Minimally invasive trans-mediastinal endoscopic approach to insert phrenic stimulation electrodes in the human diaphragm: a preliminary description in cadavers

Jalal Assouad,*, Hicham Masmoudi, Camille Steltzlen, Dominique Grunenwald, Vincent Delmas, Thomas Similowski

Department of Thoracic Surgery, Hôpital Tenon, Assistance Publique-Hôpitaux de Paris, 4 Rue de Chine, 75020 Paris, France
Université Paris V, René Descartes, Department of Anatomy and Body Donation, Paris, France
Department of Pneumology, Hôpital Pitié Salpêtrière, Assistance Publique-Hôpitaux de Paris, Université Paris VI, Pierre et Marie Curie Paris, ER10 UPMC, Paris, France

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Abstract

Objective: Diaphragm pacing by phrenic nerve (PN) stimulation is currently used for patients with central respiratory paralysis to be weaned from mechanical ventilation. Electrodes are inserted either through bilateral thoracotomy or through four ports laparoscopy. The aim of this experimental work is to demonstrate the feasibility of trans-mediastinal bilateral implantation of PN electrodes using a flexible gastroscope introduced through a cervical incision in human cadavers.

Methods: Ten refrigerated and non-embalmed cadavers were used. The gastroscope was introduced through a cervical incision into the latero-tracheal space and subsequently into both pleura by opening the mediastinal pleura. After identification of the PN, electrodes were introduced through an intercostal space to the desired diaphragmatic location using a long, pliable needle with the electrode loaded in its lumen.

Results: Results are described for each hemi-diaphragm not for an anatomic subject. Mediastinal exploration and introduction of the video gastroscope into the pleural cavities proved easy in all subjects. Pleural adherences were present in five hemi-diaphragms. The central tendon of both hemi-diaphragms could be identified unambiguously in all the subjects. Identification of the entry point of the phrenic nerve into the diaphragm was straightforward in 10 hemi-diaphragms. In the remaining 10, this proved more difficult because of mediastinal fat or lung parenchyma. Introduction of the electrode-holding needles through the intercostal space and their insertion close to the phrenic nerve entry point was also easy. Withdrawal of the needle from the diaphragm and ‘capture’ of the hook were successful on the first attempt in 14 hemi-diaphragms, but failed in six others in whom a second attempt was necessary. Conclusion: Trans-mediastinal implantation of PN stimulation electrodes is possible using a flexible endoscope. This application of endoscopic surgery could allow a minimally invasive placement of PN electrodes in patients with central respiratory paralysis, for example, at the time of tracheostomy.

Keywords: Diaphragm; Pacing; Phrenic nerve; Endoscope; Minimally invasive; Mediastinum

1. Introduction

Phrenic nerve stimulation for diaphragm pacing is a therapeutic approach used in highly selected patients with central respiratory paralysis with the aim of weaning them from mechanical ventilation [1]. Two techniques are available. With intrathoracic phrenic pacing, electrodes are implanted around the previously dissected phrenic nerves, in the thorax, through a bilateral video-assisted mini-thoracotomy [2]. With trans-diaphragmatic phrenic pacing, hook wire electrodes are implanted laparoscopically within the diaphragm as close as possible to its motor point [3]. In certain situations, it could be interesting to combine the simplicity of the intra-diaphragmatic hook wire approach with a thoracic route of implantation.

Minimally invasive surgical techniques in thoracic surgery are currently the object of intense attention. Several such techniques have been described to perform pulmonary interventions through a cervical incision in humans [4–6]. However, the risk of major mediastinal complications sets a limit to their clinical use [7,8]. Using flexible endoscopes could circumvent this difficulty. Indeed, these instruments are gaining popularity as surgical tools [9]. They are already being used during abdominal interventions performed with natural orifice transluminal endoscopic surgery (NOTES) [10–12]. Hybrid surgical–endoscopic approaches have been described for thoracic applications [9,13]. For example, the cervical incision thoracic endoscopic surgery (CITES) that...
we recently described combines the use of a flexible endoscope with the validated cervical approach used to perform mediastinoscopies [13]. This type of combination should help in developing endoscopic-assisted minimally invasive thoracic surgery.

With this in mind, we hypothesized that it would be possible to insert hook wire electrodes in the diaphragm bilaterally using the CITES technique and the flexible endoscope.

To answer this question, we tested the principle of bilateral insertion of stimulation electrodes in both diaphragms through a cervical incision in a human cadaver study using a flexible endoscope as a unique device.

2. Materials and methods

We used a standard double-channel flexible video gastroscope (STORZ™), a video mediastinoscope (STORZ™), a Karl Storz Cold Light Fontaine Xenon 100 W, a TELE PACK™ endoscopic video, and a 15” flat screen monitor. Cervical dissection was performed using a conventional instrument for open cervical surgery.

2.1. Subjects

This experimental work was conducted in the Department of Anatomy and Body Donation of the University Paris V ‘Rene Descartes’. The experimental protocol was approved by the Committee of Human Subject Research and Body Donation of the university. The procedures were carried out on 10 refrigerated and non-embalmed cadavers, aged 88—93 at time of death. The subjects’ histories did not mention chest and neck diseases, and they were free from gross morphologic abnormalities. They were studied in dorsal decubitus, with the neck hyper-extended.

2.2. Procedure

The approach used for this study was identical to the original CITES technique that we recently described [13]. A 1-cm horizontal cervical incision was performed just above the sternal manubrium, followed by the dissection of all the tissues to the pre-tracheal fascia. The upper and lateral sides of the trachea were digitally dissected. The video mediastinoscope was then introduced; using the dedicated suction—coagulation device, we performed two mediastinal windows through both mediastinal pleura (Fig. 1). On the right side, a communication between the mediastinum and the right pleural cavity was created just under the level of the superior vena cava. On the left side, the pleurotomy was also performed through the mediastinal pleura entering between the left common carotid and the subclavian arteries.

The video gastroscope was then introduced through the cervical incision and, sequentially, into the pleural cavities through the pleurotomies. On both sides, after pleural exploration, the endoscope was oriented caudally and pushed toward the lower part of the thoracic cavity. The central tendon of the diaphragm was identified (Fig. 2), and the penetration point of the phrenic nerve in the diaphragmatic dome was located. When mediastinal fat or lung parenchyma interfered with the target zone, a small (10-Fr) rigid chest tube was introduced into the pleural cavity through the cervical incision and mediastinal window parallel to the gastroscope and used to move away anatomical obstacles. A flexible needle loaded with a hook wire electrode (Synapse Biomedical Inc., Oberlin, OH, USA) was then inserted under visual control into the thoracic cavity through the adjacent intercostal space (Fig. 3). The level of this introduction was defined in relation to the anatomic presentation of the phrenic nerve; the lateral or posterior 8th or 9th intercostal space was mainly chosen. The needle had first been bent in such a way as to allow tangential insertion in the diaphragm. It was then inserted at an oblique angle into the diaphragm at the desired location (Fig. 4A). Needles and hooks were introduced in the thickness of the diaphragm over a length of 2 cm (Fig. 4B). The needle was then withdrawn while applying cephalic pressure on the diaphragm and performing small shiver movements to facilitate ‘capture’ of the hook. Finally, the needle was withdrawn from the thoracic cavity and an extra length of electrode lead was brought into the thoracic cavity using endoscopic...
graspers. A chest tube was placed through the initial cervical incision in each pleural cavity. The adequate intrathoracic positioning of the tubes was visually verified.

At the end of the procedures, we evaluated the adequacy of electrode insertion by pulling on the wire to test the force needed to remove it from the diaphragm.

3. Results

For more accuracy, results are described for each hemi-diaphragm and not for an anatomic subject. Mediastinal exploration using the video mediastinoscope was easy in all subjects. Also, introduction of the video gastroscopy into the pleural cavities through the mediastinal windows previously created proved easy in all subjects and allowed wide exploration of both pleural cavities. Pleural adherences were present in five hemi-thoraces and were limited. They were easily cut using electrocoagulation applied with the endoscopic grasping forceps.

The central tendon of both hemi-diaphragms could be identified unambiguously in all the subjects. Among the 10 subjects studied (20 hemi-diaphragms), identifying the entry point of the phrenic nerve into the diaphragm was straightforward in 10 hemi-diaphragms. In six, this proved more difficult because of the presence of mediastinal fat. In the remaining four, the visibility of the phrenic nerve entry point was hampered by the presence of lung parenchyma. This problem was easily solved using the chest tube procedure described in Section 2.

Introduction of the electrode-holding needles through the intercostal space also proved easy, as well as visual control of their orientation toward the phrenic nerve entry point. In all subjects, electrodes were inserted very close to the phrenic nerve entry point. Withdrawal of the needle from the diaphragm and ‘capture’ of the hook were successful on the first attempt in 14 hemi-diaphragms, but failed in six others in whom a second attempt was necessary.

After bilateral insertion of the electrodes and introduction of the chest tubes, we applied manual tension to the electrode leads from outside the chest. All electrodes resisted high manual tension force and their extraction was feasible without diaphragm damage.

4. Discussion

This study shows that the diaphragm can be accessed through the CITES approach, and that it is possible to insert stimulation electrodes in the diaphragm close to the entry point of the phrenic nerve.

Phrenic nerve stimulation could therefore constitute another possible application of CITES, in addition to those previously described. CITES has already been shown by our group as a way to perform pleural biopsies, sympathectomies, and lung release in a previous cadaver study [13]. Of note, while entering the right thoracic cavity through the mediastinum is secure using the current rigid tools, things get more complicated on the left side. Indeed, there is a high potential for neurological and vascular complications [5–8] on this side. The use of a flexible endoscope could reduce the corresponding risks, but it will be necessary to pay careful attention to anatomical constraints in order to define a safe procedure to explore the left thoracic cavity from a cervical entry site in the mediastinum. Trans-diaphragmatic liver or spleen punctures are another matter of concern when using CITES to implant phrenic stimulation electrodes in the diaphragm. Bending the insertion needle in such a way that it can enter the diaphragm tangentially after having been pushed through the chest wall should alleviate this risk. It is, however, very important to emphasize that visual control should be continuous and perfect during introduction of the needle. As an additional safety measure, transparietal ultrasonography could be used during insertion of the electrodes to ensure that the needle does not perforate the diaphragm.

The CITES approach could theoretically be used in all the current indications for phrenic stimulation for ventilator weaning. In conclusion, we consider this study as an incentive to pursue the development of the CITES approach in general, and its use for phrenic stimulation in particular. Animal studies will constitute the next step of this process.

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References