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Review Article:

The Expiratory Muscles in Tetraplegia

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All the well-recognised muscles of expiration, such as the muscles of the anterolateral wall of the abdomen, the expiratory intercostals, and the triangularis sterni, have a motor innervation that depends on segments situated in the thoracic or lumbar cord.[1–3] Consequently, subjects with tetraplegia caused by transection of the cervical cord have severely compromised expiratory muscle function. Cough in these subjects is markedly impaired, and the clearance of bronchial secretions is defective. As a result, retention of secretions leading to atelectasis and bronchopulmonary infections is a frequent occurrence.

Expiratory muscle function, in fact, has traditionally been perceived as being totally lost in tetraplegia. Hence, cough would be a passive process resulting only from the elastic recoil properties of the respiratory system.[4] Expiratory muscle function is totally lost indeed in subjects with transection of the upper cervical cord (Cl–C4). However, a number of spirographic studies have established that most C5–C8 tetraplegic subjects generate a small expiratory reserve volume.[5–10] Thus, although all the well-known muscles of expiration are paralysed, most tetraplegic subjects are still able to activate some muscles that can overcome the elastic resistance to deflation of the chest wall and cause emptying of the lungs. If these muscles could be identified, one could train them for strength and perhaps improve the effectiveness of cough so as to reduce the number of bronchopulmonary infections.

In order to identify these muscles, we firstly examined the pattern of chest wall motion during voluntary expiration from functional residual capacity (FRC) in a group of C5–C7 tetraplegic subjects.[11] Three pairs of linearised magnetometers were used to measure the changes in abdominal and rib cage diameters. The changes in abdominal dimensions during expiration were negligible; this was anticipated since the abdominal muscles in such subjects are paralysed. However, all subjects when expiring had a marked reduction in the anteroposterior diameter of the upper portion of the rib cage (manubrium sterni). On the basis of this finding, we thus speculated that the clavicular portion of the pectoralis major might play an important role. Indeed, this muscle bundle has a motor innervation that depends

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on nerve fibers originating in the fifth, sixth, and seventh cervical segments.[12] It may thus remain active, at least in part, in subjects who have suffered accidental transection of the lower cervical cord. Furthermore, the clavicular portion of the pectoralis major runs medially and cranially from the humerus to the medial half of the clavicle (Fig. 1). Therefore, if the arms are fixed, contraction of these fibers on both sides of the chest may pull down the manubrium sterni. Hence, the upper part of the rib cage (which is closely attached to the sternum) may move caudally as well and contract, and lung volume may be lowered.

The role played by the clavicular portion of the pectoralis major in C5–C8 tetraplegic subjects has then been tested directly in two ways.[11] Firstly, we have measured the electromyogram of this muscle bundle, and indeed large amounts of electrical activity were recorded. As shown in Figure 2, activity started as soon as the subjects began to expire from FRC, increased progressively in magnitude as expiration proceeded, and ceased in a relatively abrupt manner at the onset of the subsequent inspiration. This pattern of activity is exactly the one that would be expected if the clavicular fibers of the pectoralis major were truly responsible for the expiratory contraction of the upper rib cage. Secondly, we have positioned the subjects' shoulders in abduction to alter the orientation of these clavicular fibers and make them unable to pull down the manubrium sterni. Maintaining the shoulders in abduction produced consistently a considerable reduction in expiratory reserve volume.[11] Thus, in tetraplegic subjects, the clavicular portion of the pectoralis major is really the primary determinant of expiration.

We have subsequently tested the hypothesis that the clavicular portion of the pectoralis major is involved also in the act of coughing.[13] Figure 3 shows typical records obtained during a single cough initiated at FRC in two C6 tetraplegic subjects. Expiration and coughing was observed to elicit a large amount of electrical

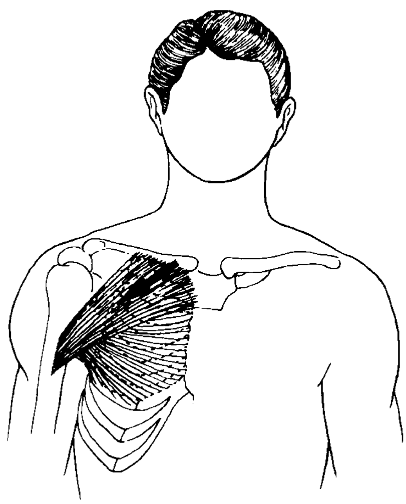

Figure 1 Diagram illustrating the expiratory action of the clavicular portion of the pectoralis major. The muscle fibers run caudally and laterally from the medial half of the clavicle to the humerus. Consequently, if the arms are fixed, contraction of these fibers on both sides of the chest displaces the clavicles and the manubrium sterni in the caudal direction. As a result, the upper part of the rib cage moves caudally as well and contracts (Reprinted, by the permission of the American Review of Respiratory Disease 139:1218–1222, 1989).

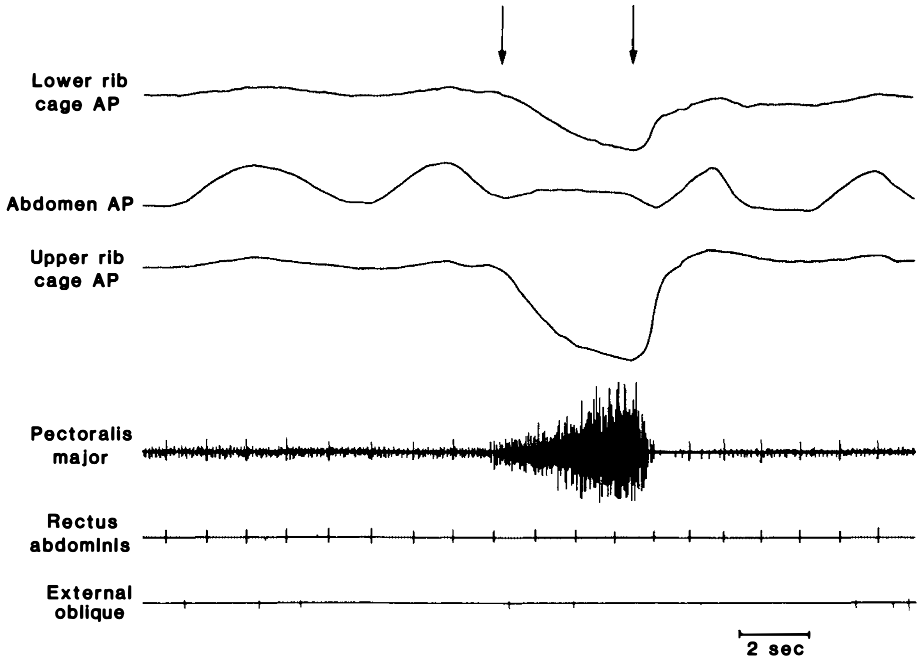

Figure 2 Pattern of respiratory muscle use during slow expiration from functional residual capacity in a C6 tetraplegic subject. The changes in anteroposterior (AP) diameter of the abdomen, lower rib cage, and upper rib cage are shown (increase upwards). Arrows mark the onset and the end of the expiratory effort. Note that expiration elicits a large amount of EMG activity in the clavicular portion of the pectoralis major and causes a clear-cut decrease in the AP diameter of the upper rib cage. The abdominal muscles show no activity, and the abdomen AP diameter in this subject increases slightly (Reprinted, by permission of the New England Journal of Medicine 314:740–744, 1986).

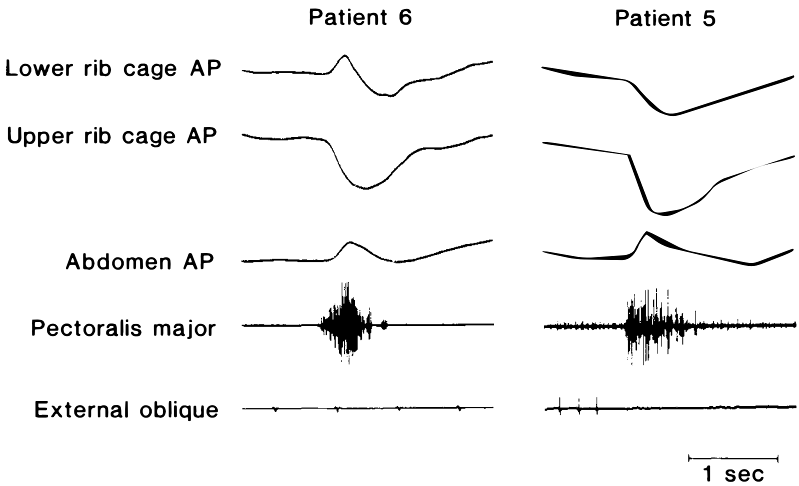

Figure 3 Pattern of respiratory muscle use and chest wall motion during a coughing effort initiated at functional residual capacity in two C6 tetraplegic subjects. The changes in antero-posterior (AP) diameter of the abdomen, lower rib cage, and upper rib cage are shown (increase upwards). In both subjects, coughing elicits a burst of activity in the clavicular portion of the pectoralis major, and promotes a marked decrease in the AP diameter of the upper rib cage together with an increase in the AP diameter of the abdomen. The abdominal external oblique muscle remains electrically silent (Reproducèd, with permission, from: Estenne M. and De Troyer A., Ann Intern Med 1990;112:22–28).

activity in the clavicular fibers and to promote a definite reduction in the anteroposterior diameter of the upper rib cage. This displacement was associated with a rise in intrathoracic pressure (not shown in the figure) that was then transmitted through the diaphragm to the abdominal cavity. As a result, in contrast to normal subjects who contract the abdominal muscles forcefully and have inward motion of the abdomen, the anteroposterior diameter of the abdomen increased. These alterations provide unequivocal evidence that due to the clavicular portion of the pectoralis major, cough in C5–C8 tetraplegic subjects is an active, rather than passive process.

We do not mean to imply that the clavicular portion of the pectoralis major is the *only* muscle involved in expiration and cough in these subjects. The latissimus dorsi and teres major muscles have a motor innervation that also depends on the fifth, sixth, and seventh cervical segments, and in most tetraplegic subjects they are also electrically active during expiration.[11] It is likely, however, that these two muscles act predominantly as fixators. By contracting in concert with the pectoralis major, they may fix the humerus, prevent the pectoralis major from shortening excessively, and thereby facilitate the action of this muscle in pulling down the manubrium sterni.

These findings may have important therapeutic implications. We have recently shown that training the clavicular portion of the pectoralis major for strength in C6–C8 tetraplegic subjects causes considerable increases in the strength of the muscle and in expiratory reserve volume. Hence, residual volume is reduced.[14] This procedure should affect intrathoracic pressure during cough as well. Therefore, training the clavicular portion of the pectoralis major should not only allow these subjects to cough at lower lung volumes and to clear bronchial secretions from more peripheral airways, but it should also enable the subjects to generate higher intrathoracic pressures. To be effective, however, cough requires the production of large positive intrathoracic pressures resulting in dynamic narrowing of the central airways and high airflow velocities,[15] and it is still uncertain whether tetraplegic subjects may achieve such a dynamic compression. Studies are thus needed to examine the behavior of the intrathoracic airways during cough in tetraplegic subjects and to assess the influence of pectoralis muscle training on this phenomenon.

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