Propulsive Contractions Induced by Electrical Stimulation in the Descending Colon of the Pig

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Introduction

After resection of the distal part of the colon due to different pathological reasons, a colostomy is common practice. Patients with a colostomy have no control over the evacuation of the colon content. Currently, they have to wear a colostomy bag, or to perform irrigation procedures in order to empty the colon. An alternative for emptying the colon could be the use of electrically induced colon contractions.

Several authors reported successful results with electrical stimulation of the gastrointestinal tract to improve gastric emptying [1], and to induce propulsive contractions in the small intestine [2]. In addition, colon transit could be improved in spinaled cats by stimulation of the colon wall using wire electrodes and 40 Hz, 5-50 mA pulses [3]. Using charge balanced rectangular pulses of 0.1-0.3 ms, 4-10 mA and 10-40 Hz, we have previously induced propulsion of a bolus in the descending colon of rats by sequential stimulation [4]. As the diameter of the colon in man is larger than that in the rat, one cannot expect the method used for rat colon stimulation to simply be copied for humans. Therefore, the method must be first tested in a larger sized animal, and the goal of the present work was to study in pigs the sequential stimulation protocol developed for the rat.

Methods

Surgical procedures. 4 female pigs, 40 – 50 kg weight, were used in accordance with an experimental protocol approved by the Danish Animal Welfare Committee. After anesthesia was induced, the colon was exposed and emptied by irrigation with warm saline.

Electrodes positioning and stimulation pattern. The electrodes were made of Teflon insulated multistrand stainless steel wires (0.4 mm diameter, AS634 Cooner Wire Inc. Chatwoth, CA). The deinsulated sites of 9 electrodes (e1-e9 in Fig. 1) were inserted under the serosa of the descending colon. The most distal electrode (e9) was located about 6 cm orally to the rectum, and the distance between 2 neighboring electrodes was 2 cm. Charge balanced rectangular pulses (15 mA, 0.3 and 3 ms, 10 Hz) were generated by a NoxiTest stimulator (NoxiTest Biomedical A/S, Aalborg, Denmark). As shown in Figure 1, stimulation was performed in 8 consecutive sessions (S1-S8). The first stimulation session S1 used electrodes e1 and e2, and elicited contraction into the colon segment delimited by the electrodes. After that motor response, the second stimulation session S2 followed, and contraction in the second

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Fig. 1. Stimulation and monitoring setup. See text for details.
stimulated segment was evoked. Based on visual control, stimulation continued in this way until all of the 8 segments had been stimulated.

**Data acquisition.** Spontaneous and electrically induced motor activity in the proximal part of the descending colon was monitored in 3 pigs, using impedance planimetry and pressure recording. Through a small incision in the colon wall, a balloon made of polyurethane (7 cm long, 3 cm in diameter) was placed inside the colon lumen. The balloon was attached to a probe carrying 2 excitation electrodes (E) and 2 pairs of detection electrodes (D). A volume of 30 ml saline was injected in the balloon through an infusion channel. The excitation electrodes were supplied with an AC current of 0.1 mA at 10 kHz, and cross-sectional areas CSA1 and CSA2 around the detection sites were estimated based on Ohms law. The detection sites were 2 cm apart, each at a distance of 2 cm from the neighboring excitation electrode. The balloon was positioned in such a manner that the first detection site was located between e1 and e2, and the second detection site between e2 and e3 (see Fig. 1). A channel to monitor pressure (P) inside the balloon was also present. Data acquisition and processing was performed using the software package Openlab (Gatehouse, Nørresundby, Denmark).

**Propulsion of intraluminal content.** In pig 3, 40 ml of semi-fluid material (powdered potato solved in saline, 1:3) was placed in front of the balloon using a silicon tube. Two sequential stimulation series (S1→S8) with 15 mA, 0.3 ms, 10 Hz pulses were applied in order to displace the material in anal direction. In pig 4, a bolus made of wax (9 cm long, 3.5 cm in diameter, 40 g weight) was placed into the proximal part of the descending colon, and sequential stimulation with 15 mA, 3 ms, 10 Hz pulses was applied in a single series.

![Fig. 2. Spontaneous and electrically induced changes in CSAs and pressure (the notations “stop” mark the cessation of the stimulation session).](image)
Results

Spontaneous motility in the descending colon was recorded during inter-stimulation periods (Fig. 2, a). Spontaneous motility consists of slow propagating contractions, which result in serial decreases and increases of the 2 CSAs.

In response to S1, the circular muscles in the stimulated segment contracted 3 to 4 s after the stimulation offset. That led to a decrease of CSA1 (Fig. 2, b). In the mean time, an increase of the intraluminal diameter occurred in the next colon segment (see CSA2 in Fig. 2, b). Due to contraction, pressure inside the balloon increased. Similar motor activity was then induced in response to stimulation session S2.

In pig 3, as a result of 2 complete stimulation series S1→S8, 40 ml of semi-fluid material was displaced distally by about 10 cm. After the completion of the second stimulation series, almost all material was present in the terminal part of the stimulated colon.

In pig 4, in result of stimulation with 15 mA, 3 ms, 10 Hz pulses, the bolus placed in the proximal part of the descending colon was distally propelled over a distance of about 16 cm. The displacement was recorded on video, and estimated to have a velocity of about 1 mm/s.

Discussion

The present results show that local contractions can be induced in the descending colon of pigs. As an effect of stimulation with 15 mA, 0.3 and 3 ms, 10 Hz charge balanced rectangular pulses, the stimulated colon segment responded by a circular “off” contraction, which started 3 to 4 s after the stimulation offset. This result is consistent with observations of Moritz et al. [5], who also induced “off responses” in dog ileum, by stimulating the gut wall with 20 mA, 1 ms, 330 Hz pulses. Although the mechanism of the “off contraction” is not clear, one could speculate that such kind of a response is due the activation of inhibitory enteric neurons, which suppress the firing of excitatory neurons as long as the stimulation is on. After the secession of stimulation, the excitatory fibers from the gut wall become able to release the neurotransmitters, which activate the muscle cells. In order to verify this hypothesis, further experiments using blockers for inhibitory transmission should be performed.

By sequential stimulation of consecutive colon segments, both semi-fluid and solid content could be propelled distally, over the whole length of the colon subjected to stimulation. These results show that local colon contractions can be coordinated to result in continuous propulsion that mimics normal peristalsis. Experiments with chronically implanted electrodes should be performed, both for testing the stimulation method in awake pigs, and to study the life of the electrodes/tissue histology in long term stimulation.

In conclusion, local contractions can be induced in the descending colon of the pig, and coordinated to result in propulsive activity. If feasible in chronic application, emptying the colon by sequential electrical stimulation could successfully replace the irrigation procedures in patients with a colostomy. In addition, a similar stimulation method could improve colon transit in patients with slow transit constipation.

References


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