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Diaphragm stimulation technology, pacemakers and use

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ABSTRACT

Diaphragm stimulation technology is used in the second-line treatment of respiratory failure due to bilateral diaphragmatic dysfunction. However, an intact diaphragm muscle function is needed for a successful diaphragm stimulation. Diaphragm pacemakers does not help in pathologies that may occur in these regions but it has been shown in studies with long-term follow-up that in patients who will be connected to a long-term mechanical ventilator, it can protect from ventilator-related infections, reduce lung atelectasis, and lead a comfortable and active life both in terms of psychology. According to diaphragm pacemaker practices, postoperative gains are unfortunately not at desired level.

Keywords: Diaphragm, pacemaker, ALS, cervical spinal cord injury, stimulation, implant.

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Introduction

Electrical stimulation of the diaphragm, first described by Duchenne conceptually as the best way to mimic natural respiration [1], was started to be implemented after the development of a device, which was first commercially distributed by Glenn et al., in the late 1960s [2]. Today, diaphragmatic pacing is used as second-line treatment in patients with respiratory failure due to bilateral diaphragmatic paralysis or severe paresis [3, 4]. Diseases in which diaphragmatic pace is used most frequently in the literature include; patients with quadriplegia occurring in high cervical spinal cord injuries [5-8], and patients with amyotrophic lateral sclerosis (ALS), a degenerative motor neuron disease [9, 10].

Design and Functions

There are 2 different permanently placed devices currently used in the world. The model, which can be placed cervically or thoracoscopically, is placed on the phrenic nerve and directly stimulates the phrenic nerve. It consists of three parts; electrodes and receiver together constitute the first part, antenna and transmitter [11]. The electrodes of this model are placed on the phrenic nerve with a cervical or thoracoscopic approach, and the receiver is implanted under the skin and connected to the transmitter by postoperatively placing the antenna on the receiver.

On the other hand, the laparoscopically used model consists of two parts; electrode and transmitter [12]. Electrodes are placed intramuscularly in the diaphragm after contraction mapping of the diaphragm is performed laparoscopically. The electrode cables are fixed on the skin by tunneling under the skin. Electrode cables are then connected to the transmitter.

Recently, there has been the use of a transvenous pacemaker that stimulates the phrenic nerve, which is temporarily placed with a catheter (2-4 weeks) [13].

To whom it can be applied?

It can be often used in quadriplegic patients connected to a ventilator, ALS patients, central hypoventilation syndrome, phrenic nerve damage, as well as central sleep apnea syndrome (Ondine's curse), idiopathic diaphragmatic paralysis, multiple sclerosis, spinal muscular atrophy, obstructive pulmonary diseases [4]. The limiting factor is the presence of an intact phrenic nerve and diaphragm muscles.

Patients with apnea due to the bilateral diaphragmatic plegia with full-thickness spinal cord damage at third cervical vertebra and above, are the most suitable patients. Nerve cell bodies of the phrenic nerve are located in the anterior horn of C3- C5, Therefore, it should be known that the phrenic nerve is intact at intermediate cervical spinal cord injuries. The most practical and non-invasive way to show that the phrenic nerve is intact, is the observation that the diaphragm descends more than 3 cm by an imaging method or by fluoroscopy or electro myelography by giving an electrical impulse from the neck percutaneously [14, 15].

On the other hand, electrodes placed intramuscularly on the diaphragm rather than on the phrenic nerve are preferred in patients with ALS, due to phrenic nerve involvement as a result of damage to motor neurons. In this case, diaphragmatic thickness becomes important for the success of the procedure. In a study of Şanlı A et al., it has been shown that mortality is significantly higher in patients with a cut-off value of diaphragmatic thickness below 3.5 mm [16].

How should it be placed?

Diaphragmatic pacemaker can be placed with a cervical, thoracic or abdominal approach. While the phrenic nerve is stimulated in the cervical and thoracic approach; the muscle is stimulated in the abdominal approach.

In upper level cervical spinal cord injuries; cervical, thoracic and abdominal approaches can all be applied. The choice depends on the surgeon's experience. In patients with diaphragmatic plegia originating from the central nervous system, one of the cervical, thoracic or laparoscopic approaches may be preferred. In lower motor neuron diseases, direct diaphragmatic (laparoscopic) innervation should be performed.

The advantage of the cervical approach over thoracic approach, is ability to place electrodes on both phrenic nerves in a single surgical procedure. It eliminates the morbidity and mortality associated with thoracic surgery when compared to the thoracic approach. The disadvantage is that the surrounding tissues and brachial plexus can be stimulated and unwanted contractions may occur.

The advantage of the thoracic (thoracoscopic) approach; is the absence of brachial plexus innervation that may develop in the cervical approach. Since the lower branch of the phrenic nerve joins the nerve trunk in the thorax, more parts of the nerve can be stimulated. The disadvantage is the mortality and morbidity that may occur due to thoracic surgery and in addition, 2 surgical procedures are required for bilateral nerve innervation.

The advantage of the Abdominal (laparoscopic) approach; is the ability to perform diaphragmatic innervation in a single surgical procedure and the possibility of phrenic nerve damage that may develop during surgery in the cervical and thoracic approach is eliminated since it is placed directly into the diaphragm muscle. The disadvantage is limited to the complications of laparoscopy.

As well as the permanent placement of the diaphragm pace, it has recently been used temporarily. The phrenic nerve is stimulated by the electrodes that are placed intravenously with the help of a catheter. It is advanced from the subclavian vein into the superior vena cava, and transvenous stimulation of the nearby localized phrenic nerves is performed. This practice has been shown to help patients wean from the ventilator and shorten the time they remain connected to the ventilator [13]. Temporary diaphragmatic pacing has been used to limit diaphragmatic atrophy or increase contraction strength in cases such as acute respiratory failure or bilateral lung transplantation, where the patients may need a long-term mechanical ventilator [13, 17-20].

What are the achievements?

An average of 12,000 new spinal cord injuries develop annually in the United States. 4% of these need a long-term mechanical ventilation [5]. The prevalence of ALS is shown as 4-6/100,000 in publications from North America and Europe, and it is estimated that there are approximately 90,000-100,000 ALS patients in the world and 3500-5000 ALS patients in Turkey [10]. Respiratory failure in ALS is the most important morbidity and mortality factor affecting the progression of the disease [21-23]. Progressive weakness of respiratory muscles leads to carbon dioxide retention and hypercarbic respiratory failure, which causes at least 84% of deaths from ALS [24].

In a study of Onders RP., While 71% of 300 quadriplegic patients with laparoscopic diaphragmatic pacing were able to be continuously separated from the mechanical ventilator for 24 hours, all of the patients could be separated for more than 4 hours per day [5].

In another study with ALS patients, ALS functioning score (ALSFRS), forced vital capacity (FVC), sniff nasal inspiratory pressure (SNIP), and polysomnographic recordings were measured in 18 patients to measure sleep quality after considering that respiratory disorders developing during sleep may be an early clue to diaphragmatic damage and the results were compared before and 4 months after laparoscopic diaphragmatic pacing. It is shown that sleep efficiency improved ($69 \pm 15\%$ to $75 \pm 11\%$, $p = 0.0394$) with fewer arousals and micro-arousals. Diaphragm conditioning has been shown to improve sleep in these severely ill patients who are not expected to experience spontaneous recovery [24].

In another study performed in 51 patients with ALS who underwent laparoscopic diaphragmatic pacing, all patients were extubated after diaphragmatic pacing and there was no 30-day mortality. After the application of the DPS device, the DPS device was operated in synchronization with the ventilator of the anesthesia during the awakening phase of the patients, and an increase of 19% was shown in the respiratory compliance of the patients [9].

In a systematic review that evaluated 12 studies conducted between 2000 and 2015, 40% to 72% of the patients became fully independent from the ventilator after the application of diaphragmatic intramuscular pacemaker. Reported complications include pneumothorax, infection, and interference with pre-existing cardiac pacemakers [7].

Conclusion

Recent studies have shown that even temporary transvenous diaphragmatic pacing catheters can be safely inserted and removed to avoid the side effects of positive pressure mechanical ventilators.

Foe the use of permanent diaphragmatic paces, on the other hand, it has been shown in studies with long-term follow-up that in patients who will be connected to a long-term mechanical ventilator, it can protect from ventilator-related infections, reduce lung atelectasis, and lead a comfortable and active life both in terms of psychology. It has been observed that the young age of patients (long survival expectation) and high family interest are factors that will increase compliance with the device.

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