Ultrasonographic Evaluation of Diaphragmatic Motion

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Objective. To evaluate the technical feasibility and utility of ultrasonography in the study of diaphragmatic motion at our institution. Methods. The study consisted of 2 parts. For part I, in 23 volunteers we performed 23 studies on 46 hemidiaphragms with excursions documented on M-mode ultrasonography. For part II, in 22 patients we performed 52 studies in 102 hemidiaphragms. In 50 studies both hemidiaphragms were studied, and in another 2 studies only 1 hemidiaphragm was studied. Patients’ ages ranged from birth to 66 years (mean, 23 years). There were 16 male and 6 female patients. Indications for the study were (1) suggestion of paralysis of the diaphragm (n = 22); (2) if the diaphragm was already known to be paralyzed, for evaluation of response to phrenic nerve or pacer stimulation (n = 9); and (3) follow-up of previous findings (n = 21). Patients were examined in the supine position in the longitudinal semicoronal plane from a subcostal or low intercostal approach. Motion was documented with real-time ultrasonography and measured with M-mode ultrasonography. Results. Of the 102 clinical hemidiaphragms studied, findings included normal motion (n = 42), decreased motion (n = 22), no motion (n = 6), paradoxical motion (n = 10), positive pacer response (n = 13), negative pacer response (n = 2), positive phrenic stimulation (n = 6), and negative phrenic stimulation (n = 1). There were no failures of visualization. Conclusions. Ultrasonography proved feasible and useful in evaluating diaphragmatic motion. In our practice it has replaced fluoroscopy. Ultrasonography has advantages over traditional fluoroscopy, including portability, lack of ionizing radiation, visualization of structures of the thoracic bases and upper abdomen, and the ability to quantify diaphragmatic motion. Key words: diaphragm; diaphragm, ultrasonography; diaphragm, abnormalities.

Many clinical problems result in abnormal motion of the diaphragm. These problems may include intrinsic abnormalities of the diaphragm such as injury from previous trauma or muscular dystrophy. Adjacent thoracic or abdominal processes, such as basal pulmonary atelectasis, pneumonia, or masses, upper abdominal masses, and extensive pleural or abdominal fluid, may also decrease motion of the diaphragm. Central nervous system disease, including brain infarction or tumor, and trauma to the phrenic nerve may impair diaphragmatic motion. A properly functioning diaphragm is necessary for lung aeration and survival. Thus, it is clinically important to know the functional condition of this structure, which is the most important respiratory muscle.

Currently, in many institutions fluoroscopy is used to assess diaphragmatic motion by a number of different...
maneuvers. Fluoroscopy requires patient transportation, which is often difficult, and it uses ionizing radiation. Conversely, ultrasonography is ubiquitous in medical facilities, requires no radiation, and may be used at the patient’s bedside. It would be ideal if sonography could replace fluoroscopy for evaluation of motion of the diaphragm. Our retrospective study was designed to assess the technical feasibility and utility of ultrasonography of the diaphragm at our medical center.

Materials and Methods

Our study used ultrasonography without comparison with other imaging modalities (e.g., fluoroscopy). It consisted of 2 parts.

Part I

The first study group was made up of 23 volunteers, in which both hemidiaphragms were studied with M-mode ultrasonography. Parameters studied and recorded were excursion with quiet breathing, maximum excursion with deep inspiration, and excursion with the sniff test (quick nasal inspiration with a closed mouth). Volunteers were examined with an Acuson 128/XP10 or Sequoia ultrasonography unit (Acuson Corporation, Mountain View, CA) and an HDL 5000 unit (ATL Ultrasound, Bothell, WA) using a 4-MHz vector transducer. Volunteers were examined in the supine position and scanned from a low intercostal or subcostal approach using the liver or spleen as an acoustic window. M-mode tracing of the posterior diaphragm from inspiration to expiration was recorded for each of the 46 hemidiaphragms, with documentation of the distances in centimeters. Volunteers’ ages ranged from 21 to 56 years (mean, 32.8 years). There were 6 male and 17 female volunteers, all of medium build.

Part II

The second portion of the study was a retrospective review from January 1996 to March 2000, during which we examined 22 patients in whom we performed 52 studies examining 102 hemidiaphragms (clinical group). Patients were examined in the supine position with a multifrequency 4-MHz vector transducer in a longitudinal semicoronal plane from a subcostal or low intercostal approach in an area extending from the midaxillary to the midclavicular lines. The equipment and technique were similar to those described for part I. In young pediatric patients, a multifrequency 7-MHz vector transducer was used from the same approach. In addition, a transverse subxyphoid plane permitted simultaneous visualization of both hemidiaphragms in this age group and in slender adults. Patients were examined during spontaneous respiration. In patients who had mechanically assisted ventilation, the ventilator was temporarily disconnected. In 3 cooperative patients, a sniff test was used to potentiate diaphragmatic motion.

Ultrasoundography was assessed at the time of performance of the examinations in both groups for direct visualization of the diaphragm and any associated abnormalities such as atelectasis or pleural effusion, qualitative evaluation of diaphragmatic excursion, and quantitative evaluation of diaphragmatic motion with M-mode ultrasonography (reported for volunteers only because of the wide spread of ages, body habitus, and associated pathologic conditions of the patient group). Studies were recorded on film and were evaluated by 1 independent reader at the time of performance of the studies. In our clinical group, diaphragmatic motion was classified as normal excursion (subjectively), decreased excursion (subjectively), paralysis, or paradoxical motion. Patients undergoing phrenic nerve stimulation were classified as having a positive or negative diaphragmatic response. Similarly, in patients with diaphragmatic pacers, we checked for a positive or negative response. In both cases a positive response was characterized by the M-mode detection of a spikelike deflection after stimulation. In some cases true diaphragmatic motion was obtained. Pacer regulation was done to obtain a maximum diaphragmatic response, beyond which an increase in amperage resulted in a decreased response.

In 20 patients both hemidiaphragms were evaluated, and in 2 patients only 1 side was studied because of a specific request by the referring physician to do so. The number of studies ranged from 1 to 10 per patient. Patients’ ages ranged from 1 day to 66 years (mean, 23 years). There were 16 male and 6 female patients, including 15 adults and 7 children. Indications for the study were (1) suggestion of paralysis of the diaphragm (n = 22); (2) if the diaphragm was already known to be paralyzed, for evaluation of response to phrenic nerve or pacer stimulation and voltage
adjustment (n = 9); and (3) follow-up of previous findings (n = 21). Clinical indications in adults included quadriplegia (n = 3), lung fibrosis with transplant (n = 1), respiratory insufficiency after thoracotomy (n = 1), elevated diaphragm shown on a chest radiograph (n = 1), failure to wean from assisted ventilation (n = 1), evaluation of phrenic nerve pacers (n = 2), and follow-up of previous findings (n = 6). Diagnoses in children included omphalocele (n = 1), diaphragmatic hernia (n = 1), respiratory distress syndrome (n = 1), choanal atresia (n = 1), hypotonic airway with bronchomalacia and myotonic dystrophy (n = 1), Guillain-Barré syndrome with pneumonia (n = 1), and transverse myelitis (n = 1).

**Results**

**Part I**
The diaphragm appeared as a single thick echogenic line. The right hemidiaphragm was seen in its entire excursion in all volunteers, whereas the left hemidiaphragm was obscured by the descending lung in 15 of 23 volunteers when the excursion was greater than 5 cm (Fig. 1). Diaphragmatic excursion in the group of healthy volunteers is listed in Table 1; diaphragmatic excursion by sex is listed in Tables 2 and 3.

**Part II**
One hundred two hemidiaphragm studies were performed and evaluated in our clinical population with the following findings: (1) there were no failures of visualization of either the right or left hemidiaphragm; (2) associated pulmonary abnormalities detected on ultrasonography included atelectasis (n = 3) and pleural effusion (n = 2); and (3) qualitative assessment of diaphragmatic motion included normal motion (n = 42), decreased motion (n = 22), no motion (n = 6; Fig. 2), paradoxical motion (n = 10; Fig. 3), positive phrenic stimulation (n = 6), negative phrenic stimulation (n = 1), positive pacer response (n = 13; Fig. 4), and negative pacer response (n = 2). Three patients underwent the sniff test to potentiate decreased or absent diaphragmatic motion (Fig. 5). Two patients had paradoxical motion indicative of paralysis on the side of concern. The third patient had a minimal response, which was insufficient for interpretation.
Discussion

The diaphragm is a dome-shaped, fibromuscular partition between the thoracic and abdominal cavities. It accounts for 75% of the increase in lung volume during quiet inspiration.

Table 1. Diaphragmatic Excursion in 23 Volunteers

<table>
<thead>
<tr>
<th>Inspiration</th>
<th>Right Hemidiaphragm</th>
<th>Left Hemidiaphragm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Range, cm</td>
<td>Mean, cm</td>
</tr>
<tr>
<td>Quiet</td>
<td>0.26–2.10</td>
<td>1.50</td>
</tr>
<tr>
<td>Deep</td>
<td>1.67–9.20</td>
<td>5.69</td>
</tr>
<tr>
<td>Sniff test</td>
<td>0.48–2.66</td>
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Table 2. Diaphragmatic Excursion in Women (17 Volunteers)

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<th>Inspiration</th>
<th>Right Hemidiaphragm</th>
<th>Left Hemidiaphragm</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Range, cm</td>
<td>Mean, cm</td>
</tr>
<tr>
<td>Quiet</td>
<td>0.26–2.10</td>
<td>1.54</td>
</tr>
<tr>
<td>Deep</td>
<td>1.67–9.20</td>
<td>5.32</td>
</tr>
<tr>
<td>Sniff test</td>
<td>0.48–2.10</td>
<td>1.53</td>
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</tbody>
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Table 3. Diaphragmatic Excursion in Men (6 Volunteers)

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<th>Inspiration</th>
<th>Right Hemidiaphragm</th>
<th>Left Hemidiaphragm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Range, cm</td>
<td>Mean, cm</td>
</tr>
<tr>
<td>Quiet</td>
<td>1.00–1.60</td>
<td>1.39</td>
</tr>
<tr>
<td>Deep</td>
<td>4.70–9.20</td>
<td>6.76</td>
</tr>
<tr>
<td>Sniff test</td>
<td>1.50–2.66</td>
<td>2.03</td>
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The main purpose of imaging of the diaphragm is in the diagnosis of paralysis. The etiology of the paralysis is multiple. Diaphragmatic motion might be affected by disease of the central nervous system, the phrenic nerve as it travels in the neck and chest, the diaphragm itself, secondary to abnormality of conduction of the neuromuscular junction or disease of the diaphragm muscle, and finally, at the paradiaphragmatic level by thoracic or abdominal disease.2 In children, one of the most common causes of phrenic nerve injury is birth trauma.3 Right phrenic nerve paralysis may be a late complication of indwelling central venous catheters.4 Temporary paralysis may be seen in a brachial plexus block for orthopedic surgery of the upper extremity.5

The diaphragm has been imaged by several modalities, most commonly by plain-film radiography and fluoroscopy. It is important to understand the radiographic and fluoroscopic findings in the evaluation of the diaphragm, because interpretation of the ultrasonographic findings is based on them. The diaphragm is usually higher in children, young adults, and obese individuals and in the recumbent position. On fluoroscopy, excursion of the diaphragm with maximum inspiration in healthy, standing patients is usually asymmetrical, with predominance of excursion of the left side more than twice as often. Four fluoroscopic signs have been reported in the diagnosis of paralysis of the diaphragm (Fig. 6): (1) elevation of the paralyzed hemidiaphragm above the normal range during inspiration; (2) decreased, absent, or paradoxical motion during quiet respiration; (3) a contralateral mediastinal shift during inspiration; and (4) paradoxical motion under conditions of increased load such as the sniff test.6

Other imaging modalities such as magnetic resonance imaging have been tested with satisfactory results. One study7 confirmed the fluoroscopically shown fact that the range of motion is greater posteriorly than anteriorly and greater laterally than medially.

Evaluation of diaphragmatic motion by ultrasonography has been reported by different authors.8–11 The first ultrasonographic study that we could find on diaphragmatic motion was published in 1975.12 Of interest in that early study is that a posterior subcostal scan in the prone position was proposed as an alternative to the anterior approach. Nowadays, the posterior approach has largely been abandoned. Currently
the most accepted technique is the anterior subcostal or coronal intercostal approach as used in our study. Visualization of the right hemidiaphragm is made possible by the presence of the liver window. Visualization of the left diaphragm is more difficult because of the smaller window of the spleen. In some cases it can be facilitated by a more coronal approach and by paralleling the ribs. Pathologic conditions such as splenomegaly, hepatomegaly with a large left lobe, and the presence of a left upper quadrant mass make evaluation of the left hemidiaphragm easier. In our patient group we had no cases of nonvisualization of the left hemidiaphragm because of the relatively lower range of excursion compared with the volunteers. Conversely, in our volunteer group the left hemidiaphragm was obscured by the expanding lung when the excursion exceeded 5 cm. This was the case in 65% of the volunteers. The supine position is preferred for the study of diaphragmatic motion because of less variability in observations on 1 side and side-to-side variability and reproducibility.

The sonographic appearance of the diaphragm has been described by some authors as 3 echogenic lines, of which the caudal line represents the diaphragm-liver complex, the middle line represents the lung-visceral pleura complex, and the rostral line results from a mirror image artifact. Other authors have described the diaphragm as 2 echogenic layers (peritoneum and pleura) sandwiching a hypoechoic line (the muscle itself). We did not recognize the reported different layers. In our studies, the diaphragm was seen as a single thick echogenic line. This is similar to what was reported by Zifko et al.

The motion of the right hemidiaphragm has been studied with ultrasonography in healthy individuals. It was shown that ultrasonography correlates well with fluoroscopy in showing that the posterior diaphragm has a greater excursion than the anterior portion. In addition, it was shown that the range of motion increases with body weight (greater in males), and that about 64% of the diaphragm movement has occurred by the time midinspiratory capacity is reached. The relationship between inspired volume and diaphragmatic motion was found to be linear.

The range of diaphragmatic motion from the
resting expiratory position to full inspiration as shown on ultrasonography was 1.9 to 9 cm. Our study of healthy volunteers yielded similar distances. It was difficult to compare results of diaphragmatic excursion in women and men because of the small number of subjects, but we noted some differences. Men had larger excursions. Similar to what has been reported in the literature, both sexes had a larger excursion on the left side than on the right side. Because of the larger excursion, men had obscuration of the left hemidiaphragm during deep inspiration more often (5 of 6) than women (10 of 17).

Some authors have used the ultrasonographically depicted increase in diaphragmatic thickness as an indirect measurement of muscle fiber contraction during inspiration. A chronically paralyzed diaphragm is atrophic and does not thicken during inspiration. On the opposite end, the resting diaphragm thickness is increased in young patients with Duchenne's muscular dystrophy and impaired respiratory muscle force. This finding is analogous to the pseudohypertrophy seen in other limb muscle groups.20

M-mode sonography records the successive positions of a structure versus time, allowing the quantification of diaphragmatic motion—normal or abnormal. The findings described for fluoroscopy also apply to ultrasonography. The rule of thumb described for fluoroscopy in 1966 still applies to ultrasonography; it states that "the unequal movement of the two leaves of the diaphragm is usual, and unlikely to be of significance unless one excursion is at least twice as great as the other."6

On ultrasonography, Cohen et al21 found that 4 of 8 patients with hemiplegia had reduced diaphragm motion during voluntary inspiration on the same side of the body paralysis. This finding was not seen during quiet respiration. In acute cerebral infarction, Houston et al22 found bilaterally decreased volitive diaphragmatic motion. A pitfall found on ultrasonography in patients with large pleural effusions is the presence of paradoxical diaphragmatic motion when the patients are examined in the standing posi-
tion, which would suggest paralysis. This finding has been reported to revert to normal motion in the supine position.\(^2\) We did not have the chance to observe this phenomenon.

In cooperative patients, the sniff test potentiates findings that might not be obvious during normal breathing (Fig. 5). In uncooperative patients, electric phrenic nerve stimulation under direct sonographic visualization of the diaphragm for response evaluation is used. In cases of diaphragmatic paralysis, this method is useful for separating central nervous system disease from lower motor neuron disease (phrenic nerve). In the first case, phrenic nerve stimulation will result in diaphragmatic motion, whereas in the second case it will not. It is also useful for differentiating a partially diminished diaphragmatic response (neuropathia) from a completely absent response (paralysis).\(^2\)

Several of our patients had implanted diaphragmatic pacemakers. Pacemakers allow patients to become independent from mechanically assisted ventilation. These systems consist of an electrode implanted in the phrenic nerve, a subcutaneous receiver, and an external transmitter. The output of the pacemaker needs to be regulated depending on the degree of diaphragmatic response. The optimal response varies with patient characteristics such as age and body habitus. Under those circumstances, we have observed that ultrasonography is excellent for providing a quantitative evaluation of diaphragmatic excursion.

In addition to its use in the study of diaphragmatic motion, ultrasonography is also useful in the evaluation of adjacent disease that might affect the diaphragm, including diaphragmatic eventration and hernias, free and loculated pleural fluid, subphrenic abscess, hepatic abscess, metastatic disease, hydatid cyst, and amoebic abscess,\(^2\)\(^4\) thoracic masses (pleural angiomyoliposarcoma, mesothelioma, metastatic adenocarcinoma, metastatic osteogenic sarcoma, malignant synovioma, and Wilms' tumor),\(^2\)\(^5\) and rupture of the diaphragm.\(^2\)\(^6\) Many if not most of these abnormalities will not be detected on fluoroscopy.

A comparison study of ultrasonography and fluoroscopy in the assessment of diaphragmatic motion was conducted.\(^2\)\(^7\) This study was important for validation of ultrasonography against fluoroscopy, the standard of reference.

The authors found no technical failure with ultrasonography; agreement in findings between both modalities was achieved in 81% of the patients; and ultrasonography showed all abnormalities seen on fluoroscopy. Ultrasonography was more sensitive to motion than fluoroscopy. In our experience we had no technical failures, and we have been helpful to our consulting colleagues with their difficult-to-image patients.

In summary, ultrasonography in the evaluation of motion of the diaphragm is an accurate technique that, in our experience, has had no technical failures and is relatively easy to master. The modality is portable, which is very important for many seriously ill patients receiving mechanical ventilation, and uses no ionizing radiation. In agreement with other authors, we think that ultrasonography should be the modality of choice in the examination of motion of the diaphragm.

References