EDITORIAL REVIEW

Interpretation of thoracoabdominal movements during breathing

M. D. GOLDMAN

Department of Medicine, Case Western Reserve University, Cleveland, Ohio, U.S.A.

Introduction

Movements of the thorax and abdomen during respiration are of interest from two points of view. First, such movements can be measured and provide a quantitative assessment of pulmonary ventilation. Secondly, thoracic and abdominal motions offer insight into the actions of the respiratory muscles.

Mead and co-workers [1-3] demonstrated a practical means of recording and calibrating thoracic and abdominal movements in normal subjects, using magnetometers to measure their anteroposterior diameter changes. More recently detailed analysis has been made [4] of lateral diameter changes of the thorax and abdomen as well. When these diameter changes are combined with measurements of intragastric and intraoesophageal pressure changes during breathing, activity and co-ordination of the different respiratory muscles can be inferred [5]. Even without pressure measurements, however, considerable use may be made of careful assessment of thoracoabdominal diameter changes in patients with chronic respiratory [6, 7] and neuromuscular disease [8]. The following examples illustrate the normal motions of the rib cage and abdomen and some of the common clinical conditions in which altered thoracoabdominal movements are prominent features.

Normal adults

In the upright posture both thorax and abdomen move outward during inspiration and return inward to the resting position during expiration, as shown in Fig. 1(a). These movements are produced largely by the action of the diaphragm and parasternal intercostals during inspiration. The diaphragm moves the abdominal wall outward by means of increasing intra-abdominal pressure. The diaphragm and parasternal intercostals act directly on the rib cage. In the supine posture the movement of the abdominal wall is relatively more prominent and that of the rib cage relatively less so.

Increased upper airway resistance

With substantial increases in upper airway resistance (e.g. large airway obstruction or small endotracheal tubes) more respiratory muscle effort is needed to overcome flow-resistant forces during breathing. As a result, oscillations of pleural pressure may be much larger than normal and the anterior wall of the more mobile portion (the lower half) of the rib cage may move inward during all or part of the inspiratory phase (and outward during all or part of expiration), while lateral expansion of the rib cage is enhanced during inspiration, as shown in Fig. 1(b). This distortion of the lower rib cage occurs because the major bulk of the inspiratory thoracic musculature (external intercostals and serrati) inset on to the ribs posterolaterally; thus their vigorous contraction directly expands the rib cage laterally, while the anterior rib cage wall moves inward because its local muscle activity is unable to resist the highly negative intrapleural pressure. The abdomen, driven by strong efforts of the diaphragm, moves normally; as a consequence, movements of the anterior rib cage are paradoxical relative to those of the abdomen (and to airflow). These paradoxical rib cage movements are more prominent in the supine position.
Fig. 1. Schematic representation of thoracoabdominal displacements during a single tidal breath, from the beginning of inspiration (in.) to the end of expiration (ex.). Anteroposterior (Ant-post) and lateral diameter changes (outward movement being indicated by the upward arrow) are shown for the rib cage and abdomen in (a) normal subjects, (b) patients with upper airway obstruction, (c) patients with increases of resistance in smaller (peripheral) airways, (d) more severe peripheral airflow obstruction and (e) diaphragm paresis. See the text for details.

Airflow obstruction with hyperinflation

In patients with low flattened diaphragms movements of the anterior thoracic wall may be relatively normal, but lateral motions may be distorted. Most commonly abdominal wall motion is normal, but the lateral thoracic walls move inward during all or part of the inspiration, as illustrated in Fig. 1(c). In such patients contraction of the flattened diaphragm pulls directly inward on the lower lateral rib cage during inspiration. However, inspiratory changes in negative intrapleural pressure are much less than those occurring with increased upper (i.e. central or extrathoracic) airways resistance because total peripheral airways resistance is small relative to that of the upper airway, and as a result, parasternal intercostal activity is sufficient to produce outward movement of the sternum.

In some severely ill patients Ashutosh et al. [6] described asynchronous breathing movements which they ascribed to accentuated elevation of the thoracic cage in patients with low flat ineffective diaphragms. Movements of the anterior abdominal walls in these patients were not in synchrony with rib cage movements or airflow. Of particular interest is the marked inward movement of the anterior abdominal wall during early inspiration, as illustrated in Fig. 1(d). We have documented similar changes in the abdominal shape in other patients with severe chronic airflow obstruction. Patients with this pattern of breathing tend to be gravely ill. In our patients this pattern of abdominal movements was associated with obvious contraction of abdominal muscles laterally during expiration, which dominates the diaphragmatic effects seen in Fig. 1(c).

We suggest the following interpretation. In the supine posture gravity acts downward on the abdominal contents so that the anterior abdominal wall is usually flaccid, while the posterolateral aspects of the abdominal wall are distended
by the weight of the abdominal contents. When the oblique muscles contract in expiration, they decrease the lateral abdominal diameter (and the lateral diameter of the lower rib cage, into which they insert). In the presence of a hyperinflated thorax these motions are exaggerated; in addition, the anterior abdominal musculature is suspended between the elevated thorax and the pelvis. As the oblique muscles contract, they increase intra-abdominal pressure, thereby resulting in a passive outward movement of the suspended anterior abdominal wall. Conversely, relaxation of the oblique muscles during inspiration results in an increase in lateral abdominal and lower rib cage diameters, decrease in intra-abdominal pressure and passive inward movement of the anterior abdominal wall. Thus the lateral abdominal movements are in phase with both airflow and rib cage movements, but movements of the anterior abdominal wall are paradoxical. If the contraction of the diaphragm is sufficiently effective, the anterior abdominal wall may move outward (and the lateral rib cage walls inward) during the mid or later portion of inspiration, resulting in a biphasic series of movements during breathing similar to that reported by Ashutosh et al. [6]. This interpretation differs from that of previous authors [7] in placing relatively greater emphasis on lateral diameter changes in rib cage and abdomen and the associated changes in thoracic and/or abdominal shape seen in patients with severe chronic airflow obstruction.

Neuromuscular disease

Striking differences in patterns of thoracoabdominal motion may be observed depending on which muscle groups are most severely affected. When extradiaphragmatic musculature is most involved, it is common to find paradoxical inward motion of the rib cage during inspiration, similar to that observed in patients with high airflow resistance, as shown in Fig. 1(b). In patients with weakened or paralysed thoracic musculature the paradoxical rib cage movement results from the loss of intercostal tone, which appears necessary for rib cage stability. Mortola & Sant'Ambrogio [9] have reported a detailed description of the thoracic instability present in tetraplegic humans relying solely on the diaphragm. When the diaphragm is most severely affected, it is the abdomen which moves paradoxically inward during inspiration, as shown in Fig. 1(e). This finding is especially prominent in the supine posture, but may be completely obscured in the upright posture if the patient uses the abdominal muscles significantly during expiration. In contrast to patients with severe chronic pulmonary disease, in whom paradoxical inward movement of only the anterior abdominal wall occurs (while the lateral abdominal walls move normally), patients with paresis or paralysis of the diaphragm exhibit more uniform inward abdominal motion without the striking abdominal shape change shown in Fig. 1(d). These patterns of thoracoabdominal movements in patients with diaphragm paralysis are discussed in two reports [8, 10].

The foregoing descriptions and the distinctions drawn between active and passive movements of thorax and abdomen are based on simultaneous measurements of abdominal and thoracic movements and abdominal (intragastric) and intra-thoracic (oesophageal) pressure changes during breathing. In addition, measurements of respiratory muscle electromyographic activity are clearly pertinent as well [11, 12]. However, the ease of making surface electromyographic measurements is largely offset by the imprecision of such tracings in defining the activity of specific muscles, a number of which often underlie the electrodes. It must be emphasized that careful clinical observation of thoracoabdominal movements during breathing alone will yield useful qualitative assessment of respiratory muscle functions. The use of mechanical or electronic devices to record respiratory movements and pressure changes add a quantitative dimension. Here, the collaboration between the clinical scientist and the physiologist is especially important if we are to achieve useful insights into the pathophysiological processes leading to advanced pulmonary disease. Another area of investigation where such collaboration has been fruitful is represented by the report of Amis et al. [13]. This study describes an important functional implication of respiratory muscle contraction, namely the analysis of ventilation–perfusion relationships in the lung and their relationship to the pattern of respiratory muscle behaviour.

Relation between movements and tidal volume

Thoracoabdominal displacements also provide a convenient and useful means of measuring pulmonary ventilation, which is unobtrusive and permits the patient to remain undisturbed by the presence of instrumentation in the airway. It is of particular value in studying patients during sleep. When our objective is to measure pulmonary ventilation, we are in effect integrating all the complexities of thoracoabdominal motion into a single summary variable, namely overall long volume change. With this perspective in mind, we
might choose empirically any method that allows satisfactory accuracy under the conditions of normal use. In many circumstances a simple measurement of thoracic displacements will suffice. However, if the relative thoracic and abdominal displacements are variable from breath to breath, it is desirable to use a method which incorporates measurements of both their separate motions.

In the analysis of thoracoabdominal motion extensive use was made of measurements of anteroposterior and lateral thoracoabdominal diameters. Alternative techniques involve mercury-in-rubber strain gauges or induction coils stretched around the rib cage and abdomen, which measure dimensions more nearly akin to circumference or cross-sectional area. Both of the latter techniques sacrifice details of thoracic and abdominal shape change for the sake of providing a single signal for each (rib cage and abdomen) which may be related to volume change. The approach outlined by Konno & Mead [1] may be used to calibrate the rib cage and abdominal signals derived from all of the above measurement techniques in terms of lung volume change. However, a computer-assisted calibration procedure developed by Stagg et al. [14] is much simpler for patients because calibration is performed during spontaneous breathing.

An essential feature common to all these approaches and measurement techniques is the implicit (or explicit) assumption that the recorded signal (for rib cage as well as abdomen) is representative of the volume change being estimated (usually in a linear fashion). In general, this will be the case when the shape of the element does not change. Thus, during normal breathing, the size of the thorax and abdomen change, but not their shape, since different dimensions change in a similar fashion. However, if anteroposterior diameter decreases but lateral thoracic diameter increases sufficiently (i.e. thoracic shape becomes more elliptical rather than circular), then overall thoracic volume displacement might differ from that inferred from a single dimensional change. In theory, such discrepancies are less likely to occur when using both lateral as well as anteroposterior diameters or cross-sectional area measurements.

In practice, in normal subjects rib-cage and abdominal shape change do not appear to limit the precision of estimates of pulmonary ventilation based on measurements of anteroposterior diameter changes during spontaneous breathing at rest or during exercise or chemically induced hyperpnoea even at ventilations exceeding 100 litres/min [1, 3, 5]. Under these conditions, thoracic and abdominal shape remain relatively uniform during breathing: anteroposterior and lateral diameters of both compartments change in unison. In the patients with hyperinflated thoraces it is clear that measurements of anteroposterior diameter changes of rib cage and abdomen might be misleading as indices of volume displacement because of the thoracic and abdominal shape changes which occur, as shown in Fig. 1. And, in fact, most reported studies of patients with chronic airflow obstruction have been limited to qualitative descriptions of thoracoabdominal movements rather than quantitative assessment of pulmonary ventilation [7]. Comparisons of different measurement techniques in the same subjects have yet to appear in the literature. Investigators using circumferential cross-sectional area or anteroposterior diameter measurements appear to obtain similar accuracy whether studying normal subjects or patients. Most tidal volume measurements during resting breathing are within 5–15% of simultaneously measured lung volume changes with a spirometer or pneumotachograph.

An additional constraint in the assessment of pulmonary ventilation from thoracoabdominal movements is the requirement that such movements, which by definition measure changes in trunk (i.e. thoracoabdominal) volume, reflect equal changes in lung volume. This is normally the case during quiet breathing at rest. However, if changes in thoracoabdominal blood volume occur during breathing, then abdominal and rib cage volume displacements will reflect the sum of any such blood volume changes plus lung gas volume change.

There are no reported measurements of vascular shifts in conjunction with measurements of thoracoabdominal volume displacements. Such measurements are currently under way in our own laboratory. Although patients with cardiopulmonary disease represent the major clinical challenge, we believe that studies in infants will be particularly useful from this point of view. The notion that respiratory implications of cardiovascular events are likely to be more significant in infants than adults is based on the presumption that the stroke volume/tidal ratio is probably much larger in infants. This may be developed along the following lines of reasoning: first, the chest roentgenogram of the infant reveals a cardiac shadow which occupies the majority of the thoracic volume, whereas the heart size is relatively much smaller in adults. Secondly, if we assume that the overall ventilation–perfusion relationships for the lung are roughly similar in infants and adults, then the relative stroke...
Thoracoabdominal movements

volume/tidal ratio would be proportional to the relative respiratory frequency/heart rate ratio. The latter is about twice as large in infants as adults. Thus the potential for important mechanical consequences of vascular shift in infants appears significant. We have observed significant discrepancies between thoracoabdominal volume displacements and simultaneous lung volume changes in infants (of the order of half to three-quarters of the size of the tidal volume) and we suspect that these volume discrepancies are related to vascular shifts.

Conclusions

It would appear that pulmonary ventilation can be measured with adequate accuracy from the combination of one abdominal and one thoracic dimension in normal subjects and most patients. In adults with substantial thoracic deformity, associated with orthopaedic or neuromuscular disease or advanced chronic pulmonary disease, measurements of more dimensions may be needed to accommodate the volume displacements associated with abdominal or thoracic shape changes and to elucidate the action and co-ordination of different respiratory muscles. In addition, the problem of vascular and other fluid redistribution remains to be evaluated, especially in infants. The rigorous application of these physiological assessment techniques to the study of patients with a wide spectrum of disease, subclinical as well as advanced, is demanding work. Patient co-operation is necessary and, invariably, patient education. The physiologist is limited to reasoned guesses and, by himself, cannot test many useful hypotheses. The role of the clinical scientist is a vital one and many significant contributions remain to be made.

References