

Technique for implanting intramuscular electrodes in the diaphragm by videolaparoscopy in pigs¹

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ABSTRACT

PURPOSE: To describe a novel approach for implanting intramuscular electrodes in the diaphragm through videolaparoscopy.

METHODS: We used twelve pigs for this videolaparoscopic technique, which permits at the same time to explore the diaphragm, to locate its motor points and to fix the electrodes in the diaphragm bilaterally. In this technique we used three trocars: one portal for a 10-mm 0° viewing angle laparoscope, one portal for the manipulation of structures and another for electrode implantation.

RESULTS: All animals survived the procedure without pneumothorax/capnothorax or other complication. Implanted electrodes provided an appropriate interface between the muscle and the electrical current generator, and electroventilation was satisfactorily generated in all animals.

CONCLUSION: This videolaparoscopic technique with three trocars enables the exploration and identification of motor points and an efficient fixation of one or two electrodes in each hemidiaphragm.

Key words: Laparoscopy. Diaphragm. Pacemaker, Artificial. Swine.

Introduction

Electroventilation has been used in patients with significant impairment of diaphragmatic function and chronic dependence on mechanical ventilation, such as those with high cervical injury (C1–C5), hypoventilation syndrome, amyotrophic lateral sclerosis (ALS) and others¹⁻⁴.

Initially, Glenn described the diaphragm activation with implantation of electrodes directly on the thoracic phrenic nerve^{5,6}, which was later refined by other researchers^{7,8}. Even when successful, this technique is not free to cause permanent damage to the phrenic nerve due to the electrode placement procedure⁹. This technique can be performed through either a unilateral or bilateral thoracotomy or thoracoscopy.

The implantation of electrodes directly into the diaphragm in its abdominal portion has emerged as an effective and safe alternative where electrodes are implanted into the muscle through videolaparoscopy and are connected to a diaphragmatic pacemaker system (DPS)⁸⁻¹². The first experiments were performed placing the electrode using either by laparotomy¹³ or laparoscopy, which showed that transdiaphragmatic pressures and tidal volumes resulting from intramuscular electrodes were comparable to those obtained with the phrenic nerve stimulation^{8,9,14}. This procedure consists of locating the motor point of the muscle or functional points corresponding to the muscle area where the branches of the phrenic nerve penetrate into the diaphragm^{10,15,16}, avoiding the need for direct manipulation of the phrenic nerve¹⁷. In all cases, the phrenic nerve must be preserved with its function for proper operation of the diaphragmatic pacemaker¹⁸⁻²¹.

Electrical stimulation of the diaphragm has allowed for a better quality of life, in addition to allowing for weaning from mechanical ventilation, decreasing the frequency of respiratory infections and reducing the amount spent on health-related costs^{22,23}.

This article aims to describe a procedure involving electrode implantation directly into the diaphragm muscle in the abdominal portion through videolaparoscopy in pigs.

Methods

The Research Ethics Committee of the Hospital de Clínicas de Porto Alegre approved this study under #10260.

Electrodes were implanted in the abdominal portion of 12 Large White pigs, weighing 25–30 kg, treated according

to the Ethical Code for Animal Experimentation of the World Health Organization²⁴. Initially, the animals received an intramuscular premedication with ketamine 20mg/kg, midazolam 0.8mg/kg meperidine and 5mg/kg, followed by peripheral vein catheterization. Anesthesia was induced with 5mg/kg intravenous propofol followed by tracheal intubation and mechanical ventilation with positive pressure (Nikkei – Takaoka, São Paulo, Brazil), maintained with a continuous infusion of propofol (0.2–0.4mg/kg) and a bolus of phentanyl 100µg. Neuromuscular blocker was not used at any time during the procedure. Body temperature and ECG were monitored throughout the surgery.

The surgery was performed using aseptic methods. The animals were kept in a supine position, and then surgical drapes were aseptically placed for performing videolaparoscopy. Initially, a conventional Veress needle was inserted for insufflation of the abdomen with CO₂. The approach used through three incisions in the abdominal wall for insertion of 10mm trocars, an supra-umbilical region for insertion of a 0° viewing angle laparoscope and other two 10 mm trocars, one in the left and other in the right side for insertion of the laparoscopic instruments (Figure 1A).

Both the right and left hemidiaphragm were bilaterally explored to locate the motor point, using an electrode attached to an endoscopic instrument developed by our group (Figure 2A). The exploration of the muscle was guided using anatomical landmarks of the abdominal portion of the diaphragm. Electrical stimuli were applied with a current of 8mA intensity and a pulse width of 300ms for selecting places where a global muscle contraction was observed (Figure 2 B,C). When were used two electrodes on each side of the diaphragm (anterior and posterior portion) we observed a better muscle contraction compared with the use of one electrode in each hemidiaphragm. The electrode implantation was performed at the same time that the site was defined, and this was only possible due to the electrode characteristics and the deployment tool developed by our group.

In 12 animals, four electrodes were implanted in the abdominal surface of the diaphragm, two on each side (anterior and posterior portion). The falciform ligament release was required, in addition to the use of a liver retractor, for a better view of the posterior portion of the diaphragm (Figure 2D). Laparoscopic trocars were removed under direct vision and the closure of the abdominal wall was performed in layers. The wires of the electrodes were placed in the subcutaneous tissue of the abdominal wall for later access (Figure 1B).

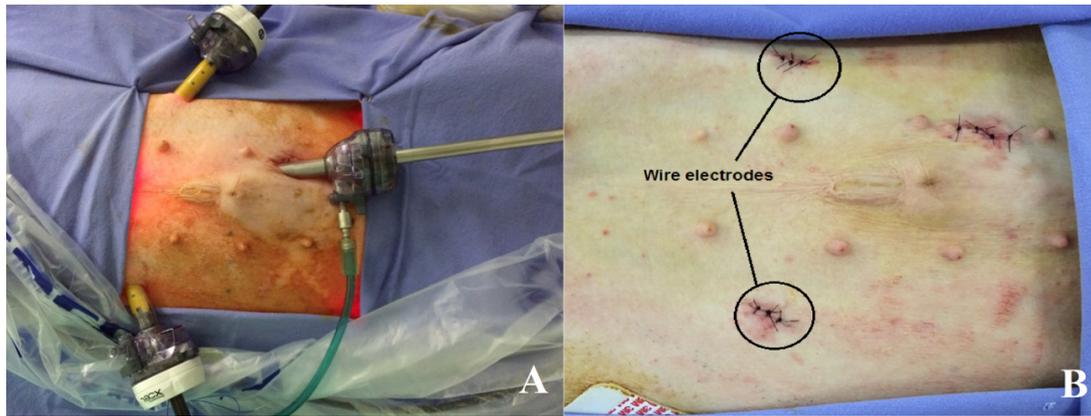


FIGURE 1 – (A) Trocar placement in the abdominal region of the pig; (B) Lead wire electrodes housed in the subcutaneous abdominal wall.

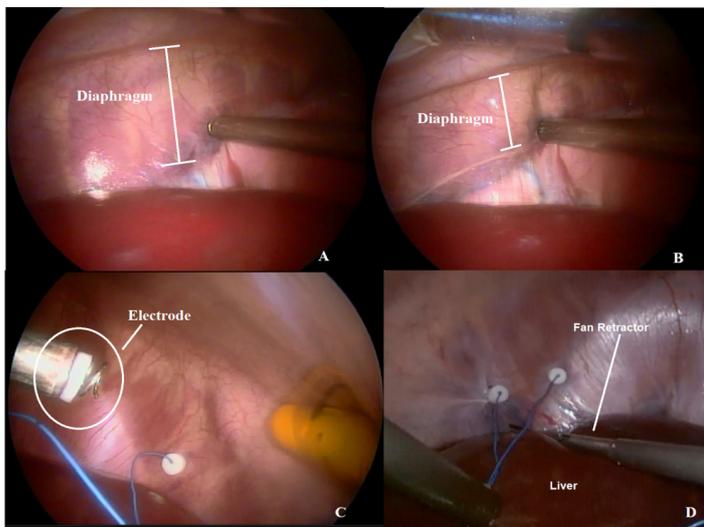


FIGURE 2 – (A) Exploiting Diaphragm with deployment device; (B) Muscle contraction during electrical stimulation; (C) Aspect of the electrode before implantation; (D) Liver retractor used for better visualization of the right hemidiaphragm.

After finishing the surgical procedure, the animals were kept under observation for 15 days at a specific location for animal care. After this observation period, the animals were anesthetized and intubated following the same previously described protocol. The wires placed in the subcutaneous tissue of the abdominal wall were exposed, and then connected to a current generator for the evaluation of muscular contraction and proper electrode attachment to the diaphragm. All animals were euthanized with an overdose of the anesthetic propofol, followed by lethal intravenous injection of potassium chloride after six hours of diaphragmatic stimulation. The diaphragm was removed for subsequent morphological evaluation.

Results

The use of three trocars proved to be sufficient for a laparoscopic approach to the implantation of the intramuscular

electrodes in the abdominal portion of the diaphragm. The average time spent on the procedure was 85 minutes. All animals survived the procedure, and only one animal had small hemorrhage due to a liver laceration during the implantation of the electrodes, but there were no clinical consequences. There was no pneumothorax during deployment that would undermine the achievement of electroventilation. The electrodes and laparoscopic deployment tool that the group developed provided an easy approach for use during the procedure. The diaphragm post-mortem evaluation enabled us to verify the electrode positioning, as well as its attachment to the muscle. All leads were properly fixed to the muscle without any evidence of muscle damage allowing for an appropriate interface for the electrical conduction.

Discussion

Diaphragmatic electrical stimulation using intramuscular electrodes is an approach to electroventilation, which has the ability to provide ventilation in the absence of spontaneous inspiratory activity. The implantation of electrodes in the abdominal portion of the diaphragm using laparoscopy is a minimally invasive and safe technique for this purpose^{2,24}. The correct location of the electrode implantation point in the diaphragm is associated with better performance in the recruitment of muscle fibers^{14,16,19}. The scanning technique allows for muscle mapping and the observation of muscle contractions occurring in several different places in the muscle. Despite the anatomical difference between the motor and functional points, the direct muscle contraction visualization technique can be used to determine the implantation place for electrodes in the diaphragm¹⁴.

Intramuscular electrodes were implanted in the diaphragm without the occurrence of pneumothorax or capnotórax. Even where we observe muscle transfixation, no pulmonary injury

or pneumoperitoneum leaking into the pleural space caused respiratory failure or difficulty in ventilation. Pneumoperitoneum is generated by pressurized CO₂ in the abdominal cavity and may cause pneumothorax resulting in clinical repercussion in only 4% of the cases. The incidence of this situation is around 42% in humans²⁵. In reports using more sensitive tests such as computed tomography, researchers have observed an incidence of gas in the chest cavity at a rate of 85% for laparoscopic procedures in general²⁵. In human studies where electrodes were implanted in the diaphragm, researchers reported the occurrence of pneumothorax during and after surgery²⁴. In another report, the most common complication observed in patients was capnotórax, which was most likely related to the electrode implantation procedure²⁶.

In a pilot study, we conducted the implantation of electrodes in the diaphragm of rabbits through laparoscopy with the use of four portals. However, we found that the procedure was feasible with only three trocars. Moreover, with this arrangement of the trocars the identification of motor points was possible for each hemi-cupula, as well as their immediate implanting. Several studies have demonstrated the use of four trocars to perform this procedure in animals^{14,17} and humans^{2,21,24}.

An average time of 85 minutes was spent on the procedure, which is relatively low, even when two electrodes were implanted in each hemi diaphragm. Some researchers report mean operative times varying from 150 to 98 minutes^{27,28}.

Conclusions

The approach of the diaphragm is feasible by videolaparoscopy using only three trocars for the implantation of two intramuscular electrodes in each hemidiaphragm. The use of two electrodes per hemidiaphragm generated a global muscle contraction enough to produce pulmonary ventilation. The use of a deployment device for the electrodes during surgery that identifies the motor points of the diaphragm and at the same time fix the electrodes to the muscle probably reduced our surgical time.

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