min</td>
<td>1–2.9*</td>
<td>1.8–6.2*</td>
<td>2.5–4.9</td>
</tr>
<tr>
<td>Spike duration (s)</td>
<td>1.2–1.5</td>
<td>1.2–1.5</td>
<td>1.3–1.9</td>
</tr>
<tr>
<td>Phase III of the MMC</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Duration (s)</td>
<td>319–635</td>
<td>205–775</td>
<td>216–564</td>
</tr>
<tr>
<td>No. of spikes/min</td>
<td>7.8–9.3</td>
<td>7.7–10.2</td>
<td>7.5–10.8</td>
</tr>
<tr>
<td>Spike duration (s)</td>
<td>2.5–3.7*</td>
<td>2.5–3.2</td>
<td>2.0–3.7</td>
</tr>
</tbody>
</table>

Table 1—Variables of myoelectric activity (MMC) in the ileum of 8 cows during a 4-day period after treatment for CDD (group 1) and 6 healthy control cows that underwent similar surgery (group 2).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group 1</th>
<th>Group 2</th>
<th>Group 1</th>
<th>Group 2</th>
<th>Group 1</th>
<th>Group 2</th>
<th>Group 1</th>
<th>Group 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration of the MMC (s)</td>
<td>1,482–3,889*</td>
<td>5,248–14,007*</td>
<td>2,299–3,866*</td>
<td>8,537–13,237*</td>
<td>2,214–5,395*</td>
<td>10,134–12,670*</td>
<td>2,743–5,022*</td>
<td>9,382–15,349*</td>
</tr>
<tr>
<td>Phase I of the bMMC</td>
<td>441–1,322*</td>
<td>1,032–2,049*</td>
<td>265–701*</td>
<td>771–1,634*</td>
<td>222–750*</td>
<td>926–2,311*</td>
<td>185–707*</td>
<td>1,097–3,623*</td>
</tr>
<tr>
<td>Duration (s)</td>
<td>0.4–2.5</td>
<td>0.9–3.1*</td>
<td>0.8–2.1</td>
<td>0.9–3.7*</td>
<td>0.2–2.5</td>
<td>0.5–3.1**</td>
<td>0.9–3.0</td>
<td>1.3–2.7**</td>
</tr>
<tr>
<td>No. of spikes/min</td>
<td>1.1–1.3*</td>
<td>0.7–1.6*</td>
<td>0.6–1.1*</td>
<td>1.1–1.8**</td>
<td>0.6–1.3*</td>
<td>0.8–1.4*</td>
<td>0.7–1.1*</td>
<td>1.1–1.7**</td>
</tr>
<tr>
<td>Spike duration (s)</td>
<td>1.204–2,575*</td>
<td>3,663–13,161*</td>
<td>1,799–3,324*</td>
<td>4,609–11,766*</td>
<td>1,217–5,015*</td>
<td>6,116–10,187*</td>
<td>2,677–4,297*</td>
<td>6,722–9,446*</td>
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<tr>
<td>Phase II of the bMMC</td>
<td>4.4–6.8</td>
<td>3.8–7.1*</td>
<td>2.8–6.3</td>
<td>2.5–6.6*</td>
<td>3.5–7.2</td>
<td>2.2–5.8*</td>
<td>4.9–9.4*</td>
<td>2.7–4.9*</td>
</tr>
<tr>
<td>Duration (s)</td>
<td>1.4–2.0</td>
<td>1.6–2.1*</td>
<td>1.2–1.6</td>
<td>1.3–2.1*</td>
<td>1.3–1.5</td>
<td>1.1–1.5*</td>
<td>1.5–1.7</td>
<td>1.3–2.4*</td>
</tr>
<tr>
<td>Duration of regular spindles (s)</td>
<td>32.7–42.0</td>
<td>40.3–49.1*</td>
<td>19.8–34.6*</td>
<td>33.4–45.9*</td>
<td>29.3–35.8*</td>
<td>39.0–44.6*</td>
<td>28.5–37.8*</td>
<td>34.9–45.4*</td>
</tr>
<tr>
<td>Duration of final spindle (s)</td>
<td>43.0–114.8</td>
<td>50.8–101.9</td>
<td>30.8–89.5</td>
<td>68.5–113.8</td>
<td>49.0–88.8</td>
<td>71.5–186.6</td>
<td>49.5–138.3</td>
<td>65.0–112.3</td>
</tr>
<tr>
<td>Percentage of phase III followed by phase IV</td>
<td>0</td>
<td>20.8*</td>
<td>16.0</td>
<td>37.5*</td>
<td>38.0</td>
<td>54.1*</td>
<td>45.0</td>
<td>37.5*</td>
</tr>
</tbody>
</table>

| Day of surgery was designated as day 0; recordings were obtained during 8-hour periods on each of the 4 postoperative days. Values are reported as interquartile (25th to 75th percentile) range. For a given variable within a day, values with different superscript letters are significantly (P < 0.05) different among groups. A-B For a given variable within a group, values with different superscript letters are significantly (P < 0.05) different among days.

Table 2—Variables of myoelectric activity (bMMC) in the spiral colon of 8 cows during a 4-day period after treatment for CDD (group 1) and 6 healthy control cows that underwent similar surgery (group 2).
2 cows (nonsignificant change), whereas this variable remained constant in group 1 cows. Phase III of the MMC was longer in group 1 than in group 2 on days 1 through 4, but the difference was significant only on days 2 and 4. Further significant differences between groups were few and were limited to single days (duration of phases I and II, spike duration in phase II, and spike frequency and duration in phase III) or inconsistent among days (spike frequency in phase II lower in group 1 than in group 2 on day 1 but higher on day 4; data not shown).

In the spiral colon, the bcMMC and its phases I and II were significantly shorter in group 1 cows, compared with findings in group 2 cows, on days 1 through 4 (Table 2). Spike duration in phase I was lower in group 1 cows than that in group 2 cows on days 1 through 4, but the difference was significant only on days 2 and 4. Compared with group 2 cows, the duration of phase III was significantly lower in group 1 cows on days 2 and 3. The number of regular spindles was significantly lower in group 1 cows, compared with findings in group 2 cows, on days 1 through 4; likewise, the duration of regular spindles was significantly lower in group 1 cows on days 2 to 4. The duration of the bcMMC was similar or shorter than the duration of the ileal MMC in cows of group 1 and distinctly longer than the ileal MMC in cows of group 2 (Figure 4).

**Electrode removal and follow-up examination**

The cows in group 1 were discharged from the clinic 2 to 24 days (median, 3 days) after uncomplicated electrode removal. One cow remained at the clinic for 24 days and was treated medically for recurrence of CDD 4 days after electrode removal.

Seven of the 8 group 1 cows remained productive members of their herds for 6 to 16 months after surgery for CDD. All cows delivered at least 1 calf after treatment for CDD, with the exception of 1 cow that aborted a fetus 5 months after the surgery. One cow died after parturition 1 year after surgery. Seven of the 8 cows fulfilled or exceeded the expectations of their owners in terms of milk yield.

**Discussion**

The study reported here represents, to our knowledge, the first report on myoelectric activity of the spiral colon of cows during the recovery period after treatment for CDD. Because no experimental model of the disease exists, motility patterns of the large intestine in cattle cannot be investigated prior to or during the development of CDD. Therefore, analysis of myoelectric activity in the intestine of cows with naturally occurring CDD immediately after surgery for correction of the condition is the only practicable approach with which to gain information on motility patterns and possible disturbances thereof in the intestinal tract of affected animals. On the basis of published data, which indicate that recurrence rates are 10% to 13% during the first 10 days after surgery for CDD, we expected to be able to record the myoelectric activity of the colon during the development of recurrence of the disease in some of the instrumented cows and thereby use relapse to investigate development of CDD. However, all 8 cows with CDD included in the study had essentially uneventful clinical recoveries, and none of them fulfilled the criteria that had been used in a previous study to define delayed recovery or recurrence of CDD during the period of electrode implantation. In contrast, 3 of 12 cows with CDD had developed recurrence or delayed recovery of the disease within 2 days after surgery in that previous study. The reasons for this discrepancy are unclear because animal husbandry and feeding were similar in our study and the previous study. Increasing the number of cows with CDD enrolled in our study would have increased the chance of relapse in 1 or several cows; however, this was not possible because of practical constraints, one of which was the difficulty in obtaining consent of owners for electrode implantation, despite the fact that the method used is well established and has been used in other studies. Indeed, after the study, all cows returned to their farms of origin to be used as dairy cows and did not develop any complications as a result of electrode implantation.

During electrode placement, a distinct difference in the behavior of the cows in the 2 groups was evident. For the most part, cows undergoing surgery for correction of CDD (group 1) stood quietly throughout the implantation procedure and closure of the abdominal wall (a period of approximately 2 hours), but the healthy control cows (group 2) became increasingly uncooperative and moved frequently in the surgery chute, which rendered electrode placement and fixation more difficult. Endorphin release after relief of intestinal dilatation in...
human patients with acute abdominal pain has been reported, and a similar mechanism may explain the quiet behavior of the sick cows after drainage of the contents of the dilated intestines. In contrast, despite the fact that the right flank area of each animal was locally anesthetized, the healthy control cows tolerated the manipulations and restraint in a surgery chute for a prolonged period less well. In consequence, the quality of data obtained from group 1 cows was considerably better than the quality of data obtained from group 2 cows, with less data missing for technical reasons (eg, electrical artifacts and electrode dysfunction). Furthermore, usable data were obtained from the segment locations in which 2 bipolar electrodes had been implanted (ileum and 2 locations in the spiral colon) in all cows on all recording days. In contrast, the fact that only 1 electrode each had been placed in the wall of the cecum and PLAC resulted in missing data for both groups over the 4 recording days because of low signal strength and artifacts. Therefore, results obtained from those 2 intestinal segments should be interpreted with caution. The myoelectric activity of those intestinal segments after surgery for CDD has been described in detail in a previous study. However, electrode location and detailed analysis of myoelectric activity were slightly different in that investigation so that direct comparison of the results of both studies is difficult. In the present study, the total number of electrodes was limited by the number of channels (8) available for filtering and amplification of the signals. At least 1 bipolar electrode was implanted in each intestinal segment under investigation, but the number of electrodes was doubled in the segment of main interest (spiral colon [2 locations with 2 electrodes each]) and in the distal portion of the small intestine because myoelectric patterns in the large intestine have been reported to be initiated or regulated by impulses from the ileum. The suitability of retrievable electrodes implanted under local anesthesia for myoelectric studies in cattle is confirmed by the results of the present study, but 2 electrodes/site are needed to ensure complete data sets are obtained. Electrode removal under local anesthesia was uneventful in all cows, and each cow treated for CDD was released from the clinic and continued a productive life in its herd of origin after the end of the recording period.

In accordance with previously reported results, normally organized patterns of myoelectric activity were present in all intestinal segments of healthy control cows from the first day after surgery to the end of the recording period. In contrast, only the ileum of cows treated for CDD had apparently normal MMC patterns from day 1 through day 4, whereas no or only incomplete MMC or bcMMC patterns were evident in the more aboral intestinal segments (ie, in the large intestine). In humans, cattle, and several other species, normal motility patterns return faster in the small than in the large intestine after abdominal surgery. Results of the present study confirm this observation for cows undergoing abdominal surgery for CDD, but they may also indicate that the ileum is not involved in the motility disorder that results in the disease.

The main finding of the present study was the absence of cyclic activity in the large intestine of most cows during the recovery phase after treatment for CDD (ie, the first 4 days after CDD surgery), whereas normal myoelectric patterns were present from the first day after surgery in all control cows. A slow progression from completely absent cyclic patterns to incomplete MMC and bcMMC (without phase III) patterns to normal MMC and bcMMC patterns was evident over the 4 recording days. This progression was more obvious in the spiral colon than in the cecum and PLAC, but this may be attributable to the higher proportion of missing values for signals from the 2 proximal locations.

In the present study, it was surprising that cows with no cyclic activity of the large intestine had a normal recovery (ie, they did not meet the clinical criteria defined previously for delayed recovery or recurrence of the disease [dry feces; severely reduced fecal output, feed intake, and milk yield; and recurrence of CDD]). Furthermore, we did not detect obvious links between patterns of myoelectric activity and clinical variables such as general condition, appetite, fecal output, and presence or absence of dilated intestinal loops at rectal examination. It is well established that myoelectric activity correlates with mechanical activity of the intestine, and mixing and propulsive functions have been ascribed especially to phase II of the MMC. Thus, organized cyclic activity would be expected to be necessary for adequate aborad transport of ingesta. However, it has been reported that restoration of motility in the small intestine of humans undergoing abdominal surgery did not coincide with clinical relief from postoperative ileus. Furthermore, intestinal motility in monogastric animals is characterized by the presence of MMC patterns (also called the interdigestive migrating motor complex), which are disrupted in the postprandial phase and replaced by irregular activity resembling phase II of the MMC. In contrast, cyclic patterns in the intestinal tract of ruminants are not disrupted by feed intake. This is because ruminants have forestomachs wherein food is stored and fermented before entering the abomasum and duodenum at a more or less constant rate. Spiking activity in the large intestine of cows with noncyclic patterns after treatment of CDD in the present study resembled irregular spiking activity of phase II in the small intestine or spiking activity during the postprandial period in monogastric species. In the small intestine of rats, dogs, and sheep, this pattern of spiking activity is associated with propulsion of intestinal contents. Similarly, intestinal contents may have been transported through the colon of cows that had these patterns in the first postoperative days. This may explain the uneventful clinical recovery of these animals despite the absence of cyclic activity in the colon. It has been suggested that differences in fecal consistency between cattle and sheep may be related to different patterns of myoelectric activity in the spiral colon. In the present study, fecal output and consistency were monitored every day for all cows, but no association of fecal consistency with patterns of myoelectric activity was evident. Different amounts of liquid contents and gas as well as different tension of the intestinal wall in the ileoceccolic area may have affected myoelectric patterns, but these variables could not be assessed reliably under the experimental conditions of the present study.
The type of noncyclic patterns with regular spikes of large amplitude resembled the colic motor complex described previously, but the spikes observed in the present study were of distinctly shorter duration (mean ± SD duration, 1.9 ± 0.6 seconds vs 8.1 ± 1.6 seconds). The bovine colic motor complex has been detected orad to a mechanical intestinal obstruction, and it has been interpreted as an attempt of the intestinal tract to overcome an obstruction. A similar but weaker pattern was evident in the large intestine of cows after surgery for CDD in the absence of luminal obstruction. The 2 types of noncyclic patterns of myoelectric activity in cows after surgery for CDD may represent an early stage in the normalization of motility after CDD, preceding the return of organized and coordinated patterns. In sheep, phase III of the MMC returns first after disruption of cyclic patterns following abdominal surgery. In the present study, the incomplete MMC observed during the recovery period in the cows treated for CDD included phases I and II, but not phase III. The causes and consequences of this discrepancy among species are unknown. In addition to the abnormal patterns of intestinal motility in some of the cows treated for CDD, some significant differences in quantitative variables of myoelectric activity were detected between the cows treated for CDD that had organized MMC and bcMMC patterns and the healthy control cows.

In the ileum, significant differences between groups were limited to phase I over the entire recording period, with reduced spiking intensity in cows treated for CDD, compared with healthy cows. Prolongation of the phase I of quiescence or decreased spiking activity in phase II (in which mixing and propulsion of intestinal contents occur) would have been more relevant in terms of intestinal transit. Furthermore, measures of spiking activity rely on the amplitude of the registered signals and can be influenced by factors such as electrode placement and fixation in the intestinal wall. However, the fact that significantly reduced spiking intensity in cows after treatment for CDD was evident on all recording days suggests a true diminution of myoelectric activity during phase I of the ileal MMC in these cows. Other differences in myoelectric activity in the ileum were limited to single variables that differed on single days and are therefore not considered to be relevant in terms of intestinal motility.

In the cecum, significant differences between the 2 groups were few and inconsistent. The level of myoelectric activity was generally lower in cows treated for CDD than it was in control cows. However, caution is required in the interpretation of data obtained from the cecum because of missing measurements. In addition, for this intestinal segment, differences between groups may be attributable to the motility disorder that causes CDD; however, an influence of the longer manipulations for drainage of cecal contents of the dilated intestinal tracts of the cows in group 1, compared with the duration of manipulations in the cows in group 2, cannot be excluded.

Differences in the PLAC variables between groups were also few and inconsistent. The MMC duration appeared to increase over time in healthy cows, in accordance with the results of a previous study. In contrast, this variable did not vary over time in the group of cows treated for CDD. The difference in MMC duration in the PLAC between groups was significant only on days 2 and 4. Phase III activity was generally more intensive in group 1 than in group 2, but differences in phase duration, spike frequency, and spike duration were significant only on single days. The role of phase III in the small intestine is to clean the intestinal lumen of debris and residual contents and to prevent retrograde flow of luminal contents. Likewise, increased phase III activity in the PLAC of cows recovering from CDD treatment may represent a mechanism to prevent a reflux of contents toward the cecum.

In contrast to the other intestinal segments under investigation, significant differences in variables of myoelectric activity in the spiral colon between groups remained constant throughout the entire recording period. The duration of the bcMMC was significantly lower in cows treated for CDD, compared with findings in control cows, on all 4 recording days, as were the durations of phases I and II. Differences in spiking intensity were not consistent over days. Between the 2 groups, the duration of phase III differed significantly only on days 2 and 3, but the number of regular spindles was lower in group 1 on all days and their duration was shorter (significantly so on days 2 to 4). The duration of the bcMMC in cows treated for CDD was reduced, compared with the control group, to such an extent that it was of similar or shorter duration than the corresponding ileal MMC. In healthy animals, as described in several reports, and confirmed in cows of group 2 in the present study, the duration of the bcMMC is approximately 3 times as long as the duration of the small intestinal MMC, which initiates and coordinates myoelectric patterns in the large intestine. The facts that the bcMMC in cows after treatment for CDD cycled mostly with a higher frequency than that of the small intestinal MMC and did not appear to be timely coordinated with ileal myoelectric activity indicate that a pacemaker in the large intestine itself is able to generate and organize complete bcMMC patterns. Such pacemakers have been identified in other species (eg, in the pelvic flexure and left dorsal and transverse colon of horses), and a large intestinal pacemaker has also been detected in cows with ileal obstruction. In those cows, an almost normally organized bcMMC was recorded in the spiral colon despite complete disruption of MMC patterns in the small intestine. Results of the present study indicated that bcMMC patterns can originate in the large intestine of cows not only when impulses from the small intestine are absent, but also in the presence of normal ileal MMC patterns. Thus, under pathological conditions (eg, following development of CDD), regulation mechanisms from the large intestine itself overcome signals from the small intestine and organize independent activity patterns.

Data obtained in the present study confirmed that abnormal patterns of myoelectric activity develop in the large intestine, especially in the spiral colon, of cows after surgery for CDD, with slow normalization over time. No association was observed between specific myoelectric patterns and specific clinical variables; thus, the importance of the observed variations in myoelectric activity cannot be further inter-
preted. However, it is evident that intestinal function including normal transit of ingesta can return prior to normalization of myoelectric patterns. Further investigations are warranted to investigate myoelectric activity of the spiral colon of cows during the development of a relapse after CDD. In addition, the effects of prokinetic drugs such as bethanechol, as has been shown to increase spiking activity in the ileocolic area of healthy cows,44 should be investigated in the large intestine of cows recovering from CDD.

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