CHEST

Diaphragm Dysfunction in Critical Illness

Gerald S. Supinski, MD; Peter E. Morris, MD; Sanjay Dhar, MD; and Leigh Ann Callahan, MD

The diaphragm is the major muscle of inspiration, and its function is critical for optimal respiration. Diaphragmatic failure has long been recognized as a major contributor to death in a variety of systemic neuromuscular disorders. More recently, it is increasingly apparent that diaphragm dysfunction is present in a high percentage of critically ill patients and is associated with increased morbidity and mortality. In these patients, diaphragm weakness is thought to develop from disuse secondary to ventilator-induced diaphragm inactivity and as a consequence of the effects of systemic inflammation, including sepsis. This form of critical illness-acquired diaphragm dysfunction impairs the ability of the respiratory pump to compensate for an increased respiratory workload due to lung injury and fluid overload, leading to sustained respiratory failure and death. This review examines the presentation, causes, consequences, diagnosis, and treatment of disorders that result in acquired diaphragm dysfunction during critical illness.

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Prevalence of Diaphragm Dysfunction in Mechanically Ventilated Patients

Over the past decade, considerable clinical effort and research has focused almost entirely on ICU-acquired limb muscle weakness, with little emphasis on the diaphragm. It has been suggested that this may be due to a lack of knowledge regarding the effects of critical illness on the respiratory muscles or the limited availability of tools to assess and monitor diaphragm function in patients in the ICU.[1,2]

Multiple recent studies have shown, however, that severe ICU-acquired diaphragm weakness develops in a large percentage of mechanically ventilated patients in the ICU.[3-7] In many of these reports, objective nonvolitional measurements using the gold standard technique to assess diaphragm strength were used. Specifically, by assessing transdiaphragmatic twitch pressure (PdiTw) generated in response to bilateral anterior magnetic phrenic nerve stimulation (BAMPS), investigators report that mechanically ventilated patients in the ICU, on average, generate a PdiTw that is only 20% of normal.[3-7] Although these represent average levels for mechanically ventilated patients, a high percentage of mechanically ventilated patients have far lower PdiTw

ABBREVIATIONS: BAMPS = bilateral anterior magnetic phrenic nerve stimulation; P_{100} = negative airway pressure generated during the first 100 ms of an occluded inspiration; PdiTw = transdiaphragmatic twitch pressure generation; RSBI = rapid shallow breathing index; TF = thickening fraction; VIDD = ventilator-induced diaphragm dysfunction

AFFILIATIONS: From the Division of Pulmonary, Critical Care, and Sleep Medicine, University of Kentucky, Lexington, KY.

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CORRESPONDENCE TO: Leigh Ann Callahan, MD, University of Kentucky, L543, Kentucky Clinic, 740 South Limestone St, Lexington, KY 40536; e-mail: lacall2@email.uky.edu

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levels, which are indicative of more severe diaphragm weakness. For example, Supinski and Callahan[6] found that 30% of patients had PdiTw levels < 5 cm H_2O, whereas only 6% of patients had PdiTw levels > 15 cm H_2O, values that are far less than those reported for normal healthy volunteers (eg, 28-38 cm H_2O).[3,8] Additional studies have confirmed that on average, 60% to 80% of mechanically ventilated patients manifest clinically significant diaphragm dysfunction.[9,10] Moreover, a recent study indicates that diaphragm weakness is present twice as often as limb weakness in critically ill patients.[9]

A Practical Approach to Recognition of Diaphragm Dysfunction in Critically Ill Patients

Unfortunately, despite the preponderance of evidence that respiratory muscle dysfunction is a common form of organ failure in critical illness and is associated with poor acute and long-term outcomes (discussed further on), clinicians frequently fail to consider this diagnosis. Theoretically, any patient who requires mechanical ventilation should be considered to be at risk for the development of diaphragm weakness. There are, however, several specific clinical scenarios that suggest the presence of diaphragm abnormalities. Although not intended to be comprehensive, the situations described further on may offer a practical approach to the recognition of diaphragm weakness in critically ill patients and can be easily detected at the bedside.

First, the presence of abdominal paradox, a marked inward motion of the abdomen during inspiration, is often a clue to the existence of severe diaphragm weakness or bilateral diaphragmatic paralysis.[11-14] In these patients, inspiratory contraction of the intercostal muscles "sucks" the flaccid diaphragm into the chest, resulting in an inward motion of the abdominal wall. In contrast, during inspiration in normal subjects, the active diaphragm moves downward and prevents inward motion of the abdomen. The clinical finding of abdominal paradox is most easily seen when patients are in the supine position; however, we have observed abdominal paradox during weaning trials or when patients are receiving low levels of pressure support, suggesting that diaphragm weakness may be present. There is, however, an important caveat to the consideration of abdominal paradox as a sign of diaphragm dysfunction. Pronounced expiratory muscle activation can induce diaphragm paradox in the absence of intrinsic diaphragm dysfunction; as a result, additional testing is needed to confirm that true diaphragm weakness is present when this clinical sign is observed.

In addition, diaphragm dysfunction should be considered when a mechanically ventilated patient is making poor progress during weaning trials despite clinical improvements in pulmonary infiltrates, the lung examination, and several days of therapy (eg, administration of antibiotics or bronchodilators) to treat the underlying pulmonary disorder. The possibility of severe diaphragm weakness should also be entertained in patients with recurrent unexplained episodes of respiratory failure. Of course, undiagnosed coronary artery disease should also be a consideration for patients who present with this clinical phenotype.

It is also extremely useful to assess simple bedside indices of lung and respiratory system function (ie, respiratory system static compliance, inspiratory airway resistance, and the rapid shallow breathing index [RSBI])[15,16] in mechanically ventilated patients who are not making adequate progress. A combination of relatively good lung mechanics but a high RSBI is a clue that respiratory muscle weakness may be present. As an example, one classic study[17] found that patients with acid maltase deficiency-induced respiratory muscle weakness were commonly misdiagnosed with forms of intrinsic pulmonary diseases (eg, COPD) and that a correct diagnosis was achieved once objective testing was used to exclude other forms of respiratory failure.

The chest radiograph may also sometimes suggest the possibility of a significant diaphragm pathologic condition. Although not specific,[18] unilateral or bilateral hemidiaphragm elevation can be seen with diaphragm paralysis or severe weakness, and this finding should prompt the use of simple tests (eg, diaphragm ultrasonography) to determine if diaphragm motion is adequate (see the sections on diagnosis further on).

A final clinical situation that warrants consideration of severe diaphragm dysfunction is patients who have no prior history of lung disease who present with hypercapneic respiratory failure and a normal chest radiograph. In these instances, patients may have pre-existing undiagnosed primary neuromyopathic processes, such as amyotrophic lateral sclerosis, Guillain-Barre syndrome, chronic inflammatory demyelinating polyneuropathy, myasthenia gravis, carnitine deficiency, Pompe disease, polymyositis, or inclusion body myositis.[12,18-22] Although there can be considerable heterogeneity in the presentation of many of these disorders, as well as marked variation in the