Electrical stimulation of the descending colon in pigs with chronically implanted electrodes

Sevcencu C
Rijkhoff NJM
Nygaard Lærke H
Jørgensen H
Mark M
Sinkjær T

1 Center for Sensory-Motor Interaction, Aalborg University, Denmark
2 Danish Institute of Agricultural Sciences, Department of Animal Nutrition and Physiology, Research Centre Foulum, Denmark
3 Department of Gastroenterology, Viborg Hospital, Denmark

Abstract

The aim of the present work is to develop a method to propel colon contents by electrical stimulation of the colon wall. Six to 8 wire electrodes, and a cannula to irrigate and fill the gut were implanted in the descending colon of 4 pigs. In the next 2 months, weekly experiments were performed to measure the electrode impedance, propel colon content, record pressure responses to stimulation, and visualize colon contractions induced by electrical stimulation. The experiments showed that: 1) the electrode impedance increased in time; 2) colon contractions in response to electrical stimulation could be seen or recorded during a 52 days interval after the implantation in 3 of the pigs; 3) semi-solid material could be displaced by electrically induced contractions, and evacuated through the anus in 2 of the pigs.

1 Introduction

After removal of a distal part of the colon, a colostomy is common practice. Colostomy patients have no control over the evacuation of the colon content. Currently, they wear a colostomy bag, or perform irrigation to empty the colon. While wearing a colostomy bag is inconvenient, irrigation is generally avoided because it is time consuming. An alternative to empty the colon could be the use of electrically induced contractions.

By stimulation the colon wall using wire electrodes, colon transit could be improved in spinalized cats [1], and sequential stimulation of descending colon segments in dogs resulted in propulsion of semi-fluid content [2]. Using charge balanced rectangular pulses of 0.3 and 3 ms, 15 mA and 10 Hz, we have previously induced local contractions in the descending colon of pigs. By sequential stimulation of consecutive colon segments, local colon contractions resulted in peristaltic-like activity, which propelled solid and semi-fluid content along the stimulated region [3]. The goal of the present study was to investigate in pigs: 1) if and for how many days after the implants colon contractions can be induced using chronically implanted electrodes; 2) if propulsion of colon content can be elicited by electrical stimulation using chronically implanted electrodes; 3) if the electrode configuration and positioning used in the acute studies are suitable for chronic implants.

2 Methods

2.1 Surgical procedures

Four pigs (P1-P4), 80 – 90 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 through a midline incision. At the proximal part of the descending colon, a silicon cannula (35 cm long, 1.4 cm in diameter) was placed in the colon lumen and secured to the colon wall with unabsorbable sutures. Three deinsulated sites of six to 8 wire electrodes were inserted under the serosa of the descending colon. Each of the active sites was secured at both ends to the colon wall with absorbable sutures. The electrode was placed near the cannula, and the last one 12 to 15 cm distally to the cannula. The distance between 2 neighboring electrodes was 2 cm (Fig. 1). The electrodes were made of...
Teflon insulated multistranded stainless steel wires (0.4 mm diameter, AS634 Cooner Wire Inc. Chatsworth, CA). To label the electrodes, the stainless steel wires were soldered to copper wires with different colors for the insulation. The leads were placed in a silicone tube filled with silicone so that the connections between the electrodes and the copper wires were embedded in silicone. The tube was percutaneously brought outside the body. Through a different stab wound, the cannula was also brought outside the body on the left side of the abdomen. After the implantation (day 0), the pigs were allowed to recover for 10 to 14 days.

2.2 Experimental procedures

The colon was stimulated weekly. During the study, the wounds were cleaned and the bandages changed twice a week. Except for the first two experimental sessions in P1 and P2, the pigs were anaesthetized before the experiments.

Propulsion of luminal content. Experiments to induce propulsion of luminal content were done in P2 and P3. First, the colon was rinsed with warm saline, which was pumped in the lumen through the cannula. Then, 150 to 200 ml of porridge containing 100 plastic pallets was pumped in the colon. After 10 to 15 min to allow spontaneous evacuation of the porridge, the colon was rinsed again to wash the unexpelled material. Identical volume of porridge and number of plastic pallets were then pumped in the colon, and electrical stimulation was applied in consecutive series for 10 to 15 min. Each series consisted of sequential sessions using consecutive pairs of electrodes and 12 mA, 3 ms, 10 Hz pulses. The expelled volume of porridge was estimated in P2. In P3, the pellets expelled spontaneously or in response to electrical stimulation were counted.

Impedance measurements. In P3 and P4, the electrode impedance was measured weekly with an impedance-meter at 1 KHz. Impedance was measured between each of the external copper leads, and a reference electrode placed on the skin of the pig.

Pressure recording. On days 21 and 42, pressure responses to electrical stimulation were recorded in P3 and P4. Pressure was monitored using a customer-made pressure device. The monitoring balloon was pushed 30 cm inside the colon through the anus.

Colonscopic visualization of colon contractions. Colonoscopy during electrical stimulation was performed in P2 (day 45) and P3 (day 28). The probe was inserted through the anus in the implanted region of the colon, and electrical stimulation was applied at different locations.

The terminal experiment. A terminal experiment was performed on day 52 in P1 and P2, and on day 70 in P4. After the anesthesia, the colon was exposed, the leads of the electrodes were connected to the current source, and stimulation was applied using 15 mA, 3 ms, 10 Hz pulses. At the end of the experiments, the pigs were killed with an overdose of anesthesia.

3 Results

3.3 Propulsion of luminal content

In P2 (day 10), a volume of porridge was expelled through the anus in response to each of the 6 stimulation sessions that were performed (about 10-15 ml each time). In P3 (day 35), the volume of porridge expelled in response to electrical stimulation was larger as compared to that expelled by spontaneous activity (evacuated pellets: 65 vs. 51).

3.4 Electrode impedance

On day 14, in both P3 and P4, the impedance was infinite for 1 electrode, and between 0.23 to 0.31 KΩ for the other 7. On day 49, P3 died during the experiment, probably because an overdose of anesthesia. The impedance of the electrodes in P3 was infinite, or high as compared to day 14 (5.92 to 18.9 KΩ). In P4 (day 49), the impedance was 0.72 and 0.84 KΩ for 2 of the electrodes, 16.30 to 17.60 KΩ for another 3 electrodes, and infinite for the others. On day 70, only 1 of electrodes in P4 had impedance below 1 KΩ, while the other 7 had infinite impedance. As observed during the terminal experiment, those 7 electrodes were disconnected from the external copper leads, and that explained why their impedance was infinite. When measured directly at the end of the stainless steel wires, the impedance was 0.70 to 0.91 KΩ.

3.5 Pressure recordings

In response to the stimulation offset an “off” pressure increase of about 10 cm H 2O was induced in P3 on day 28. The magnitude of the pressure increase was similar in response to stimulation using 6 to 15 mA pulses (see Fig. 2). Lower pressure increase was recorded 23 days later. No pressure response could be recorded in P4.
3.6 Colonoscopic visualization of colon contractions

In both P2 and P3 colon contractions induced by electrical stimulation using 12 to 20 mA, 3 ms, 10 Hz pulses completely closed the colon lumen (Fig. 3). Contraction was always of an “off” type, starting a couple of seconds after the stimulation offset.

3.7 The terminal experiment

During the terminal experiments performed in P1 and P2 (day 52), stimulation induced relaxation as a response of the stimulation onset, and contraction as a response to the stimulation offset. Stimulation failed to induce contraction in P4 (day 70).

4 Discussion and Conclusions

The present results show that colon contractions can be induced in the descending colon of pigs using chronically implanted electrodes. As observed by colonoscopy and during the terminal experiment in 2 pigs, contractions were of an “off” type and led to pressure increase of about 10 cm H₂O. When consecutive colon segments were activated sequentially, propulsion of semi-fluid colon content was elicited. This is consistent with our previous results in acute studies in rats and pigs [3], and with the results of Lin et al. [4]. The fact that colon contractions could be induced 52 days after the implantation of the electrodes shows that the electrode configuration and positioning are suitable to face the mechanical stress exerted by the gut wall during circular and longitudinal contractions and relaxations.

References


Acknowledgements

This work was supported by the Danish National Research Foundation and the Danish Research Council, and Coloplast Company.