Eur Resp J
1988, 1 495–497

EDITORIAL

Clinical significance of abnormal rib cage-abdominal motion

J.W. Fitting*

Our understanding of respiratory movements of the rib cage and abdomen has gained depth from a number of recent studies on chest wall mechanics, enabled by the development of methods of measurement. This article evaluates how abnormal rib cage-abdominal motion can be interpreted by the clinician in the light of the present knowledge.

Measurement principles

A major conceptual breakthrough occurred in 1967 when KONNO and MEAD proposed that, under the condition of a fixed spinal position, the chest wall can be considered as a system with two degrees of freedom [1]. They stated that any change in lung volume is accommodated by the sum of the changes in dimensions of the rib cage and of the anterior abdominal wall. When the airways are closed, the chest wall becomes a system with a single degree of freedom, so that changes in dimensions of the rib cage and abdominal wall are equal and opposite in direction.

Rib cage and abdominal motion can be measured by two methods. As originally described, magnetometry can be used to measure the anteroposterior diameter of the rib cage and abdomen. Respiratory inductance plethysmography is now more widely used to measure the changes in cross-sectional area of the rib cage and abdomen [2]. The signals of either method are usually displayed on an X-Y plot, with the rib cage dimension on the ordinate and the abdominal dimension on the abscissa, as in the Konno-Mead diagram. In reality, it has been shown that the chest wall, in particular the rib cage, possesses a greater degree of freedom [3, 4]. Nevertheless, the model of two degrees of freedom has allowed deeper insight into chest wall mechanics and is a practical tool for clinical interpretation of respiratory movements.

Action of respiratory muscles

The respiratory muscles can be subdivided into three groups, the actions of which can be inferred to a certain extent from chest wall motion: the rib cage inspiratory muscles (parasternal intercostals, scalenes, sternocleidomastoids), the diaphragm, and the abdominal muscles. Some of the effects produced by their contraction are easily understood. Globally, the action of the rib cage inspiratory muscles is to lift and expand the rib cage. The action of the abdominal muscles is to reduce the dimensions of the abdomen and of the lower part of the rib cage to which they are attached.

The relationship between diaphragmatic contraction and rib cage-abdominal motion is far more complex. This is due to the fact that the upper part of the abdomen is located within the rib cage. In this region, the diaphragmatic fibres are arranged longitudinally and are apposed to the lower rib cage, hence the name of "area of apposition" of the diaphragm [5]. Therefore, the abdominal cavity is limited by three mobile structures: the dome of the diaphragm, the area of apposition of the diaphragm to the lower rib cage, and the anterolateral abdominal wall. One action of the diaphragm, pushing upon the poorly compressible abdominal contents, is to increase abdominal pressure and to expand the anterolateral abdominal wall. By the same action, however, the diaphragm also expands the lower part of the rib cage, the increment in abdominal pressure being transmitted through the area of apposition. In addition, the diaphragm expands the lower rib cage by pulling directly on its costal insertions.

When the diaphragm contracts, its dome moves caudally, causing an inward displacement of one part of the abdominal container. This is accommodated by an outward displacement of the other two mobile structures, the lower rib cage and the anterolateral abdominal wall, in proportions which vary according to the compliance of each of these structures. It follows that the movements of the diaphragm cannot be assessed accurately from those of the abdominal wall alone. An inspiration with considerable shortening of the diaphragm can be performed without change in abdominal dimension. Furthermore, an isometric contraction of the diaphragm is associated with an inward displacement of the abdominal wall [6, 7]. This complex relationship does not permit simple interpretation of rib cage-abdominal motion and must be considered by the clinician when observing the respiratory movements of his or her patient.

*Division de Pneumologie, Département de Médecine Interne, CHUV, CH-1011 Lausanne, Switzerland.

Abnormal motion patterns

Nevertheless, the normal pattern of rib cage and abdominal motion during breathing is well established and any alteration of this pattern can be qualitatively interpreted. Normally, both compartments expand during inspiration in quiet breathing. The simplest abnormal pattern is represented by a constant paradoxical movement of one compartment. Thus, a paradox of the upper part of the rib cage (inward displacement during inspiration) is the consequence of severe weakness or paralysis of the rib cage inspiratory muscles. It is observed in quadriplegic patients breathing with the diaphragm, either spontaneously or with phrenic pacing [8, 9]. Conversely, a constant abdominal paradox is observed in severe weakness or paralysis of the diaphragm. In case of paralysis, it is produced by a paradoxical movement of the diaphragm which is stretched by the fall in pleural pressure. Otherwise, an abdominal paradox may manifest a weak diaphragmatic con-traction, which is not necessarily associated with diaphragmatic elongation. The abdominal paradox should be looked for in the supine position, since abdominal muscles are often recruited during expiration in the upright position and may therefore mask the paradox. A less pronounced abnormality is manifested by a departure from the normal partition between rib cage and abdominal motion, without paradox.

In the seated position compared to supine the activity of rib cage inspiratory muscles is higher [10], the compliance of the rib cage is higher, and the compliance of the abdomen is lower [11]. As a consequence, rib cage expansion predominates during quiet breathing in the seated position and abdominal expansion predominates in the supine position. The partition between rib cage (RC) and abdominal (AB) motion can be quantified by magnetometry or respiratory inductance plethysmography and is usually expressed by the index,

$$RC/V_T=RC/(RC+AB) \quad \text{where } V_T=\text{tidal volume}$$

Normally, the rib cage represents approximately 70% of total chest wall expansion in the seated position and 25% in the supine position, for both sexes [12].

Diaphragmatic shortening cannot be quantitatively assessed from abdominal motion, but a smaller than normal abdominal movement (increased RC/V_T) implies some degree of diaphragmatic dysfunction and/or increased recruitment of rib cage muscles. This is exemplified by patients with chronic obstructive pulmonary disease (COPD) who may show a predominant motion of the rib cage in the supine position [2, 13]. They manifest a dysfunction of the diaphragm, which is shortened and flattened by hyperinflation. Roughly, the more the rib cage predominates, the less efficient is the diaphragm. Note that, in this case, the rib cage is affected differently by the failing diaphragm and by the extra recruitment of rib cage muscles. As the diaphragm generates less abdominal pressure and as the area of apposition of the diaphragm is decreased by hyperinflation, less expanding force is applied to the lower rib cage. Moreover, the flattening of the diaphragm reduces the expanding force exerted by its costal insertions and may even provoke an inward movement of the lower lateral rib cage (Hoover's sign). On the other hand, the rib cage inspiratory muscles lift and expand the upper rib cage.

The contribution of rib cage and abdomen to tidal volume varies little in normal subjects breathing quietly. This variability in compartmental contribution to tidal volume can be expressed by the standard deviation of RC/V_T when motion is quantified [14]. Under some circumstances, the contribution of rib cage and abdomen may change markedly from breath to breath. Thus, clear rib cage predominance may alternate with clear abdominal predominance, the extreme pattern being the onset of transient paradox of one or the other compartment. This pattern has been observed in normal subjects breathing against high loads, during protocols inducing inspiratory muscle fatigue: whilst the target mouth pressure was well maintained, wide variations in gastric pressure developed, as well as in rib cage and abdominal movements [15]. These subjects showed two abnormalities: a transient abdominal paradox, and a cyclic alternation of breaths with predominant rib cage or abdominal motion which was termed "respiratory alternans". Similar abnormal patterns were observed in a series of patients undergoing a weaning trial from mechanical ventilation. Abdominal paradox and respiratory alternans, as judged by inspection and palpation, developed in the patients with unsuccessful trials. Such patients showed signs of respiratory muscle fatigue, manifested by a fall in the high/low ratio of diaphragmatic EMG [16]. It has been proposed that respiratory alternans may be a strategy to cope with respiratory muscle fatigue, allowing the diaphragm and the rib cage muscles to recover partially in alternation [15].

Such a concept implies that fatigue can develop separately in different respiratory muscles. This has recently been proven in normal subjects breathing ag-ainst high loads with different ribcage-abdominal patterns: EMG signs of fatigue appeared in the diaphragm, or in the parasternal intercostals and sternocleidomastoids, according to the pattern of recruitment of these muscles [17]. However, two other recent studies, in which abnormal rib cage and abdominal motion were quantified with several indices, suggest that respiratory alternans and paradoxical motion may not necessarily be related to fatigue [14, 18]. In normal subjects breathing against inspiratory resistances, an abdominal paradox and an increased variability in compartmental contribution to V_T was present with high (fatiguing) loads, but also to a lesser degree with low (nonfatiguing) loads. The abnormal pattern appeared early and did not worsen with time during the fatiguing runs. The authors conclude that abnormal rib cage and abdominal motion is related to the load and not to respiratory muscle fatigue [14]. In patients undergoing a weaning trial from mechanical ventilation, paradoxical motion and variability in compartmental contribution were higher in the unsuccessful trials.

Abnormal motion was also present in successful trials and considerable overlap existed between the two groups for several indices [18]. These two studies indicate that respiratory alternans and abdominal paradox can occur in the absence of respiratory muscle fatigue. If respiratory alternans represents a strategy to cope with high loads unrelated to fatigue, its underlying stimulus remains to be found. Dyspnoea may be relieved by varying the contribution of chest wall compartments to tidal volume. However, this hypothesis appears unlikely since in normal subjects breathing against external loads, the sensation of inspiratory effort is similar whether rib cage or abdominal motion predominates [19].

The question of whether the source of respiratory alternans and abdominal paradox is fatigue itself, or the high load likely to induce fatigue, is of little practical importance. The fact that this abnormal pattern can occur in conditions which do not lead to fatigue is of greater concern. Respiratory alternans and abdominal paradox may, when moderate, reflect an increased load, and when more severe herald respiratory muscle fatigue. Distinguishing between the benign and the dangerous abnormal pattern represents a difficult task for the clinician.

References

1. Konno K, Mead J. – Measurement of the separate volume changes of rib cage and abdomen during breathing. *J Appl Physiol*, 1967, 22, 407–422.

2. Sackner MA, Gonzales H, Rodriguez M, Belsito A, Sackner DR, Grenvik S. – Assessment of asynchronous and paradoxical motion between rib cage and abdomen in normal subjects and in patients with chronic obstructive pulmonary disease. *Am Rev Respir Dis*, 1984, 130, 588–593.

3. Ringel ER, Loring SH, Mead J, Ingram RH. – Chest wall distortion during resistive inspiratory loading. *J Appl Physiol: Respirat Environ Exercise Physiol*, 1985, 58, 1646–1653.

4. Sampson MG, De Troyer A. – Role of intercostal muscles in the rib cage distortions produced by inspiratory loads. *J Appl Physiol: Respirat Environ Exercise Physiol*, 1982, 52, 517–523.

5. Mead J, Loring SH. – Analysis of volume displacement and length changes of the diaphragm during breathing. *J Appl Physiol: Respirat Environ Exercise Physiol*, 1982, 53, 750–755.

6. Grassino A, Goldman MD, Mead J, Sears TA. – Mechanics of the human diaphragm during voluntary contractions: statics. *J Appl Physiol: Respirat Environ Exercise Physiol*, 1978, 44, 829–839.

7. Loring SH, Mead J, Griscom NT. – Dependence of diaphragmatic length on lung volume and thoracoabdominal configuration. *J Appl Physiol*, 1985, 59, 1961–1970.

8. Danon J, Druz WS, Goldberg NB, Sharp JT. – Function of the isolated paced diaphragm and the cervical accessory muscles in C1 quadriplegics. *Am Rev Respir Dis*, 1979, 119, 909–919.

9. Mortola JP, Sant'Ambrogio G. – Motion of the rib cage and the abdomen in tetraplegic patients. *Clin Sci*, 1978, 54, 25–32.

10. Druz WS, Sharp JT. – Activity of respiratory muscles in upright and recumbent humans. *J Appl Physiol: Respirat Environ Exercise Physiol*, 1981, 51, 1552–1561.

11. Estenne M, Yernault JC, De Troyer A. – Rib cage and diaphragm-abdomen compliance in humans: effects of age and posture. *J Appl Physiol*, 1985, 59, 1842–1848.

12. Sharp JT, Goldberg NB, Druz WS, Danon J. – Relative contributions of rib cage and abdomen to breathing in normal subjects. *J Appl Physiol*, 1975, 39, 608–618.

13. Sharp JT, Goldberg NB, Druz WS, Fishman HC, Danon J. – Thoracoabdominal motion in chronic obstructive pulmonary disease. *Am Rev Respir Dis*, 1977, 115, 47–56.

14. Tobin MJ, Perez W, Guenther SM, Lodato RF, Dantzker DR. – Does rib cage-abdominal paradox signify respiratory muscle fatigue? *J Appl Physiol*, 1987, 63, 851–860.

15. Roussos C, Fixley M, Gross D, Macklem PT. – Fatigue of inspiratory muscles and their synergic behaviour. *J Appl Physiol*, 1979, 46, 897–904.

16. Cohen CA, Zagelbaum G, Gross D, Roussos Ch, Macklem PT. – Clinical manifestations of inspiratory muscle fatigue. *Am J Med*, 1982, 73, 308–316.

17. Fitting JW, Bradley TD, Easton PA, Lincoln MJ, Goldman MD, Grassino A. – Dissociation between diaphragmatic and rib cage muscle fatigue. *J Appl Physiol*, 1988, 64, 959–965.

18. Tobin MJ, Guenther SM, Perez W, Lodato RF, Jeffery Mador M, Allen SJ, Dantzker DR. – Konno-Mead analysis of rib cage-abdominal motion during successful and unsuccessful trials of weaning from mechanical ventilation. *Am Rev Respir Dis*, 1987, 135, 1320–1328.

19. Fitting JW, Chartrand DA, Bradley TD, Killian KJ, Grassino A. – Effect of thoracoabdominal breathing patterns