Role of Selected Muscles of Respiration as Influenced by Posture and Tidal Volume*

David C. Reid, M.D.;** John Bowden, and Patricia Lynne-Davies, Ph.D.†

Studies of the activity of accessory respiratory muscles were conducted in 30 normal subjects (15 male and 15 female subjects, age 5 to 62 years). Electromyograms were recorded over the right serratus anterior muscle and the adjacent sixth intercostal space, and the results were correlated with tidal volume. Phasic respiratory activity in the serratus anterior muscle was detected in every subject but was markedly affected by the prevailing posture and level of ventilation (appearing at mean tidal volumes equivalent to 60.5 percent of vital capacity when subjects were standing relaxed, and equivalent to 35.2 percent of vital capacity when subjects were seated, leaning forward with elbows supported). The activity was predominantly inspiratory in timing but in some subjects extended into early expiration. No significant differences were noted in subjects of different ages, sex, height, or weight. Similar results were recorded from the inspiratory intercostal muscle. On the basis of these findings, we conclude that, contrary to reports, the serratus anterior muscle should be classified as an accessory muscle of respiration, at least at increased levels of ventilation, and that its activity is most pronounced in postures that place the muscles' origin in an advantageous position for moving the ribs.

In 1867, Duchenne¹ reported that faradic stimulation of the serratus anterior muscle resulted in protraction of the scapulae and further deduced that with the scapulae fixed, this muscle would function as an accessory muscle of respiration. This point of view was generally accepted for several decades, and it was taught that with the shoulders fixed, the serratus anterior muscle "elevates the ribs, and so dilates the cavity of the chest, assisting the pectoral and subclavius muscles."²(³⁶⁶) In line with this concept, the nerve to the serratus anterior muscle was at that time termed "the long thoracic external respiratory nerve of Bell."²(³⁶⁶)

Gradually this aspect of the muscles' function received less emphasis,⁴ and some 20 years ago, several workers reported that they were unable to detect phasic respiratory activity in electromyographic recordings from the serratus anterior muscle.⁴⁴ These studies were performed on subjects while standing, seated, and supine, and during a variety of respiratory maneuvers involving varying tidal volume (TV) and minute ventilation, as well as during coughing.

The position of the shoulder girdle was not controlled in any of these studies. As a result of these reports, subsequent reviews held that the serratus anterior muscle had no accessory respiratory function,⁵,⁶,⁷ a view expressed in most current textbooks of anatomy.⁹-¹³ Such statements ignore the work of other investigators who have reported phasic respiratory electromyographic activity at high values for TV and who have suggested that such activity might assume greater significance in some disease states where the patient characteristically fixes the shoulder girdle.⁵,¹⁴ However, this suggestion has not been tested experimentally.

Because of this confusion, the present study was designed to ascertain whether posture might influence the respiratory activity, if any, of the serratus anterior muscle.

MATERIALS AND METHODS

Thirty normal subjects with no histories of allergy or chest disease were tested. The group consisted of 15 male subjects with a mean age of 27 years (range, 5 to 62 years) and 15 female subjects with a mean age of 29 years (range, 18 to 55 years). Electromyographic activity was recorded simultaneously by surface electrodes from the intercostal muscles of the sixth interspace and the digitation of the serratus anterior muscle attaching to the sixth rib on the right side (to minimize cardiac interference).

To ensure that the recording electrode was correctly positioned over the serratus anterior muscle, direct faradic stimulation was applied over the muscle's origin in the lateral chest wall. Stimulation anterior to this point resulted in contraction of the intercostal muscles locally, manifested by a sensation of pain, whereas stimulation of the serratus muscle (indicating correct localization of the electrode) resulted in involuntary
protraction of the subject's shoulder girdle. The direct faradic stimulation was provided by a muscle stimulator (Multitone Progressive Treatment Unit), which produced square wave impulses 1.0 msec in duration at a rate of 50/sec and trains lasting 1,500 msec. A ground electrode was placed around the right upper arm.

The recordings were made on a three-channel electromyograph (Disa). Flow and volume during respiration were registered by means of a pneumotachygraph with a flow transducer (Vertek) and flow volume converter (VR 4000). All of these measurements were recorded on a seven-channel tape recorder (Hewlett-Packard) incorporating a high band pass frequency filter to minimize cardiac and associated artifacts. The tape was subsequently replayed onto a recorder (Hewlett-Packard) at one-eighth the recording speed to facilitate analysis of the record. Several subjects were retested using bipolar needle electrodes, in order to confirm the recording obtained by using surface electrodes.

With the functional residual capacity held constant, each subject breathed at gradually increasing values for TV until maximum inspiratory capacity was mobilized. The subjects were then instructed to breathe rapidly while maintaining a relaxed, supported anterior muscle. This was expressed as an absolute value in percent of the VC while the subject was standing and 47.8 percent of the VC when the subject was sitting; however, phasic action potentials were recorded as early as 36.0 percent of VC and 35.2 percent of VC in the standing leaning and the sitting leaning positions, respectively (Fig 1). No significant differences could be seen between the sexes. The mean values for female subjects, although not significantly different from that of the male subjects, were consistently slightly higher (Fig 2). This probably reflects the resistance offered by an overall slightly greater subcutaneous fat layer to the transfer of electrical activity to the surface electrodes. All subjects, regardless of age, followed the same basic pattern, even those furthest from the mean (Fig 3). These deviations could not be explained on the basis of age, height, or weight. Those subjects who were restudied four weeks apart demonstrated essentially similar results on retesting (Fig 4).

As anticipated, there was considerable background activity related to posture, particularly when the arms were flexed and abducted, but this was clearly distinguishable from the phasic respiratory efforts (Fig 5). Within the respiratory cycle, phasic activity began early in inspiration, regardless of the

Table 1—Percent of VC (± SE) at Which Phasic Respiratory Activity is Present in Serratus Anterior Muscle*

<table>
<thead>
<tr>
<th>Position</th>
<th>All Subjects</th>
<th>Male Subjects</th>
<th>Female Subjects</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of subjects</td>
<td>30</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Position 1</td>
<td>60.5 ± 2.7</td>
<td>59.9 ± 3.9</td>
<td>60.7 ± 3.9</td>
</tr>
<tr>
<td>Position 2</td>
<td>44.3 ± 1.7</td>
<td>42.3 ± 3.1</td>
<td>46.4 ± 3.1</td>
</tr>
<tr>
<td>Position 3</td>
<td>47.8 ± 2.0</td>
<td>45.6 ± 3.3</td>
<td>48.6 ± 3.3</td>
</tr>
<tr>
<td>Position 4</td>
<td>36.0 ± 1.9</td>
<td>34.0 ± 3.0</td>
<td>38.0 ± 3.4</td>
</tr>
<tr>
<td>Position 5</td>
<td>35.2 ± 1.5</td>
<td>33.3 ± 2.8</td>
<td>37.1 ± 2.9</td>
</tr>
</tbody>
</table>

*Position 1, standing relaxed; position 2, standing hands on hips; position 3, sitting hands on hips; position 4, standing leaning; and position 5, sitting leaning.
FIGURE 1. Percentage of VC at which phasic respiratory activity can be detected in serratus anterior muscle with subjects in various body positions. Bars indicate ± 1 SD. Differences between observed values were significant at 1-percent level in all cases except positions 4 and 5, which were not significantly different (P > 0.05).

FIGURE 2. Mean values, expressed as percent of VC, at which phasic respiratory activity appeared in serratus anterior muscle in male and female subjects, respectively, contrasted with results for overall group. Values for female subjects, though higher, were not significantly different. Position 1, standing relaxed; position 2, standing hands on hips; position 3, sitting hands on hips; position 4, standing leaning; and position 5, sitting leaning.

position of the shoulder girdle. The activity did not always cease abruptly at the end of inspiration but often tapered off during the initial part of the expiratory phase.

Recordings of the serratus anterior muscle were always clearly distinguishable from recordings of the adjacent intercostal muscle. The latter were also scrutinized for the pattern and duration of activity. Phasic patterns of action potentials were rarely noted with values for TV under 0.75 L. The most common pattern was that of gradually increasing amplitude of action potentials throughout inspiration; peaking at the end of inspiration and then tapering off as carry-over activity during early expiration. As maximum inspiratory capacity was approached, peaks of activity could be seen at both the end of inspiration and the end of expiration (Fig 5).

Discussion

The results clearly show that the serratus anterior muscle is an accessory muscle of respiration in normal subjects, at least at high values for TV. It is generally known that the resting position of the chest wall is equivalent to approximately 55 percent of the VC. Below this volume the chest wall has a natural
Figure 4. Results obtained in three subjects during original study, compared with values recorded on retesting four weeks later. Position 1, standing relaxed; position 2, standing hands on hips; position 3, sitting hands on hips; position 4, standing leaning; and position 5, sitting leaning.

Figure 5. Typical tracings showing surface electromyograms recorded over sixth right intercostal space and right serratus anterior muscle and showing air flow and tidal volume.

The tendency to expand, while above this volume, it tends to recoil inward toward the resting position. With the subject in the relaxed standing position, the activity in the serratus anterior muscle was noted to start at a mean value of 60.5 percent of the VC. This would represent a volume at which the elastic recoil of the rib cage is added to the already increasing tendency of the lungs to recoil to a lower volume.

Moreover, the muscle plays a more important role in respiration when the arms are elevated or abducted sufficiently to bring the scapulae in a more lateral position on the chest wall. This posture no doubt places the origin of the muscle in a more advantageous position to move the ribs. With the arms elevated and abducted, the inspiratory effort of the serratus anterior muscle begins at a mean value of 35.2 percent of the VC. Recruitment of the muscle at lower lung volumes in these circumstances must require a complex interaction of sensory and motor reflex mechanisms, which might be controlled either centrally or at a spinal level, or both.16

The carry-over of activity from inspiration into early expiration, most marked in the intercostal muscles but also evident in some subjects in the serratus anterior muscle, suggests a breaking action opposing the elastic recoil forces of the lung, rather than an active expiratory effort.14,15 This carry-over has been noted in other respiratory muscles, particularly the diaphragm,17,18 and is an example of eccentric muscular work, whereby a muscle contracts and simultaneously allows controlled divergence of its origin and insertion against resistance. Some of the expiratory activity recorded from the intercostal muscles also represents what is probably the primary function of the intercostal muscles, namely, that of providing an intercostal membrane that can adjust to various positions of the ribs and simultaneously maintain its tension.5,15,17,18

As more work on the primary and accessory muscles emerges, it becomes increasingly obvious that the terms, inspiratory and expiratory muscles, are unsatisfactory. Many of the muscles have roles in both phases of the respiratory cycle, working alternately concentrically and eccentrically. This is explained by two major differences between the mechanics of movement of the rib cage and movement of other parts of the body: (1) the almost complete lack of inertia in the rib cage, and (2) the fact that, unlike the limbs, the respiratory system has a definable resting position which will always prevail during relaxation.

As a result of these considerations, it becomes important that the inspiratory effort is not overdamped; for were this the case, inspiration would
cease abruptly, since it requires the continuous application of a counterforce to resist the tendency of the respiratory system to recoil to its resting position. Similarly, at the onset of expiration, these elastic recoil forces must be controlled in order that the transition to expiration develops smoothly rather than explosively. This need is satisfied by the continued brief contraction of the inspiratory muscles, which are now performing negative work. Were these requirements not satisfied, breathing would become inefficient and energy cost would be inordinate.18

In retrospect, the decision to dismiss the serratus anterior muscle as an accessory respiratory muscle may well have been premature and based on inadequate data. Works such as that of Jefferson and associates,19 which has subsequently been widely quoted,47 was performed using 30 dogs; but of these, only three animals were used in the part of the study concerned with the nerve to the serratus anterior muscle. Their conclusions, in fact, do not exclude the possibility that the serratus anterior muscle functions as an accessory respiratory muscle, since Jefferson et al19 state only that “under hypercapnea, questionable accentuation of action potentials synchronous with inspiration was observed.” Considerable emphasis47,12 has also been placed on an abstract, without confirmatory experimental detail, which appeared in the proceedings of the Anatomical Society.8

By contrast the results of the present study comply with the general rules of body economy, namely, that people tend to adopt positions that are most advantageous for muscular work in terms of expenditures of power and energy. This has been proved for activities such as walking and jogging and is probably true of breathing. The underlying reflexes concerned in this mechanism are unexplained but probably involve spinal reflexes, with muscle spindles playing an important role. In terms of clinical implication, perhaps patients in respiratory distress should be encouraged to adopt these leaning postures by adjustment of pillows and bed tables.

In conclusion, on the basis of our results, the serratus anterior muscle must be considered an accessory respiratory muscle. It has been emphasized that for each muscle the whole spectrum of activity must be described, and that the concept of pure inspiratory and expiratory muscles is inadequate and perhaps misleading. Furthermore, it is interesting to recall the characteristic posture of patients in respiratory distress or of overstressed athletes, a position that has been shown to be most efficient for at least one of the accessory respiratory muscles.

ACKNOWLEDGMENTS: We gratefully acknowledge the advice and assistance of Dr. Michael Grace, who performed the statistical analysis.

REFERENCES
7 Basmajan JV: Muscles Alive: Their Functions Revealed by Electromyography (2nd ed). Baltimore, Williams and Wilkins Co, 1967