Diaphragmatic Pacing in Spinal Cord Injury

Kevin Dalal, MD[a,*], Anthony F. DiMarco, MD[b]

KEYWORDS

• Diaphragm • Phrenic nerve • Tetraplegia

KEY POINTS

- The diaphragm is innervated by cervical nerves C3 to C5, but a patient may be able to mobilize the diaphragm with only partial innervation of the diaphragm.
- Testing diaphragm function may be accomplished with the "sniff test" of diaphragm elevation under fluoroscopy. Further, electrodiagnostic testing of phrenic nerve function also may be used to show a response in diaphragm function.
- Diaphragm pacing has been shown to be an effective way of weaning and maintaining patients off of mechanical ventilation, thus lowering the care burden, and liberating the patient to be more mobile, and lessening the potential for morbidity.

INTRODUCTION

There are more than 11,000 new cases of spinal cord injury (SCI) each year. Approximately 50% of these patients have tetraplegia, and of those, approximately 4% require mechanical ventilation long term.[1] The patient with tetraplegia faces significant challenges beyond the mobility and sensory impairments imposed by the injury. Chief among these issues is that of respiratory impairment. Patients with tetraplegia, depending on whether the injury is complete or incomplete, will have varying degrees of respiratory dysfunction based on the amount of residually intact innervation to the muscles of inspiration and expiration. The muscles of expiration include the abdominal musculature and intercostals, which are innervated by nerves coming from the thoracic cord, and are less likely to be functionally intact in a patient with a cervical injury. The chief muscle of inspiration is the diaphragm, which is innervated by motoneurons from the cervical spinal cord, and thus susceptible to dysfunction in tetraplegia.

The standard of care for patients who cannot adequately mobilize their diaphragm (in addition to a host of other comorbidities that could compromise respiratory

Disclosure: The author has no financial disclosures.
[a] Department of Physical Medicine and Rehabilitation, University of Miami-Miller School of Medicine, 1120 North West 14th Street, Suite 936, Miami, FL 33136, USA; [b] Rammelkamp Research Center, MetroHealth Medical Center, 2500 MetroHealth Drive, Cleveland, OH 44109, USA
* Corresponding author.
E-mail address: kdalal@med.miami.edu

Phys Med Rehabil Clin N Am 25 (2014) 619–629
http://dx.doi.org/10.1016/j.pmr.2014.04.004 pmr.theclinics.com
1047-9651/14/$ – see front matter

function) is to perform a tracheostomy and mechanically ventilate the patient. This article outlines the negative implications of mechanical ventilation, and discusses the possibility and benefits of allowing the patient to breathe with the assistance of exogenous diaphragm pacing.

PHYSIOLOGY OF BREATHING

As previously mentioned, the primary muscle of inspiration is the diaphragm, a thin, dome-shaped sheet of skeletal muscle, with muscular tissue converging on a central tendon that forms the crest of the dome. The muscle fibers originate from various structures, including the lumbar vertebrae and abdominal wall posteriorly, the ribs laterally, and the xiphoid process and floating ribs anteriorly. The central tendon is closer to the anterior of the thorax and, thus, the posterior muscle fibers are longer, traveling a farther course to converge on the tendon. The diaphragm is pierced by 3 apertures, which allow passage of the vena cava, the esophagus, and the aorta.[2]

During inspiration, the diaphragm contracts, which creates a negative-pressure vacuum, and draws air into the thoracic cavity through the respiratory system. The diaphragm contracts volitionally during the daytime hours and automatically during sleep, based on CO2 levels monitored in the brain's respiratory centers. When the diaphragm relaxes, air is exhaled by the elastic recoil of the lung and the pleural cavity. In forced exhalation, such as a cough, the internal intercostal muscles and abdominal muscles work antagonistically to the diaphragm. Additionally, the diaphragm can be used in nonrespiratory capacities by suddenly increasing intra-abdominal pressure, as in the processes of vomiting, defecating, and urination.

The diaphragm is innervated by the phrenic motoneurons, which are supplied by cervical spinal nerves C3, C4, and C5. These spinal nerves combine peripherally to form the paired phrenic nerves, which progress caudally through the thorax and insert into the diaphragm. In the event of a cervical SCI, the interruption of respiratory bulbospinal pathways can lead to respiratory paresis or paralysis.

In higher-level cervical injuries, the spinal roots, which directly contribute to the phrenic nerves and innervate the diaphragm, are spared, but the roots from the respiratory centers in the medulla to the cord are still interrupted. These patients will definitely require exogenous ventilation. However, there are many disadvantages to mechanical ventilation, and these higher-level injuries may be candidates for diaphragm pacing.

MECHANICAL VENTILATION

In such cases of acute or chronic respiratory failure, the use of positive-pressure mechanical ventilation can serve as a life-sustaining measure. Some patients may tolerate less-invasive means of mechanical ventilation, but at least initially, many patients are managed via the traditional measure of positive-pressure ventilation via a tracheostomy.[3] Up to 20% of newly injured patients with SCI may require mechanical ventilation initially, but many patients improve in the following weeks. Regardless, between 200 and 400 patients per year become dependent on lifelong ventilator support.[4]

However, mechanical ventilation is susceptible to increased morbidity from pneumonia, as well as earlier mortality.[5] When compared with an able-bodied 20-year-old, the life expectancy for a 20-year-old patient with SCI on long-term mechanical ventilation decreases markedly from 58.6 to only 17.1 years. According to the National Spinal Cord Injury 2002 Database, survival rates decreased from 84% in the nonventilated patient to only 33% in the ventilated population.[1]