Characteristic of duodenal myoelectric activity in relation to food in piglets during the 3rd and 4th week of life

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Abstract

The relationship between duodenal myoelectric activity and liquid food intake was investigated in eight conscious piglets with bipolar electrodes implanted on the wall of the duodenum. Piglets were fed with commercial milk formula and the effects of volume and feed dry matter intake on duodenal myoelectric activity were measured by means of an analog–digital recording system.

The cyclic pattern of duodenal myoelectric activity, i.e. the migrating myoelectric complex (MMC), was preserved when piglets received small meals at regular intervals. The duration of the whole MMC cycle, as well as the duration of phase II of the MMC, were only weakly correlated (r=0.2, P<0.05 for both parameters, respectively) to the amount of ingested food. However, the increase of the amount of feed dry matter intake of a meal from 2.1 to 4.5 g kg⁻¹ of live body mass (LBM) as well as an increase of volume of a meal from 13 to 26 ml kg⁻¹ LBM significantly increased the duration of the MMC cycles (P<0.05) due to the elongation of phase II of the MMC (P<0.05).

The present study shows that in piglets fed with a liquid diet the upper gut motility response to food is similar to that previously observed in adult animals.

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1. Introduction

Weaning may be defined as the process by which mammals cease suckling and begin to ingest solid feed (Counsilman and Lim, 1985). In modern pig production, weaning frequently comprises an abrupt change of diet and feeding regime from the ingestion of small quantities of maternal milk up to 36 times per day (Puppe and Tuchscherer, 2000), to eating greater amounts of dry feed a fewer times a day, e.g., 8 times a day (Bruininx et al., 2002). Such dietary changes, together with the behavioural stress and resulting changes in the structure and functions of the gastrointestinal (GI) tract, are often manifested in reduced growth, the occurrence of post-weaning diarrhoea and increased mortality (Leibbrandt et al., 1975; Alexander, 1994).

Although structural development, GI secretion and absorption during postnatal period as well as the effect of weaning on secretory and absorptive physiology are well described in pigs (Marion et al., 2003; Hedemann et al., 2003; Boudry et al., 2004), the relationship between diet and GI motility in piglets around weaning

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is not fully understood yet (Lærke et al., 2000). Since the first observation by Szurszewski (1969) in fasting dogs, it has been well established in many animal species and humans (Wingate, 1981; Zenilman et al., 1976) that during the interdigestive state the small intestine exhibits a characteristic pattern of myoelectric and motor activity termed migrating motor complex (MMC). The MMC consists of a quiescent period (phase I) during which little or no electrical response activity (ERA) and thus little or no contractile activity is observed, followed by a period of intermittent electrical and mechanical activity (phase II), followed by phase III where each slow wave of electrical control activity (ECA) is associated with spike potentials of ERA and muscular contractions occur with the maximal rate (Szurszewski, 1987). The function of the MMC, and specifically the regular occurrence of phase III of the MMC is to propel luminal contents along the intestine, thereby promoting intestinal clearance and maintaining intestinal homeostasis (Code and Marlett, 1975). In many mammals, the MMC is disrupted by meal ingestion so as to produce a postprandial pattern (Read et al., 1984; Sarna, 1989). The postprandial pattern is characterized by an increase in the frequency of spike potentials of ERA and the lengthening of the time between two subsequent phases III periods (Code and Marlett, 1975; Di Magno et al., 1979) and resulting increase in the intestinal digesta flow (Girard and Sisson, 1992). In adult pigs, however, the MMC is interrupted when the animal is fed discrete, large meals, but not by ad libitum feeding with the same diet (Bueno and Ruckebusch, 1976). Other research has shown that the caloric load regulates the characteristics of the amplitude of contraction and the duration of the intestinal postprandial pattern in adult pigs (Gregory et al., 1986), dogs (Schang et al., 1978; Schmid et al., 1992) as well as in adult humans (Schenfeld et al., 1998). Furthermore, it was demonstrated in adult dogs that during enteral infusion of low caloric load, MMC persisted, apart from a lengthening of phase II and resulting increase in duration of the MMC cycles; only higher caloric load caused complete disruption of the MMC and appearance of postprandial pattern (Defilippi, 2003).

Published data on motility in neonatal piglets have shown that the consumption of cow’s milk (Burrows et al., 1986) or dry solid feed (Lesniewska et al., 2000) three times a day disrupts the MMC, whereas the MMC was not disturbed in piglets of similar age that were nursed by their sows every 1.0–1.5 h (Lesniewska et al., 2000). There is no data available on the relationship between the MMC and the characteristic of ingested feed (e.g., caloric load) in neonatal piglets, however based on the previously published observations in piglets (Burrows et al., 1986; Lesniewska et al., 2000) it could be hypothesized that the effect of feed on intestinal motility in piglets depends on caloric load and/or meal volume, as has been observed in adult pigs and dogs.

The aim of the present study was therefore to evaluate the characteristic of the intestinal motility in relation to the dry matter and volume of ingested milk formula in piglets during the 3rd and 4th week of life.

2. Materials and methods

The protocol used in the present study complied with the Danish Ministry of Justice, law no. 726 (9 December 1993) concerning animal experimentation and care of experimental animals.

2.1. Animal management

The experiment was carried out on eight neonatal piglets of both sexes from different litters in two experimental trials. All piglets were obtained from the pig herd at the Danish Institute of Agricultural Sciences, Research Centre Foulum, Denmark. Piglets, chosen according to their live body mass (LBM) in a range of 2 to 2.3 kg, were removed from their sows at two days of age and immediately moved to the intensive care unit at the Research Centre Foulum. The rearing system for neonatal piglets comprised one cage divided into four compartments, an electronic feeding system, Pig’oline (model Foulum, Boss produkter a.s., Ulstrup, Denmark) for separate feeding of four piglets, an electromagnetic stirrer and four heating lamps. The rearing system has been described in more details elsewhere (Hedemann and Lesniewska, 2003). On the day of removal from the sows, the piglets were kept together in one compartment of the cage. From the next day they were housed in individual compartments that allowed limited contact (visual but not physical) with each other. The room was lit artificially from 07:30 h to 22:30 h. Each piglet was weighed and had its body temperature measured every morning.

After five days of adaptation to the new environment, piglets were prepared for electromyography (EMG) of the gastrointestinal smooth muscle in vivo as described previously (Lesniewska et al., 2000). Briefly, a 4-cm long incision was made vertically from the right, last intercostal space, and the duodenum was localised. Silver, bipolar, serosal silicon based (Silastic, Dow Corning GmbH, Wiesbaden, Germany) electrodes were implanted on the wall of duodenum and oriented in the
circular muscle, 5 to 6 cm (electrode 1) and 10 to 11 cm (electrode 2) posterior to the pylorus. The lead electrode wires, covered with Silastic tubing (Silastic, Dow Corning GmbH, Wiesbaden, Germany), were implanted subcutaneously between the surgical wound and a 2-cm incision made on the back of the piglet. For the surgery, piglets were anaesthetised with halothane (Halocarbon Lab., River Edge, USA) using a gas mixture of O₂ and NO₂ (at the ratio of 2:3), where the ratio of halothane to gas mixture was 0.5 to 1%, vol./vol. After surgery, the piglets were allowed to recover for 5 days, and for the first 3 days were given the analgesic Tempgesic (Buprenorphinum, 0.05 mg.kg⁻¹ LBM; intramuscular administration; Reckitt and Colman, Hull, U.K.) and treated with an intramuscular administration of an antibiotic at 0.2 ml kg⁻¹ LBM (Streptocillin® Vet., containing of 200,000 IE of Benzylpenicillinprocain, and 250 mg of Dihydrostreptomycin in 1 ml of solution; Boehringer Ingelheim, Hellerup, Denmark).

2.2. Feeding regimen and diet

The animals were fed a commercial milk formula for piglets (Porcomel, Nukamel Olen, Hoogbuul, Belgium). The ingredients declared by producer are: milk products, oils and fats products from the processing of cereal grains, and minerals; powdered skimmed milk content 50% according to EEG nr. 1725/79. The chemical composition of the formula is given in Table 1. Milk formula was mixed with warm water (50 °C) and after cooling to the ambient temperature of 32 °C it was added to the mixing compartment of the electronic feeding system (Pig’oline, Boss produkter). The daily

<table>
<thead>
<tr>
<th>Component</th>
<th>g kg⁻¹ dry matter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross energy, kJ 100⁻¹ g dry matter</td>
<td>2119</td>
</tr>
<tr>
<td>Protein</td>
<td>226</td>
</tr>
<tr>
<td>Fat</td>
<td>257</td>
</tr>
<tr>
<td>Lactose</td>
<td>327</td>
</tr>
<tr>
<td>Starch</td>
<td>92</td>
</tr>
<tr>
<td>Glucose</td>
<td>15</td>
</tr>
<tr>
<td>Crude fibre</td>
<td>1.0</td>
</tr>
<tr>
<td>Ash</td>
<td>85</td>
</tr>
<tr>
<td>Ca</td>
<td>8</td>
</tr>
<tr>
<td>P</td>
<td>7</td>
</tr>
<tr>
<td>Vitamin A, µg g⁻¹ dry matter</td>
<td>14.7</td>
</tr>
<tr>
<td>Vitamin E, µg g⁻¹ dry matter</td>
<td>155</td>
</tr>
<tr>
<td>Amino acids:</td>
<td></td>
</tr>
<tr>
<td>Cysteine</td>
<td>5.16</td>
</tr>
<tr>
<td>Lysine</td>
<td>17.98</td>
</tr>
<tr>
<td>Methionine</td>
<td>5.01</td>
</tr>
<tr>
<td>Threonine</td>
<td>13.61</td>
</tr>
<tr>
<td>Fatty acidsa</td>
<td></td>
</tr>
<tr>
<td>14:0</td>
<td>1.7</td>
</tr>
<tr>
<td>16:0</td>
<td>47.5</td>
</tr>
<tr>
<td>18:0</td>
<td>4.7</td>
</tr>
<tr>
<td>18:1</td>
<td>35.9</td>
</tr>
<tr>
<td>18:2</td>
<td>8.6</td>
</tr>
</tbody>
</table>

a Fatty acid concentrations <1% are not included.
allowance of milk formula offered to the piglets was based on the level of protein intake observed in suckling piglets (Holub and Dolezel, 1994) i.e., starting with 11 g kg\(^{-1}\) LBM.24 h\(^{-1}\) on the 3rd day of life and then it was increased progressively by 0.1 g of protein per kg\(^{-1}\) LBM.24 h\(^{-1}\) during pre-trial period and by 0.1 g of protein per kg\(^{-1}\) LBM.48 h\(^{-1}\) during experimental period. The feeding frequency was set up according to Brooks and Burke (1998), i.e., piglets were fed every hour with equal meals except for a night time break of 4 h (from 24:00 h to 04:00 h). The milk formula remaining in the mixing compartment of the electronic feeding system as well as drinking bowls was measured twice a day. Water was available ad libitum.

2.3. Experimental procedures

For all EMG recordings of duodenal myoelectric activity (Fig. 1), the lead electrode wires were connected to the signal amplifiers (BioAmp, ADInstruments, Melbourne, Australia) and signals were recorded with an Apple computer-based data recording system (MacLab 8e, ADInstruments, Melbourne, Australia). Raw data representing electrical control activity (ECA) and electrical response activity (ERA) were sampled with a sampling rate of 100 samples per second (100 Hz) per each channel. Simultaneously, filtered signals representing the ERA without ECA were collected with low and high cut-off frequency filters of 10 and 50 Hz respectively, as proposed by Sarna (1989). Filtering was achieved by on-line frequency analysis of waveform from the application program Chart v. 3.4.2 (ADInstruments).

2.3.1. Relationship between feed intake and duodenal myoelectric activity

The 6 h EMG recordings of duodenal myoelectric activity were performed on each piglet starting from the 6th postoperative day. Two piglets were studied each day, e.g., the first animal was under study from 8:00 until 14:00 and the second animal was under study from 14:00 until 20:00. During each recording the animals were fed every hour. From the day of the first recording, volume and concentration of each meal offered to all piglets was increased progressively every two days to allow the randomized EMG recording of each animal at each stage of growth. The recordings were carried out over a period of 14 days. To measure the feed intake from each meal offered, the volume of milk formula remaining in the drinking bowls after each feeding was measured and removed immediately after the piglet under study moved away from the drinking bowl.

2.3.2. Effect of the dry matter intake and meal volume on duodenal myoelectric activity

The effect of the meal volume on the duodenal myoelectric activity was investigated when piglets were 15–16 days old and weighed 3.8 (s.e. 0.07) kg. From the beginning of a recording session piglets received three equal meals (13 ml kg\(^{-1}\) LBM and 2.1 g kg\(^{-1}\) LBM), followed by meals of the same dry matter load (2.1 g kg\(^{-1}\) LBM) but of higher volume (26 ml kg\(^{-1}\) LBM) while duodenal EMG was carried out.

When piglets were 17–18 days old and weighed 4.2 (s.e. 0.08) kg, after three equal meals (13 ml kg\(^{-1}\) LBM and 2.1 g kg\(^{-1}\) LBM) offered at hourly intervals, animals were offered meals of the same volume (13 ml kg\(^{-1}\) LBM) but of the higher dry matter content (4.5 g kJ kg\(^{-1}\) LBM) while duodenal EMG was carried out.

After completing the experimental protocol, the piglets were killed using an overdose of barbiturate. Post-mortem examinations performed at the conclusion of experiment revealed no signs of inflammation around the implanted electrodes or lead wires.

2.4. Data management and statistical analysis

The daily growth of the piglets was calculated as the difference in individual body weight between consecutive days over the experimental period. Feed efficiency ratio (FER) was calculated over the whole period of the experiment as the amount of milk formula powder (in grams) per kilogram of LBM gain.

The following EMG recording characteristics were determined: (1) duration of MMC cycles, (2) duration of particular phases (phases I, II, III) of the MMC cycle, and (3) the frequency of the individual spikes in ERA burst per minute (BMP) during phase II as well as phase III of the MMC.

Each recording was analysed individually for both electrodes i.e., electrode 1 (E1) and electrode 2 (E2). The data from electrodes were compared using Student paired t test. For the duration characteristics, there were no significant differences (P>0.05) between the electrodes; therefore the data were aggregated into an average. The frequencies of the individual spikes in ERA burst per minute recorded from E1 and E2 were significantly different (P<0.05); therefore the data from each electrode were evaluated individually.

2.4.1. Relationship between feed intake and duodenal myoelectric activity

The characteristics of each meal consumed by piglets during EMG recordings included the volume of milk formula consumed (in milliliters per kilogram
of LBM) and the feed dry matter intake (in grams per kilogram of LBM).

The duration and the frequency characteristics of duodenal myoelectric activity and the feed intake characteristics were first evaluated using the following model:

\[ Y_{ijk} = \mu + \alpha_i + \beta_j + \gamma_k + \alpha\beta_{ijk} + \alpha\gamma_{ik} + \beta\gamma_{jk} + \epsilon_{ijk} \]

where \( Y_{ijkl} \) is the dependent variable, \( \mu \) is the overall mean, \( \alpha_i \) is the effect of animal \((i=1,...,8)\), \( \beta_j \) is the effect of growth level \((j=1,...,7)\), \( \gamma_k \) is the effect of the position of the MMC cycle within the recording session (each session contained 4, 5 or 6 cycles, depending on the number of full cycles available in the record), \( \alpha\beta_{ijk} \) is the interaction between animal, growth level, and the MMC cycle, \( \alpha\gamma_{ik} \) is the interaction between animal and the MMC cycle recorded during each recording session, \( \beta\gamma_{jk} \) is the interaction between growth level and the MMC cycle recorded during each recording session, and \( \epsilon_{ijkl} \) represents the unexplained random error.

All tested characteristics of duodenal myoelectric activity, including duration of the MMC cycles, duration of phases I, II, III of the MMC, the frequency of ERA during phase II as well as phase III of the MMC were not significantly affected \((P>0.05)\) by the animal, the growth level, and the cycle variables. The interactions, i.e. the interaction between animal, growth level and the MMC cycle recorded within the recording session, the interaction between animal and the MMC cycle, and the interactions between growth level and the MMC cycle within the recording session were not significant \((P>0.05)\) for all interactions.

The characteristics of consumed meals i.e., volume intake (ml kg\(^{-1}\) LBM per meal) and dry matter intake (g kg\(^{-1}\) LBM per meal) were both significantly dependent on the animal variable \((P<0.05)\) for both parameters); therefore the animal effect was included in the calculations of correlations coefficients. Two-tailed partial correlation was used to obtain first order correlation coefficients \((r_{xy.i})\), for the duration \((i.e.,\) the duration of the MMC cycles as well as the phases II and III of the MMC, during which meals were consumed) and the frequency characteristics \((i.e.,\) the frequencies of the individual spikes in ERA burst per minute recorded from E1 and E2 of phases II and III of the MMC) of duodenal myoelectric activity \((y)\) and the characteristics of consumed meals \(i.e.,\) volume and dry matter intake \((x)\), controlling for the effect of animal \((i)\).

2.4.2. Effect of the dry matter intake and meal volume on duodenal myoelectric activity

The effect of dry matter intake and volume of meal on duodenal myoelectric activity was estimated using data from six piglets, as two out of eight animals did not consume the full offered volume of milk formula during a recording session. The effect of dry matter intake and meal volume on duodenal myoelectric activity was evaluated using repeated measure analysis of variance (ANOVA) with dry matter intake \((2.1 \text{ vs. } 4.5 \text{ g kg}\(^{-1}\) LBM) and meal volume \((13 \text{ vs. } 26 \text{ ml kg}\(^{-1}\) LBM) as an independent categorical variable and animal \((i=1,...,6)\) as within-subjects factor. When ANOVA indicated a significant difference, Tukey’s post hoc test was used to compare the effect of dry matter intake and meal volume on each studied parameter of duodenal myoelectric activity.

The level of statistical significance was assigned as \(P<0.05\) in all performed analysis. Data are expressed as mean values with the standard error of mean (s.e.) unless stated otherwise. The statistical analyses were performed with SPSS 11.0.1 for Windows program (SPSS, 2001).

3. Results

The average daily weight gain of the piglets during the experimental period was 229 (s.e. 3.6) g. The average value of FER throughout the experimental period was 668 (s.e. 54.7) g of milk formula powder kg\(^{-1}\) LBM gain.

3.1. Relationship between feed intake and duodenal myoelectric activity

The duration of phase II of the MMC was significantly correlated with the consumed volume of milk formula \((r=0.20, P<0.05)\) as well as with the dry matter intake \((r=0.20, P<0.05)\) per one meal. The duration of phase III of the MMC was negatively correlated with the consumption of the milk formula \(i.e.,\ r=-0.2, P<0.05\) for both volume and dry matter intake, respectively. The duration of MMC cycles was positively correlated with the duration of phase II of the MMC \((r=0.97, P<0.001)\) and to a lesser extent with the duration of phase III of the MMC \((r=0.18, P<0.05)\). The duration of phase II of the MMC did not correlate with the duration of phase I \((P>0.05)\) and phase III \((P>0.05)\) of the MMC. The duration of phase I of the MMC was positively correlated with the duration of phase III of the MMC \((r=0.38, P<0.001)\).

The frequency of the individual spikes in ERA burst of phase II and phase III recorded by both electrodes (E1 and
E2) did not show significant correlation with the volume of meal and dry matter intake \((P>0.05\) for all estimated parameters). The frequency of the individual spikes in ERA burst of phase II recorded from electrode 1 and electrode 2 were positively correlated with each other \((r=0.44, P<0.01)\). The frequency of ERA of phase III recorder from electrode 1 and electrode 2 were also positively correlated with each other \((r=0.54, P<0.001)\).

### 3.2. Effect of the feed dry matter intake and meal volume

The duration of phase II of the MMC as well as the duration of the MMC cycles were significantly longer \((P<0.05\) for both parameters) when piglet consumed meals of two times higher volume \(i.e., 26\) vs. \(13\) ml kg\(^{-1}\) LBM \((Fig. 2)\). The duration of phase I and phase III of the MMC was not significantly \((P>0.05\) for both phases) affected by the volume of consumed meal \((Fig. 2)\). An increase in the dry matter intake from \(2.1\) to \(4.5\) g kg\(^{-1}\) LBM significantly increased the duration of Phase II of the MMC \((P<0.05)\) as well as the duration of the MMC cycle \((P<0.05)\) \((Fig. 3)\), whereas the duration of phase I and phase III were not affected \((P>0.05\) for both phases) by the increase in the dry matter intake \((Fig. 3)\). The frequency of ERA of phase II and phase III, recorded from both electrodes 1 and 2 were not significantly affected \((P>0.05\) for both phases and both electrodes) by the increase in the meal volume \((Fig. 4)\).
and dry matter content ($P>0.05$ for both phases and both electrodes) (Fig. 5) of the consumed meal.

4. Discussion

The results of the present study show that in piglets during their 3rd and 4th week of life the duodenal myoelectric activity response to consumed feed was similar to that observed in adult animals. When piglets from the present study were fed small meals in hourly intervals the variation in the duration of the MMC cycles as well phases II of the MMC was only 4% related (as indicated by the correlation coefficients) to the volume and caloric load of consumed meals. However, an increase in dry matter intake and volume of consumed meal caused significant elongation of the MMC cycles mainly due to an increase in duration of phase II of the MMC. Previous work on adult pigs has shown that the increasing amount of solid feed ingested per individual meal elongated the period between subsequent phase III intervals (Bueno and Ruckebusch, 1976). Recently, important additional observations by Defilippi (2003) showed that the duodenal motor response to the increase of caloric load of nutrients administered intraluminally in adult dogs was characterised by the gradual transition from cyclic MMC to postprandial pattern, due to the lengthening of cycles associated with an increased duration of phase II.

The dry matter intake or volume of meal consumed by the piglets in the present study did not appear to affect or correlate with the frequency of the individual spikes in ERA burst per minute during phases II and III of the MMC. Defilippi (2003) showed that the mechanisms controlling switching of cyclic MMC to postprandial pattern had a lower threshold compared to those controlling the frequency and amplitude of intestinal contractions. However, it would need to be investigated whether in neonatal piglets, high dry matter intake or volume of a liquid meal could cause an increase in frequency of the individual spikes in ERA burst. It was previously shown that in piglets directly after weaning solid feed consumed three times a day induced a long-term postprandial pattern with higher frequency of the individual spikes in ERA burst when compared with phase II of the MMC (Lesniewska et al., 2000).

All piglets in the present study had a good appetite and appeared clinically healthy throughout the experiment. Their daily LBM gain was similar to the daily LBM gain previously observed in piglets nursed by the sows (e.g., 195 g day $^{-1}$; Noblet and Etienne, 1986). Moreover, the values of FER observed in our piglets were similar to values observed previously in suckling piglets without surgical modification (Noblet and Etienne, 1987). Thus the results of the present study are representative for suckling piglets without surgical modifications, under farm conditions. Therefore, the motility response to feed in 15–18 day old piglets under farm conditions could be similar to that observed in adult animals.

In summary, our findings indicate that in 15–18 day old piglets weaned at 2 days of age, the response of upper gut motility to feed is similar to that observed in adult animals.

References


SPSS, 2001. SPSS. SPSS, Chicago, IL, USA.


