Diaphragm pacing after bilateral implantation of intradiaphragmatic phrenic stimulation electrodes through a transmediastinal endoscopic minimally invasive approach: pilot animal data†

Jalal Assouadab,*, Hicham Masmoudia,b, Jesus Gonzalez-Bermejoc,d, Capucine Morélot-Panzinic,d, Moustapha Diope, Dominique Grunenwalda and Thomas Similowskic,d

a Department of Thoracic Surgery, Assistance Publique - Hôpitaux de Paris, Tenon Hospital, Paris, France
b Bio-surgical research laboratory, University 'René Descartes', Paris 5, France
c Department of Respiratory and Critical Care Medicine, Assistance Publique-Hôpitaux de Paris, Pitié-Salpêtrière Hospital, Paris, France
d Research unit ER10, Paris 6 University, Paris, France
e Synapse Biomedical Inc., Oberlin, OH, USA

* Corresponding author. Department of Thoracic Surgery, Hôpital Tenon, 4 rue de Chine, 75020 Paris, France. Tel: +33-1-56017822; fax: +33-1-56017987; e-mail: jalal.assouad@tnn.aphp.fr (J. Assouad).

Received 15 June 2011; received in revised form 25 August 2011; accepted 1 September 2011

Abstract

OBJECTIVES: Phrenic nerve stimulation for diaphragm pacing allows patients with central respiratory paralysis to be weaned from mechanical ventilation. Two procedures are available, either intrathoracic (bilateral thoracotomy) or intradiaphragmatic (four ports laparoscopy). The present experimental work assesses the feasibility, safety and efficacy of a trans-mediastinal implantation of intradiaphragmatic phrenic nerve stimulation electrodes using a flexible gastroscope through a cervical incision.

METHODS: We operated on nine ewes. After selective bronchial intubation, we dissected the latero-tracheal space and opened both mediastinal pleura. We then introduced a flexible gastroscope into the pleural cavities, in a sequential manner. The phrenic nerves were located and followed up to the diaphragm dome. Electrodes loaded within a long, pliable needle were introduced through the adjacent intercostal space and implanted in each hemidiaphragm, at a ‘tendinous’ location (as close as possible to the entry of the nerve in the central tendon), and at a more lateral ‘muscular’ location. Postoperatively, the animals were ventilated using bilateral phrenic nerve stimulation. After euthanasia, abdominal verification of the electrodes position was performed through a laparotomy.

RESULTS: The mediastinal and pleural parts of the procedure were uneventful. The insertion of electrodes was associated with transdiaphragmatic puncture and small abdominal haematomas in the first two animals studied. After a slight modification of the insertion technique, this was not observed anymore. Phrenic nerve stimulation produced efficient ventilation, with tidal volumes significantly higher when delivered at the tendinous site than at the muscular site.

CONCLUSIONS: The trans-mediastinal implantation of intradiaphragmatic phrenic nerve stimulation electrodes is feasible, appears reasonably safe, and allows efficient ventilation.

Keywords: Minimally invasive surgery • Diaphragm • Mediastinum • Animal model • Pacing

INTRODUCTION

Diaphragm pacing through phrenic nerve stimulation allows patients with central respiratory paralysis, e.g. due to high cervical cord lesions, to be weaned from mechanical ventilation [1]. Compared with positive pressure mechanical ventilation, diaphragm pacing reduces the frequency of respiratory infections [2]. It improves quality of life [3–5], partly through restored olfaction [3]. It also reduces health costs [4, 5].

†Presented at the 19th European Conference on General Thoracic Surgery, Marseille, France, 5–8 June 2011.

Two approaches are currently available. Contact electrodes can be implanted around the phrenic nerves in the thorax through a bilateral video-assisted mini-thoracotomy [6–8]. This technique requires careful dissection of the phrenic nerves. Stimulation results from the transcortaneous radiofrequency transmission of energy and settings from an external device to implanted receivers. Alternatively, intradiaphragmatic phrenic nerve stimulation electrodes can be implanted within the diaphragm itself during a laparoscopic procedure [9, 10]. This technique does not involve dissection of the phrenic nerves, but a careful mapping of the phrenic motor point is required to identify the optimal implantation site [11]. Stimulation is provided through hookwire electrodes connected percutaneously to an external device.
If proven possible, implanting intradiaphragmatic hookwire electrodes in the diaphragm through a cervical and transmediastinal route instead of the current laparoscopic approach could be of interest in certain clinical situations. This would be the case when laparoscopy is difficult or contra-indicated for any reason, or to reduce the number of surgical procedures when a tracheotomy is indicated. The emerging Cervical Incision Thoracic Endoscopic Surgery (CITES) [12] could open such a possibility, as suggested by a pilot study in human cadavers [13].

With this in mind, the present study investigates the feasibility, safety and efficacy of the bilateral insertion of hookwire electrodes in the diaphragm using CITES. Three main issues are addressed, as follows:

- First, does the cervical transmediastinal bilateral pleural approach allow the identification of both phrenic nerves and the insertion of stimulation electrodes in the two hemidiaphragms?
- Secondly, can this result be achieved safely in living animals?
- Thirdly, does the so-implemented phrenic nerve stimulation provide efficient diaphragm pacing; namely, capable of maintaining ventilation and blood gases?

### MATERIALS AND METHODS

#### Animals and animal care

We studied nine ewes, weighing ≃45 kg (and hence 18 hemidiaphragms). The regional ethics committee for animal experimentation of Ile-De-France (Université Paris 5 René Descartes) approved the experimental protocol, and the animals received humane care in compliance with the European Convention on Animal Care.

The animals were pre-medicated with an intramuscular injection of Acepromazine 1.3 mg/kg, 30 min before anaesthesia induction with intravenous propofol (Diprivan®, Astra Zeneca; 6 mg/kg). Tracheal intubation was performed with a regular single lumen tube, internal diameter 8.5 mm. Mechanical ventilation was administered in the controlled mode using an Aestevia-5 anaesthesia ventilator (Datex Ohmeda, Madison, WI, USA) with the following settings: tidal volume 15 ml/kg, frequency 18 per minute and FiO₂ 60%. Following induction, anaesthesia was maintained with 1–2% inhaled isoflurane (Forene®). Blood pressure was continuously monitored during the procedure using a catheter inserted in the auricular caudal artery.

During the surgical procedure, selective bronchial intubation was achieved either using an Arnt endobronchial blocker (Cook Medical, Bloomington, IN, USA) placed under bronchoscopic guidance for exclusion of the main bronchus, or using a Fogarty’s catheter (for exclusion of the additional bronchus on the right side).

#### Surgical technique

The animals were positioned with their back on the operating table, with a 30° reverse-Trendelenburg incline and the neck hyperextended. A 2–3 cm horizontal cervical incision was performed just above the sternal manubrium (Fig. 1). Because of the particularly well-developed thyroid gland that is characteristic of the species, partial thyroidectomy was necessary to access the lower trachea. The latero-tracheal space (Fig. 2) was dissected according to the previously described technique to create bilateral pleural windows (Assouad 2010). This being done, the flexible gastroscope was guided into the left and right thoracic cavities by inserting a short 10 Fr chest tube in the pleural windows. This tube was used to displace anatomical structures interposing themselves between the gastroscope and the phrenic nerve.

Once the gastroscope was in the pleural space, the trunk of the phrenic nerve was identified and followed up to its entry point into the diaphragmatic dome.

To insert the electrodes into the diaphragm, a pliable needle loaded with a hookwire electrode (Fig. 3) was then introduced through the nearest intercostal space under visual control and tangentially inserted in the muscle. Two electrodes insertion sites were defined. The first site (one electrode per hemidiaphragm) was the entry point of the phrenic nerve trunk in the central tendon of the diaphragm, the corresponding electrode being henceforth referred to as the ‘tendinous electrode’. The transthoracically inserted needle was exteriorised 1–2 cm beyond its entering point to ensure the actual intra-diaphragmatic position of the hook. The second insertion site corresponded to the entry points of the two main terminal branches of the phrenic nerve into the muscular zone of the diaphragm (two electrodes per hemidiaphragm). These electrodes are henceforth referred to as ‘muscular electrodes’. At this site, the transthoracically inserted electrodes were left within the thickness of the muscle (Fig. 4).

After verification of the hook position, the introducing needle was withdrawn from the thoracic cavity with small shiver movements to facilitate the ‘capture’ of the hook in the diaphragm. An extra length of electrode lead was brought into the thoracic cavity using endoscopic grasps. After a final visual verification of the electrodes placement, the lungs were manually inflated to release any potential atelectasis.

The cervical incision was then closed and both chest tubes connected to a –20 aspiration drainage system (Pleurevac, Teleflex Medical, France).

#### Endoscopic material

We used a double-channel flexible videogastroscope, a videomediastinoscope, a Xenon 100W cold light fontaine, a TELE PACK™ endoscopic video system and a 15 flat screen monitor (Karl Storz GmbH & Co, Tuttingen, Germany).

Figure 1: Cervical incision above the manubrium showing the lower trachea (black arrow) and the partially resected thyroid gland (white arrow).
Fifteen minutes of controlled mechanical ventilation were allowed after the end of the surgical procedure, with a FiO₂ of 60%. The electrodes were connected to the NeuRx DPS™ stimulator (Synapse Biomedical Inc., Oberlin, OH, USA) that delivers biphasic stimulation to each electrode with a common indifferent electrode placed subcutaneously. The stimulation parameters were: pulse amplitude 25 mA, pulse duration 200 µs, pulse frequency 20 Hz, no pulse amplitude ramp, inspiration time 1.1 s and respiratory rate 12 breath/min. Bilateral stimulation was first performed for 30 min using the ‘tendinous’ electrodes, and then for 30 additional minutes using the ‘muscular’ ones, with the animals breathing room air. The three periods (‘mechanical ventilation’, whole 15 min; ‘tendinous stimulation’, last 15 min; and ‘muscular stimulation’, last 15 min) were compared in terms of ventilatory variables (tidal expiratory volume, transcutaneous oxygen saturation) and of haemodynamic variables (cardiac frequency and systemic blood pressure).

Post-procedure controls

At the end of the experimentation, the animals were euthanized using T61® (Hoechst Roussel Vet France, Pantin, France). A large transversal laparotomy was performed to verify the position of the electrodes in the diaphragm from the abdominal cavity and to look for potential abdominal complications.

Statistical analysis

Numerical data (comparison of ventilatory modes) are described by their median and interquartile range. To avoid any assumption about data distribution and equality of variance, the three ventilatory modes (‘mechanical ventilation’, ‘tendinous stimulation’, ‘muscular stimulation’) were compared using Friedman’s non-parametric analysis for repeated measures and Dunn’s post hoc pairwise test when a significant difference was detected. Differences were considered statistically significant when the probability $P$ of a type I error was below 5%.

Role of funding bodies in data interpretation

None.
**RESULTS**

The following results pertain to 9 animals and 18 hemidiaphragms; three electrodes were implanted in each hemidiaphragm ($n = 54$); two sites of stimulation were compared for each hemidiaphragm (‘tendinous’, one electrode; ‘muscular’, two electrodes activated simultaneously).

**Surgical procedures**

Induction, anaesthesia, positioning on operation table and the setup of the monitoring devices were uneventful. Complete selective intubation was feasible on the right side in 7/9 animals and on the left side in all animals. The introduction of the gastroscope into the pleural cavities was easy. Caudal exploration of the chest was also uneventful.

The phrenic nerve trunk and its two biggest terminal divisions were identifiably straightforwardly in six hemidiaphragms. In the remaining 12 cases this proved less easy, because of incomplete lung deflation in two cases (right side), and because of an interposition of deflated lung parenchyma over the entry point of the nerve in the diaphragm in 10 cases. In all of these 12 cases, it proved possible to clearly visualize the phrenic nerve and its terminal branches after using the chest tube to move the lung aside.

The introduction of the electrode-holding needles through the intercostal space did not create particular difficulties and did not provoke bleeding. Visual control of the orientation of the needle towards the phrenic nerve entry point was easily achieved using the gastroscope. Needles and hooks were introduced in the dia- phragm as close as possible to the defined points over 1–2 cm; again uneventfully. Three electrodes could be implanted in each of the 18 hemidiaphragms, generally during the first attempt. It proved easy to avoid superficial veins while inserting the hooks.

**Ventilation trials**

The outcomes of the two stimulation trials, when compared with the corresponding variables recorded during mechanical ventilation, are presented in Table 1 and in Fig. 5. Intradiaphragmatic phrenic nerve stimulation using the electrode inserted at the ‘tendinous’ location produced a tidal volume that was not significantly different from the tidal volume set during mechanical ventilation according to the usual animal care procedures. On the contrary, intradiaphragmatic phrenic nerve stimulation using the pair of electrodes inserted at the ‘muscular’ location, with identical stimulation parameters, produced a tidal volume that was significantly inferior to the volume produced at the other stimulation location (Fig. 5). This did not translate into clinically relevant changes in cardiac frequency or blood pressure, in spite of some statistically significant changes (Table 1). Of note, there was a modest and non-statistically significant tendency for $\text{SpO}_2$ to be higher during intradiaphragmatic phrenic nerve stimulation than during mechanical ventilation, in spite of the higher $\text{FiO}_2$ in the latter condition.

**Postoperative evaluation**

The laparotomy performed after euthanasia showed a limited haematoma located at the dome of the liver in one animal (the first studied) and a similar lesion in the wall of the small bowel in another animal (the second studied). In a third case (third animal studied), the lead of the ‘tendinous’ electrode was partially visible from the abdominal cavity, without any intra-abdominal injury.

**DISCUSSION**

This study shows that it is possible to safely and easily identify the phrenic nerves and access both hemidiaphragms using a flexible endoscope inserted in the mediastinum through a single cervical incision. It underlines the interest of combining an endoscopic approach with recently described minimally invasive thoracic surgical techniques that rely on a cervical approach [14–16]. Importantly, the flexible nature of the endoscope is key to alleviating the risk of mediastinal complications. This concept, known as Cervical Incision Thoracic Endoscopic Surgery (CITES) [12], has analogies with that of Natural Orifice Transluminal Endoscopic Surgery (NOTES) for abdominal interventions [17–19].

We chose to study ewe rather than dogs or pigs mostly for anatomical reasons. Indeed, dogs have a fenestrated mediastinum that would have made the procedure impossible for obvious reasons. This is very rare in ewe and in pigs, but preliminary experiments on pigs showed that a very thick upper part of the sternum made mediastinal navigation with the flexible gastroscope extremely difficult, contrary to what had been

---

**Table 1:** Comparison of controlled mechanical ventilation (MV) and intradiaphragmatic phrenic nerve stimulation performed at the two electrodes implantation sites

<table>
<thead>
<tr>
<th>Studied parameters</th>
<th>MV</th>
<th>psT</th>
<th>psM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cardiac frequency (beat min$^{-1}$)</td>
<td>91[87.5–94.5]</td>
<td>87*[79.0–90.5]</td>
<td>90*[82.5–92]</td>
</tr>
<tr>
<td>Mean arterial blood pressure (mmHg)</td>
<td>40[30.0–50.5]</td>
<td>36[27.0–50.5]</td>
<td>33[29.5–50.5]</td>
</tr>
<tr>
<td>Transcutaneous oxygen saturation ($\text{SpO}_2$, %)</td>
<td>97[92.5–100]</td>
<td>100[97.5–100]</td>
<td>99[96.5–100]</td>
</tr>
</tbody>
</table>

See Materials and Methods (psT: intradiaphragmatic phrenic nerve stimulation, ‘tendinous’ electrode site; psM: intradiaphragmatic phrenic nerve stimulation, ‘muscular’ electrode sites). Values as median [interquartile range] (minimum–maximum). *$P < 0.05$ compared to MV. **$P < 0.05$ compared to psT.
observed in human cadavers [13]. Therefore, in spite of some noticeable differences with human mediastinal anatomy (greater length of the trachea, additional right tracheal bronchus, greater size of the thyroid gland), the ewe model appeared to provide a good experimental compromise.

Of note, all the animals tolerated the entire procedure very well. Nevertheless, abdominal complications resulting from transdiaphragmatic punctures are a matter of concern. This occurred three times (33% of the animals, 16.5% of the hemi-diaphragms), in two cases with wall hematomas (22% of the animals). Such a rate of complications would obviously not be acceptable. We, however, note that these incidents occurred in the first three animals that we studied, namely the first three living subjects ever studied with this approach. In the following six animals, we slightly modified the insertion technique, with a more tangential introduction of the ‘carrier’ needle in the diaphragm under continuous visual control. This should provide protection against lesions of abdominal organs, and indeed no transdiaphragmatic puncture occurred with this approach. Further studies will be needed to precisely delineate safety issues. Trans-parietal ultra-sonography during the insertion of the electrodes could be an additional safety measure.

With stimulation settings resembling those used in patients with a therapeutic indication of diaphragm pacing [4], the two modalities of electrodes insertion that we used in the present study were not equivalent regarding tidal volume production. When stimulation was performed at the ‘tendinous’ site, tidal volumes were roughly equal to the volume set during controlled mechanical ventilation. When stimulation was performed at the ‘muscular’ site, the tidal volumes produced were systematically and significantly lower. Because we did not randomize the stimulation sequence, diaphragmatic fatigue occurring at the end of the stimulation session could theoretically have occurred. However, it is very unlikely that diaphragm contractions producing a ‘normal’ tidal volume in animals not submitted to an inspiratory load would have crossed the fatigue threshold as usually defined from the pressure–time product of the diaphragm [20]. In addition, the results are rather homogeneous between animals (Fig. 5), which makes us suspect that the difference between the two techniques is somehow due to a different pattern of activation of the diaphragm. Further studies, including a more detailed evaluation of the diaphragm response to phrenic stimulation, will be needed to clarify this issue. The present data, however, provide precious guidance by suggesting that during a transmediastinal approach, the optimal site of insertion of intradiaphragmatic phrenic nerve stimulation electrodes might well be the entry point of the phrenic nerve trunk in the central tendon of the diaphragm. Of note, even though no significant difference was detected, SpO2 values tended to be higher during intradiaphragmatic phrenic nerve stimulation, and this was true even during the ‘muscular’ electrodes where used in spite of the lower tidal volume. This is in line with the fact that phrenic nerve stimulation should direct ventilation predominantly toward the lower lobes and therefore improve the ventilation–perfusion ratio, when compared with mechanical ventilation which should produce a more homogeneous—and therefore less physiological—lung ventilation. This result is all the more relevant as the FiO2 administered to the animals was markedly higher during mechanical ventilation than during phrenic stimulation. Because we did not apply any positive end-expiratory pressure during mechanical ventilation, this...
observation is likely to be in line with anaesthesia-induced atelectasis [21, 22] being re-opened by phrenic stimulation.

The CITES approach could theoretically be used to implant intradiaphragmatic phrenic nerve stimulation electrodes in the current indications of diaphragm pacing. They include high cervical cord lesions with intact phrenic motoneurons [4] and central alveolar hypoventilation of any cause. In these indications, the CITES approach could be useful in cases where laparoscopy is contra-indicated, or to avoid phrenic nerve dissection that is required for intrathoracic phrenic nerve stimulation. Of note, this would only be true in patients without prior tracheostomy that constitute an obstacle to CITES because of the associated infectious risk. In the case of high cervical cord lesions, the CITES approach would be particularly interesting if there is an evolution of practices toward very early implantations, which is not an unreasonable option to consider in the future. In the case of central hypoventilation, congenital or acquired, many patients are chronically ventilated non-invasively, using a face mask or a nasal mask. If an indication of phrenic nerve stimulation is retained in such a patient, it could be carried out using the CITES approach, in the absence of a pre-existing tracheostomy.

The CITES approach could also help extend the current indications of diaphragm pacing in two separate directions, as follows: first, diaphragm pacing provides negative pressure ventilation. This can represent a distinct advantage in patients in whom positive pressure ventilation can be deleterious, namely those who suffer from or are at risk of elevated intracranial pressure [see review in 23]. However, in these patients, the abdominal gas inflation required to perform a laparoscopic procedure is contra-indicated because it would certainly increase intracranial pressure. The CITES approach could solve this issue because no elevation in intrathoracic pressure is expected during the corresponding surgical procedure. Secondly, should diaphragm pacing become a method to counteract diaphragmatic disuse atrophy in mechanically ventilated patients [see review in 24], the CITES approach would be particularly suitable to implant temporary intradiaphragmatic phrenic stimulators. This could indeed be done concomitantly to a tracheostomy, sparing the patients one operation, i.e. the laparoscopic implantation of intradiaphragmatic phrenic nerve stimulation electrodes.

In conclusion, we consider this study as an incentive to pursue the development of the CITES approach, of which the insertion of electrodes into the diaphragm for the purpose of phrenic nerve stimulation (that has already been described with NOTES [25]) could constitute another application, in addition to the ones already proposed (namely pleural biopsies, sympathometries and lung release) [12].

ACKNOWLEDGEMENTS

The authors are grateful to Anthony Ignagni for technical assistance with the device configuration and identifying appropriate placement of electrodes. They thank Julie Piquet for her help in the operating room and animal care. They thank Paul Robinson for his help with English style and grammar.

Funding

Storz Medical France (Guyancourt, France) lent the endoscopic material used in this study and partly funded the animal costs. Synapse Biomedical Inc. (Oberlin, OH, USA) provided all the stimulation material free of charge. The ‘Laboratoire de recherche bio-chirurgicale Fondation Alain Carpentier, Université Paris S, Paris’ partly funded the animal costs. The study was supported by a 2011 grant from ‘Fondation Gueules Cassées’, Paris, France.

Conflict of interest: Jalal Assouad, Hicham Masmoudi, Jesus Gonzalez-Bermejo, Capucine Morélot-Panzini, Dominique Grunenwald and Thomas Similowski have no perceived conflict of interest regarding this study. Moustapha Diop is an employee and stock owner of Synapse Biomedical Inc.

REFERENCES

**EDITORIAL COMMENT**

**Animal model of transdiaphragmatic phrenic pacing through cervical approach**

Françoise Le Pimpec-Barthes*

Department of Thoracic Surgery, Assistance Publique-Hôpitaux de Paris, Georges Pompidou European Hospital, Paris Descartes University, Paris, France

* Corresponding author. Department of Thoracic Surgery, Georges Pompidou European Hospital, 20 rue Leblanc, 75908 Paris, France. Tel: +33-1-56093459; fax: +33-1-56093380; e-mail: francoise.lepimpec-barthes@egp.aphp.fr (F. Le Pimpec-Barthes).

**Keywords:** Diaphragm pacing · Phrenic nerve pacing · Animal model · Minimally invasive surgery

The objective of phrenic pacing is to improve the quality of life of ventilator-dependent patients with diaphragm paralysis while restoring a natural negative pressure breathing with their own diaphragm. Weaning from the mechanical ventilator obtained by this technique improves the patient’s independence and allows a more physiological and comfortable breathing as well as an improved sense of smell and speech [1]. Since the first success of phrenic nerve pacing through a direct bilateral cervical approach reported by Glenn et al. in 1972 [2], allowing a total support of ventilation in a tetraplegic patient, the improvements of this concept have concerned the site of implantation and the surgical approach. The objectives were to obtain a safe, effective and minimally invasive technique for this orphan procedure concerning few patients in the world. First, implantation was done into the pleural cavity to avoid the breaking risk of electrodes at the cervical level and to obtain a complete nerve stimulation. Classical thoracotomy was then replaced by a video-assisted mini-thoracotomy approach (VATS), which has proven to be a safe procedure [3]. In this technique by VATS, quadripolar electrodes are implanted around the phrenic nerve with low electric thresholds (1 or 2 mA) without nerve tiredness and excellent long-term results. The implantation of bipolar electrodes by video thoracoscopy (VT) alone or with robotic assistance [4] was reported in short series always requiring nervous dissection. Still with this mini-invasive surgery strategy, the idea of indirect nerve stimulation without any nerve dissection, using a simple hook wire electrode placed into the diaphragmatic muscle, was then proposed mainly in tetraplegic patients after complete studies on the animal model [5]. In this abdominal approach by the standard laparoscopic technique, not requiring respiratory exclusion, a first mapping procedure is needed to identify the motor points of each hemidiaphragm before the insertion of the two stainless steel intramuscular electrodes [6]. This basic surgical technique, much easier than the reference technique by direct nervous stimulation, only consists in simply introducing the electrode inside the diaphragm muscle. The crucial point is to identify the accurate site of implantation. Results in human series were superposable to those observed with the reference technique by a thoracic approach. Safety of this technique allowed its utilization in childhood or adolescence [7] and trials in patients with amyotrophic lateral sclerosis. The application of Natural Orifice Transluminal Endoscopic Surgery (NOTES) was also evaluated in the animal model to assess the feasibility of transgastric mapping and the implantation of a percutaneous electrode [8].

In this issue of the Journal, Assouad et al., from Paris [9], report an animal study analysing the feasibility to perform diaphragm pacing through the transcervical mediastinal approach. After general anaesthesia and selective bronchial intubation performed in nine ewes, the supra sternal cervical approach was done to introduce a flexible endoscope into each pleural cavity. This study shows the feasibility of implanting muscular electrodes near the entrance points of the phrenic nerves into each hemidiaphragm with the help of a transsthoracic chest tube to identify the phrenic nerve ending in 12 of 18 hemidiaphragms (67%). Safety of the technique was obtained after short training. Immediate efficiency...