EMG RESPIRATORY STUDIES

Peter B. Saadeh, MD
Christine Fitzpatrick Crisafulli, MD
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In the clinical setting, electromyographers are often requested to evaluate patients with respiratory dysfunction or failure to wean from a ventilator. The electrodiagnostic medicine consultation may eventually help in determining the diagnosis, the prognosis, and the management of these patients.

The largest and, usually, the most difficult group to study are patients in the medical and surgical intensive care unit (ICU), who are on mechanical ventilation and are unable to be weaned. Other groups include patients with acute or chronic neuromuscular diseases (e.g. Guillain-Barre, ALS, myopathies), traumatic injuries (spine/chest), or phrenic nerve impairment.

In addition to routine nerve conduction studies and needle EMG, phrenic nerve conduction and needle EMG of the diaphragm are often required for full electrodiagnostic medicine consultations of patients with respiratory dysfunction.

**BASIC CONSIDERATIONS**

Respiration depends on the integrity of the lungs as a gas-exchanging organ and of the neuromuscular respiratory system and chest wall as a ventilatory pump. The neuromuscular respiratory system consists of the muscles of respiration, peripheral nerve supply to these muscles, and a central control mechanism within the brain stem. The diaphragm is the most important muscle of respiration. Accessory respiratory muscles include the sternocleidomastoids, scaleni, intercostals, and abdominal muscles.

Partial or complete failure of the diaphragm can lead to respiratory dysfunction and the need for intubation and mechanical ventilation. Central respiratory drive dysfunction may occur in head injuries, cerebral edema, and encephalopathy. Peripheral neuromuscular causes of respiratory dysfunction include diseases that affect the anterior horn cells (motor neuron diseases, poliomyelitis), phrenic nerves (Guillain-Barre syndrome, trauma, complications of cardiothoracic surgery and liver transplants), neuromuscular junction (myasthenic syndromes, botulism), and myopathies. Complicated abdominal surgery, especially in the weak and elderly, can seriously affect normal breathing. In the past two decades, advances in critical care medicine have led to the recognition of the complications of sepsis, multiple organ failure, and some medications such as high doses of corticosteroids and neuromuscular blocking agents as significant causes of both neuropathic and myopathic respiratory compromise and failure to wean from mechanical ventilation.

**CLINICAL AND LABORATORY ASSESSMENT OF PERIPHERAL NEUROMUSCULAR RESPIRATORY DYSFUNCTION**

Abnormalities of respiratory rate and rhythm, use of accessory muscles, and the presence of paradoxical breathing (respiratory alternans) are clinical signs of respiratory compromise. An elevated and immobile or hypomobile diaphragm on radiography, fluoroscopy, or ultrasonography may also indicate respiratory dysfunction. Vital capacity, tidal volume, negative inspiratory force, and maximum voluntary ventilation are used to measure pulmonary ventilation. Arterial blood gas concentrations and pulse oximetry determine adequacy of oxygenation.

Prior to the electrodiagnostic medicine consultation, patients on mechanical ventilation should be assessed for inspiratory movements of both diaphragms. It can easily be done by disconnecting the monitored patient from the ventilator, and by observing the elevation of the abdominal wall on either side during inspiration.

In the ultrasonographic evaluation of diaphragmatic movement, testing should begin only after the patient initiates voluntary respiratory activity.

**ELECTRODIAGNOSTIC MEDICINE CONSULTATIONS OF THE RESPIRATORY MUSCLES AND NERVES**

Electrodiagnostic medicine consultations were previously limited to phrenic nerve conduction and recording of the diaphragmatic compound muscle action potential (DCMAP), using either surface or esophageal electrodes.
Transdiaphragmatic pressure generated by inspiration or by phrenic nerve stimulation has also been measured using a gastroesophageal seal electrode. Shift of power spectrum in surface recordings of diaphragmatic activity has been claimed by some to detect development of muscle fatigue. This shift in the power spectrum, however, has not been shown to bear a relationship to the form of fatigue that is physiologically significant. The phrenic myoneural junction has rarely been studied. Intercostal nerve conduction and needle EMG of the intercostals muscles have been reported. With the exception of the phrenic nerve conduction studies and the recently described safe and reliable techniques for needle EMG of the diaphragm, none of the other methods have gained widespread use in the routine electrodiagnostic medicine consultation of the respiratory system.

PHRENIC NERVE CONDUCTION STUDIES

Anatomic Considerations

The phrenic nerve is chiefly derived from the fourth cervical root, with contribution from the third and fifth roots. It emerges in the neck at the upper border of the thyroid cartilage, passing between the sternocleidomastoid and anterior scalenus muscles. It lies in proximity to the brachial plexus. The phrenic nerve descends into the thorax at the junction of the medial one fourth and the lateral three fourths of the clavicle. The right phrenic nerve descends through the thorax and into the diaphragm at its central tendon. There it divides into three main branches to innervate the anterior sternal, lateral costochondral, and posterior crural part of the diaphragm. The left phrenic nerve is slightly longer, going around the heart before reaching similar innervation of the left diaphragm.

PHRENIC NERVE STIMULATION AND RECORDING TECHNIQUES

The phrenic nerve is stimulated supramaximally in the neck, behind the sternocleidomastoid muscle, at the upper level of the thyroid cartilage. The sternocleidomastoid muscle can be identified by manual palpation or by asking the subject to rotate the head to the contralateral side. The upper border of the thyroid cartilage can be manually palpated and is located midway between the angle of the mandible and the clavicle. The head should be returned to the neutral position during stimulation. A bipolar stimulating electrode is used with the cathode caudal to the anode. A square wave pulse stimulus of 0.2 to 0.5 ms duration is applied. The filter settings are 10 Hz to 10 KHz, and the gain is 100 to 200 (v/division. The ground electrode is placed over the midsternum.

For recording, a 10 mm active electrode is placed 3 to 5 cm above the xyphoid process and the reference electrode over the seventh or eighth intercostals space above the costochondral junction (Figure 1). The eighth intercostal space is between the eighth and ninth rib cartilages. It can be located by counting down the spaces, starting with the second intercostal space at the level of the sternal angle. An easier, alternative way to identify the eighth intercostal space is to locate the ninth rib cartilage. This corresponds to the junction of the lateral border of the rectus abdominis, the linea semilunaris, and the costal margin (Figs. 2 and 3). The ninth rib cartilage also corresponds to the junction of the paramidclavicular line and the costal margin, as described later. The reference electrode is placed above that rib cartilage.
RESULTS

The DCMAP is usually biphasic, with the initial phase upward (Figure 4).

The adult mean latency is 7.7±0.77 ms (range 6-10 ms). In children under 12 years of age, the latency range is 2 to 6 ms.

The baseline to peak amplitude is 0.79 ± 0.19 mV; (range 0.4-1.2 mV).

The duration of upward deflexion is 18.08 ±3.06 ms (range 12-24 ms). The duration of the total response is less than 40 ms.

The right to left latency difference is insignificant. The difference in amplitude is less than 40%.

OTHER PHRENIC NERVE CONDUCTION TECHNIQUES

1) Stimulation in the neck, at the level of the thyroid cartilage. Recording with two electrodes 3.5 to 5cm apart in the eighth and ninth interspaces, with the anterior electrode in the anterior axillary line.21

2) Stimulation of the phrenic nerve with a monopolar needle electrode in the neck at the level of the cricoid cartilage and a reference plate electrode over the sternal manubrium.19

3) Magnetic stimulation of the phrenic nerve in the neck.28

4) Stimulation of the phrenic in the supraclavicular fossa. Active recording electrode at the intersection of a horizontal line from the xiphoid to the anterior axillary line. Reference electrode below the umbilicus.20

5) Stimulation in the supraclavicular fossa, recording active over the xiphoid and reference over the costal margin, 16cm from the active electrode.5

Phrenic nerve conduction latencies are similar when stimulating the phrenic nerve in the neck (<10 ms). The latency is 1 to 2 ms shorter when the nerve is stimulated in the supraclavicular fossa (<8ms).

TECHNICAL CONSIDERATIONS

Percutaneous stimulation of the phrenic nerve in the neck is a relatively easy technique. The main difficulty is the occasional presence of swelling or surgical wounds. In these cases, supraclavicular stimulation can be attempted. We have no personal experience with electromagnetic stimulation.

Another difficulty commonly encountered when supramaximally stimulating the phrenic nerve is the simultaneous stimulation of the nearby brachial plexus with a visible contraction of the shoulder musculature and an evoked response that is of shorter duration than the diaphragmatic response, i.e. a latency of approximately 4 milliseconds (Figure 5). We use two ways to deal with this artifact:

1) Since the phrenic nerve lies anterior to the brachial plexus, the bipolar stimulating electrode should be pressed firmly behind the sternocleidomastoid muscle and then directed more anteriorly, away from the brachial plexus.

2) A second channel may be used to simultaneously record the DCMAP of a muscle innervated by the upper brachial plexus such as the deltoid, thus separating the phrenic nerve from the brachial plexus response.

Figure 3 Anterior aspect of the chest. Surface relations of the costal margins, pleura, lungs, and of insertion of the needle EMG electrode under the ninth rib cartilage.26

Figure 4 Compound muscle action potentials recorded from the diaphragm with stimulation of the phrenic nerve in the neck
Electrocardiographic artifact may also affect the amplitude of the diaphragmatic response. This can be avoided by stimulating the phrenic nerve after the QRS complex, or by superimposing several diaphragmatic responses. Some authors also recommend that the phrenic nerve should be stimulated when the diaphragm is at rest (i.e. at functional residual capacity). The amplitude of the diaphragmatic response is at its maximum at this time. Again, a few superimposed diaphragmatic responses will overcome this artifact.

In ICU patients, the DCMAP amplitude and the correlation between right and left should be interpreted with caution since it is volume conducted and it depends on two main factors:

1) Adequacy of phrenic nerve stimulation, which can be affected by swelling and other local tissue changes in the neck

2) The impedance of the chest wall, which is directly related to the thickness of the tissue that separates the skin from the diaphragm, where it attaches to the chest wall.

Repetitive stimulation studies of the phrenic nerve have rarely been reported. Supramaximal repetitive phrenic nerve stimulation is difficult in awake patients and is usually intolerable.

**SAFETY OF PHRENIC NERVE CONDUCTION STUDIES**

There have been no reported complications of routine phrenic nerve conduction studies by various authors. Safety precautions in patients with cardiac pacemakers should be taken into consideration.

**INTERCOSTAL NERVE CONDUCTION STUDY**

Intercostal nerve conduction can be obtained by stimulating the intercostal nerves at the inferior border of the ribs and recording over the rectus abdominis. The clinical usefulness of this study remains unproved.

**NEEDLE ELECTROMYOGRAPHY OF THE DIAPHRAGM**

Anatomic and Physiologic Considerations

The dome-shaped diaphragm inserts on the back of the xiphoid process, the inner surface of the cartilage and adjacent portions of the last six ribs, and the lumbar arcuate ligament and vertebrae. The internal thoracic (mammary) arteries descend behind the lateral border of the sternum. A significant branch, the musculophrenic artery, leaves the internal thoracic artery at the level of the sixth intercostal space and passes obliquely downward and laterally behind the seventh, eight, and ninth costal cartilages. Neurovascular bundles run along the inferior border of each rib. The right hemidiaphragm is molded over the convex surface of right lobe of the liver and the left hemidiaphragm over the left lobe of the liver, the fundus of the stomach, the spleen, and the colon.

The diaphragm is the main inspiratory muscle in quiet breathing, with some contribution from the intercostals muscles, the parasternal muscles, and the intercostals. The external intercostals and accessory neck muscles are activated in labored inspiration.Expiration is accomplished passively. Forced active expiration is accompanied by contraction of the abdominal and internal intercostals muscles.

**ELECTROMYOGRAPHIC TECHNIQUES**

The diaphragm can be studied with a needle EMG electrode, using three approaches: subcostal, lower lateral intercostals, and substernal. The choice depends:

1) on the experience of the electrodiagnostic medicine consultant and his or her familiarity with the anatomy and physiology of the neuromuscular respiratory system and

2) the safety, reliability and ease of the procedure.
**SUBCOSTAL APPROACH**

In the subcostal approach, the EMG needle electrode is inserted under the costal margin behind the eighth, ninth, or tenth rib cartilage (Figures 2 and 3). The ninth rib cartilage can be delineated by counting down the ribs, the second one being palpated at the sternal angle. The ninth rib cartilage also corresponds, by surface anatomy, to the proximal limit of the linea semilunaris, which delineates the lateral margin of the rectus abdominis muscle. These anatomic landmarks may become indistinct in obese or surgically scarred patients. In such cases, the ninth rib cartilage can be located at the junction of a line drawn from a point located halfway between the jugular notch of the sternum and the lateral border of the clavicle down to the costal margin. This line is 2 to 3 cm medial to the midsclavicular line and has been called, for the purpose of this study, the paramidclavicular line (Figure 3). The eight and ninth rib cartilages lie within two fingerbreadths on either side of this line. Behind these rib cartilages, the muscular costal attachment of the diaphragm lies 2 to 5 cm caudal to the inferior border of the pleura and an additional 2 to 3 cm remote from the lung.

The EMG machine is placed at a sweep time of 10 ms/division and a gain of 100 to 200 (V/division. A 50-mm monopolar or concentric needle electrode can be used. For the monopolar needle, the reference electrode is placed on the costal margin near the needle insertion. The ground electrode is placed over the sternum. The electromyographer stands to either side of the patient and, with the free hand, firmly and continuously depresses the patient’s abdomen below the costal margin. The pressure is such that the costal margin is sharply delineated. The needle, which is held parallel to the depressed abdominal wall, is inserted under and behind the ninth rib cartilage. It is then slowly advanced parallel to and closely hugging the posterior aspect of the chest wall. The needle first passes through the skin and the abdominal fascia. At a depth of 1 to 2 cm, it reaches the abdominal muscles, and muscle insertional activity is elicited. If the patient is not completely relaxed, voluntary electrical activity, synchronous with expiratory effort may be recorded at this level. Advancing further to a depth of 3 to 3.5 cm, the needle enters the costal insertion of the diaphragm. The rhythmic electrical activity of inspiration is recorded as bursts of an interference pattern of 300 to 600 (V in amplitude and 1 to 3 seconds in duration (Figure 6). The bursts are separated by regular intervals of electrical silence during passive expiration. The rhythmic inspiratory activity can be studied with a sweep time of 100 to 500 ms/division.

It is important to confirm the location of the EMG needle in the diaphragm by observing inspiratory electrical activity. This inspiratory activity may not be evident in a mechanically ventilated patient without spontaneous respiration. In such cases, an assistant may temporarily disconnect the ventilator; within 60 seconds, rhythmic electrical activity coincident with inspiratory effort will be recorded. If a patient is unable to tolerate brief disconnection from the ventilator, the ventilator pressure support may be reduced to a level, which will just overcome ventilator/airway resistance (approximately 8 to 10 cm of H2O). Recording of this inspiratory activity is the only confirmation of the correct placement of the EMG needle in the diaphragm. If no satisfactory inspiratory EMG activity is detected, the needle can be redirected under the tenth or, preferably, the eighth rib cartilage. This is done by partially withdrawing the needle to a depth of 1 to 2 cm and redirecting it laterally or medially. Alternatively, it may be completely withdrawn and reinserted under the costal margin within two fingerbreadths of the initial insertion. Firm manual abdominal wall depression should be maintained during these maneuvers. The needle should also be constantly held hugging the posterior chest wall.

The presence of fibrillation potentials and positive sharp waves is strongly suggestive of neurogenic impairment. In a partially denervated diaphragm, fibrillation potentials and positive sharp waves are observed between the bursts of inspiratory electrical activity (Figure 7). In a completely denervated diaphragm, there is absence of inspiratory electrical activity, and only fibrillation potentials and positive sharp waves may be seen. Complete absence of inspiratory electrical activity may also indicate a lack

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**Figure 6** Needle EMG of the diaphragm during normal rhythmic breathing.  

**Figure 7** Diaphragmatic needle EMG recordings. A. Completely denervated diaphragm. B. Partially denervated diaphragm with positive sharp waves (arrows).
of central respiratory drive or faulty needle EMG technique. In these circumstances, the location of the EMG needle becomes uncertain. Therefore, the interpretation of the electodiagnostic findings depends on proper knowledge of the local anatomy, the presence of localized abnormal EMG activity at the presumed location of the diaphragmatic insertion, phrenic nerve conduction studies, and clinical observation of diaphragmatic motion on fluoroscopy or sonography.

LOWER LATERAL INTERCOSTAL APPROACH

In the lower lateral intercostals approach, a monopolar needle is inserted laterally at any intercostals space above the costal margin between the anterior axillary line and the midclavicular line. The needle passes at a right angle to the skin and penetrates the subcutaneous tissues and external oblique or rectus abdominus and the intercostals muscles. It then enters the diaphragm, as evidenced by the appearance of bursts of inspiratory motor unit potentials.

SUBSTERNAL APPROACH

In the substernal approach, the patient is placed supine in a hyperlordotic position, with a pillow under the lumbar region. With the abdomen depressed, the EMG needle is introduced 3 to 5 cm behind and hugging the sternum until an inspiratory activity is recorded.

SAFETY FACTORS AND CHOICE OF TECHNIQUE FOR NEEDLE EMG OF THE DIAPHRAGM

In the subcostal approach, if the abdominal wall under the costal margin is constantly depressed by the free hand of the electrodiagnostic medicine consultant, the needle should pass through the skin and abdominal muscles before safely reaching the diaphragm. The needle is sufficiently away from the lungs, vessels, and abdominal viscera. No complication has been reported by electrodiagnostic medicine consultants using this technique. In our series, the study was technically unsatisfactory in 10% of patients.

The lower lateral intercostals approach appears to be an easier technique in patients who are breathing quietly (i.e. when the diaphragm is the only activated muscle), and the observed EMG activity is not contaminated with other respiratory muscle activity. However, in patients with labored breathing or on passive mechanical ventilation, inspiratory diaphragmatic breathing may become indistinct, and the location of the EMG needle uncertain. In our experience with this approach, we found it difficult to ascertain the direction and depth of the needle insertion in the absence of distinct inspiratory diaphragmatic activity. Pneumothorax has been reported with the lateral intercostals approach. The anatomical landmarks of diaphragmatic movements may change when the lungs are hyperinflated or in patients on mechanical ventilation.

The substernal approach offers no advantage over the other two methods. Furthermore, there may be additional risks using this approach, since the EMG needle may be close to the internal thoracic vessels running behind the sternum.

PRECAUTIONS IN DIAPHRAGMATIC NEEDLE EMG

Needle EMG of the diaphragm is contraindicated in patients with morbid obesity, agitation, frequent cough or hiccoughs, local infections, or coagulopathy. When using the lower lateral intercostals approach, patients should be monitored for at least 1 hour after the procedure for possible signs of pneumothorax, including chest pain, tachypnea, tachycardia, hypotension, and hypoxemia.

NEEDLE EMG OF INTERCOSTAL MUSCLES

A needle is inserted obliquely between two ribs into the intercostals muscles. The needle should be close to the lower rib to avoid the intercostals neurovascular bundle. Extreme care should be taken not to go deep and puncture the lung, causing a pneumothorax.

TECHNICAL CONSIDERATIONS IN RESPIRATORY NEUROMUSCULAR ASSESSMENT

Most patients requiring respiratory neurophysiologic studies are in the ICU. This is generally a hostile environment for electrodiagnostic medicine consultations. It is advisable to work with an assistant. Electrical interference may be a major problem in the ICU. Adequate skin preparation, maintaining the preamplifier as close as possible to the recording electrode, the use of a 60-cycle filter and the temporary removal of nonessential electrical monitoring devices may help reduce this interference. Occasionally helpful is the grounding of the electrodiagnostic medicine consultant by contact with the patient’s skin. Physiologic factors such as swelling and abnormal skin temperatures should be considered when interpreting results. One should also be aware of preexisting conditions such as diabetes, carpal tunnel syndrome, entrapment neuropathy, focal muscle pathology secondary to local surgical trauma or intramuscular injections, and other metabolic disturbances. Profuse fibrillation and positive sharp waves may be present in the flaccid muscles of hemiplegic and paraplegic patients. In such situation, the
non-hemiplegic muscles should be studied first. In ICU patients, the amplitude of the DCMAP should be interpreted with caution.

**CLINICAL APPLICATIONS OF ELECTRODIAGNOSTIC MEDICINE CONSULTATIONS OF THE NEUROMUSCULAR RESPIRATORY SYSTEM**

Respiratory electrodiagnostic medicine consultations may establish the presence and nature of neuromuscular involvement in ICU patients with critical illness weakness and respiratory failure.

**CRITICAL ILLNESS NEUROPATHY-MYOPATHY,

In the mid eighties, Bolton reported the frequent occurrence of sensorimotor peripheral polyneuropathy in critically ill patients with sepsis and multiple organ failure who also present with weakness and failure to wean from the respirator. The concept of critical illness polyneuropathy (CIP) was initially widely accepted as an explanation for the respiratory failure in these patients. The main clinical presentation was weakness in more than one muscle and in more than one limb. Although, weakness is usually more distal, patients with more proximal weakness have also been described.

The electrodiagnostic medicine features of CIP include:

1) DCMAP profoundly reduced in amplitude or absent.
2) Normal or slightly abnormal motor nerve conduction and distal latencies.
3) No conduction block or temporal dispersion.
4) F waves may be unobtainable.
5) No evidence of neuromuscular junction failure on repetitive stimulation.
6) SNAP reduced in amplitude or absent.
7) The phrenic nerve may show reduced or rarely absent amplitude.
8) Needle EMG shows profuse fibrillation and positive sharp waves in limb muscles and less frequently in the diaphragm.

In the mid 1990s, CIP was challenged as the sole explanation of muscle weakness and respiratory failure in critically ill patients. Critical illness myopathy (CIM) rather than neuropathy was considered to be the leading etiological factor for critical illness weakness. The term “acute quadriplegic myopathy” was often used to describe this condition.

**WHY CRITICAL ILLNESS WEAKNESS IS MYOPATHIC RATHER THAN NEUROPATHIC**

The presence of electrodiagnostic medicine consultation findings of neuropathy may not explain the severe weakness and respiratory failure. Clinically asymptomatic patients with diabetes may show all the above described electrodiagnostic medicine consultation findings of neuropathy with no complaints of muscle weakness or respiratory dysfunction. Muscle biopsies in many critically weak patients show evidence of acute necrotizing or myosin depletion myopathy. Even with a negative biopsy and no elevation of CK, the muscle weakness can be caused by muscle inexcitability due to molecular dysfunction. This can be demonstrated by intramuscular electrical stimulation of muscle showing no or decreased response in myopathies and normal responses in neuropathies. Decreased or absent distal sensory responses could be an associated finding and may not exclude a myopathy.

In more than one study, both neuropathic and myopathic findings in the same weak muscles were reported. The CK levels may be normal or slightly elevated. Patients who have received high doses of corticosteroids or neuromuscular blocking agents (e.g. vecuronium) are at particular risk to develop a myopathic condition.

The electrophysiological findings in CIM may not be much different than what is seen in CIP: mainly, very low DCMAP, normal nerve conduction and F waves, and profuse fibrillation and positive sharp waves on needle EMG. Myopathic findings of short duration potentials and an early recruitment may not be easily detectable. This may occur because of the difficulty of eliciting a sustained muscle contraction in these very sick patients, or simply as a result of loss of muscle excitability due to molecular factors.

The reported management and the prognosis of both neuropathic and myopathic conditions is basically the same i.e. supportive care and treatment of the underlying systemic illnesses. Partial or complete recovery can occur in a few weeks to months.

**OTHER NEUROMUSCULAR RESPIRATORY CONDITIONS**

During open-heart surgery, ice slush may be used to cool the heart and protect the myocardium during period of reduced blood flow. The proximity of the phrenic nerve makes it vulnerable to the effect of cold, with varying degrees of impairment from simple conduction block to axonal damage resulting in
long-term ventilator dependence. Phrenic nerve conduction studies and needle EMG of the diaphragm have proved to be important tools in assessing the extent of the damage to the phrenic nerves and determining long-term prognosis. Non-evoked or prolonged phrenic nerve responses were found in most patients showing clinical and radiological signs of postoperative diaphragmatic weakness or paralysis. The recovery of phrenic nerve conduction paralleled radiologic improvement of diaphragmatic paralysis.

Traumatic injuries to the brachial plexus can be associated with additional injury to the phrenic nerve and may be the cause of respiratory dysfunction.

In Guillian-Barre Syndrome, a primarily demyelinating disease with slow peripheral and phrenic nerve conduction, the additional presence of denervation in the diaphragm was found to be associated with a less favorable prognosis. Other neuromuscular conditions that affect the respiratory system can also be studied, such as cervical spine injuries or disease, amyotrophic lateral sclerosis, various myopathies and neuromuscular junction disorders, and congenital anomalies of the diaphragm.

In electronic pacemakers candidates, electrodiagnostic medicine consultation is the only way to determine the viability of the phrenic nerve before implanting the pacemaker. Phrenic nerve stimulation also helps to calibrate the pacemaker.

Abnormalities of central respiratory drive due to encephalopathy can often be detected by observing patterns of respiration. Phrenic nerve conduction and needle EMG of the diaphragm may be of value in assessing the quality of central respiratory drive.

**SUMMARY**

The cause of respiratory failure includes many neuromuscular etiologies beside diaphragmatic fatigue. Reliable electrodiagnostic medicine consultations can greatly facilitate diagnosis and clinical management. Although a number of electrophysiologic techniques are available to study the respiratory system, many are not clinically useful. The most useful methods include phrenic nerve conduction studies and needle EMG of the diaphragm. The anatomy, methods, and technical considerations of these procedures have been reviewed. Phrenic nerve conduction studies can be performed using various stimulation and recording sites. These studies may show evidence of phrenic nerve dysfunction, such as nonevoked responses and prolonged latencies. The amplitude and duration of the DCMAP are of less diagnostic value. Needle EMG of the diaphragm can be performed by a subcostal, lower lateral intercostal, or substernal approach. We prefer the subcostal approach in most cases for reasons of safety and assurance of proper needle position. The subternal approach seems to offer no advantages and may incur additional risks. EMG signs of diaphragmatic denervation can be identified. The presence of inspiratory EMG activity indicates, in the very least, partial innervation of the diaphragm.

Routine phrenic nerve conduction studies and needle EMG of the diaphragm do not necessarily identify diaphragmatic muscle fatigue.

Electrodiagnostic medicine consultation evidence of neuromuscular respiratory pathology may greatly aid in the diagnosis and management of a number of common conditions, including chronic illness neuropathy and myopathy and surgical or traumatic phrenic nerve impairment.

**References**
