Scalene and sternomastoid muscle function[1]

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RAPER, A. JARRELL, W. TALIAFERRO THOMPSON, JR., WILLIAM SHAPIRO, and JOHN L. PATTERSON, JR. *Scalene and sternomastoid muscle function.* J. Appl. Physiol. 21(2): 497–502. 1966.—The present study tests and proves the hypothesis that scalene muscles contract with increasing strength during upward shift in respiratory position and delineates factors related to onset of accessory muscle activity. The scalene electromyogram obtained through needle electrodes was electrically rectified and integrated to quantify isometric muscle strength expressed as percentage of maximum. Sternomastoid electromyogram, scalene electromyogram, and integral, intraesophageal pressure, mouth pressure, lung volume (bag-in-box system with wedge spirometer), and airflow (pneumotachograph) were recorded simultaneously. In all subjects scalene strength progressively increased as actively maintained, but stationary respiratory position approached full vital capacity. Comparison of scalene strength with intraesophageal pressure during Müller maneuvers showed scattered data; however, a relationship exists. Onset of muscle activity was found related to respiratory rate, end-expiratory position, rapidity of inspiration, and volume inspired. During maximum ventilatory efforts muscle onset preceded inspiration by up to 0.2 sec. The data delineate factors calling into play scalene and sternomastoid muscles and demonstrate a relationship between scalene force, intrathoracic pressure, and lung volume.

isometric scalene force; rectified integrated electromyogram; lung volume; sternomastoid electromyogram; scalene electromyogram

THE DETERMINANTS of the onset of contraction of the accessory respiratory muscles have been the subject of several investigations in the past. The scalene and sternomastoid muscles appear to be the most important accessory inspiratory muscles (3). Their origin and insertion suggest that these muscles act to raise the chest cage during inspiration but their degree of contribution to ventilation under differing circumstances is not known. Campbell (3) believed that the sternomastoids contributed more than the scalenes to ventilation. He also showed by electromyographic studies that the scalenes were used during quiet breathing by some (but not all) normals studied, were regularly employed at −10 cm of water intraalveolar pressure, and during moderately increased ventilation. The sternomastoids, on the other hand, were not used until somewhat higher rates of ventilation were attained, but were used regularly at −10 cm of water intraalveolar pressure during conscious efforts. During slow but maximal inspiratory efforts (vital capacity) the scalenes were employed earlier than the sternomastoids (2). He also noticed a gross correlation between the intensity of EMG activity (as determined by inspection) and certain maneuvers.

Thompson et al. (10) showed that the onset of contraction of the scalenes as detected by palpation corresponded well with the earliest EMG activity, that they were employed during many maneuvers in which the sternomastoids were not active and that their use preceded that of the sternomastoids in the development of chronic lung disease. Determinants of scalene activity appeared to be end-expiratory position, rapidity of inspiration, and volume of air inspired.

Chronic obstructive lung disease is associated with pathologically increased expiratory resistance which has been shown to result in increased residual volume, thus making greater elastic forces available to effect expiration (4). However, this same elastic force must be overcome during inspiration, and it would seem possible that the muscles of inspiration would then show an increased strength of contraction as compared to normal breathing. In addition, the prolonged expiration shortens time available for inspiration, since most patients with advanced chronic lung disease have no respiratory pause, thus the tidal volume must be inspired in less time than normally for the same respiratory rate. The increased activity necessary to accomplish this is believed (9) to utilize increased amounts of oxygen and to result in increased CO_2 production, contributing its part to a basic metabolic consequence of advanced chronic obstructive lung disease, i.e., insufficient oxygen uptake available for nonrespiratory uses and impaired excretion of CO_2, as arterial P_{CO_2} must rise to maintain rate of carbon dioxide elimination.

The present study was designed to test the hypothesis

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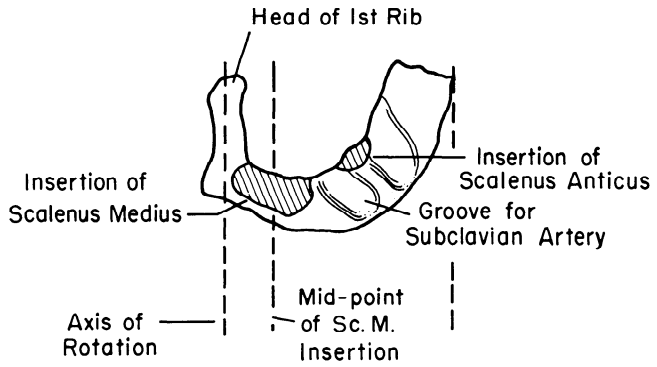

FIG. 1. Diagram showing anatomy of human first rib, with axis of rotation and scalenus medius insertion marked.

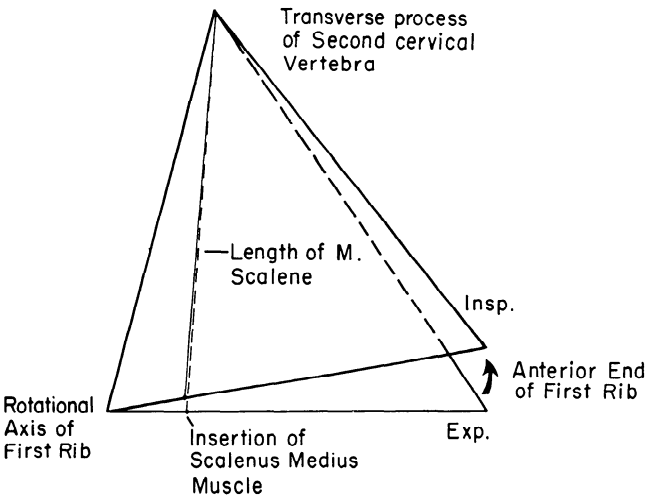

FIG. 2. Illustration of proportions of triangles measured externally in inspiration and expiration.

that the scalene muscles contract with increasing strength with an upward shift in end-expiratory chest position and further to delineate the effects of end-expiratory position, volume inspired, rapidity of inspiration, and respiratory rate on the onset of sternomastoid and scalene activity.

METHODS

Seven normal young men were studied, aged 23–31 years. All except one (*JC*) had normal exercise tolerance. This young man was normal at examination except for moderate obesity. The study was performed in the seated position with the head carefully supported and the spine relaxed.

Uninsulated subdermal needle electrodes (Grass Instrument Co., Quincy, Mass.) were utilized for the EMG, two needles being inserted 1 cm apart and 0.5 cm deep into the right middle scalene muscle and two into the right sternomastoid muscle. These needles were 1.3 cm in length, and 0.3 mm in diameter. None of the subjects suffered discomfort attributable to the needles. The indifferent electrodes were placed subcutaneously in the right arm. The sternomastoid leads were connected with the EKG/EEG/Phono channel of an Electronics for Medicine oscillographic recorder. The scalene leads were connected to a similar channel modified to rectify the signal, which was then fed into an amplifier integrator with infinite time decay, as described by Fink and Scheiner (6). The integrated EMG has been found linearly related to isometric muscle force in the human gastrocnemius muscle by Lippold (8), using plate electrodes. To test the system used in the present study, needle electrodes were inserted, and the EMG of human biceps muscle was integrated while isometric biceps tension was used to support a variety of weights through a pulley system. Under these conditions the relationship of integrated EMG to isometric force was indeed directly linear, except at the extreme upper range of force. It is tentatively assumed that this relationship also holds true for the scalene muscles.

To gain information about the order of magnitude of the change in scalene muscle length during contraction, the first thoracic neural spine, the sternoclavicular joint, and the lateral projection of the transverse process of the second cervical vertebra of one subject were marked on the skin, using relationships as depicted in a standard anatomy text (7). The distances between these points were measured repeatedly with calipers in full inspiration and expiration. Correction was made for the estimated distance from the dorsal end of the first neural spine to the axis of the first rib, and for clavicle thickness. The topmost origin of the scalenus medius was utilized because these fibers are outermost. Utilizing the position of the insertion of the scalenus medius on the first rib, as depicted by accepted authority (7) (see Fig. 1), it was

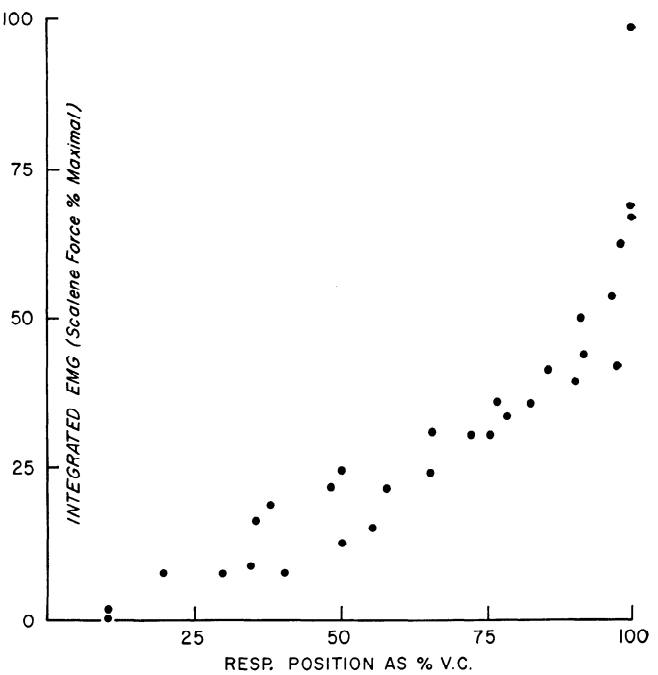

FIG. 3. Values obtained in *subject 3*, plotting scalene strength (integrated EMG) as percent maximal against percent vital capacity. These values were in static positions, no airflow, with airways open, using patient as own control.

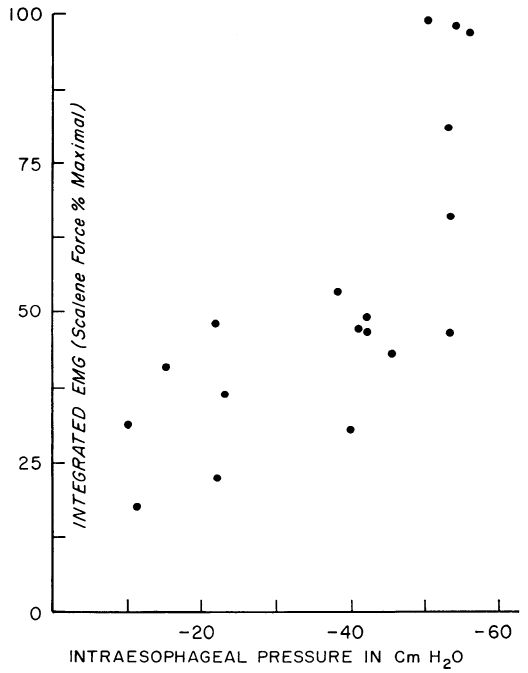

FIG. 4. Values obtained during Müller maneuvers in *subject 3*, intraesophageal pressure plotted against scalene strength (integrated EMG) ($r = 0.73$, $P < 0.01$).

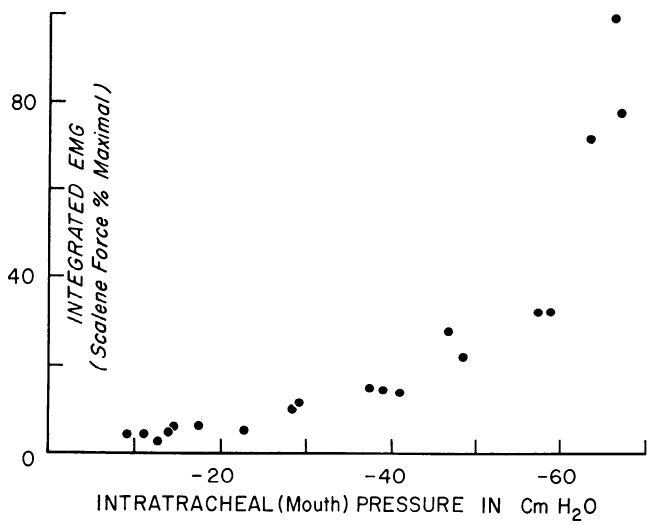

FIG. 5. Values obtained in *subject 3* during inspiration against a closed airway, with glottis open. Scalene strength against intratracheal pressure, end-expiratory position constant.

found that the anteroposterior distance from the rotational axis of the first rib to the midpoint of the scalene insertion was 21% of the length of the anterior-posterior axis of the first rib. The triangles as measured in full inspiration and full expiration were plotted on grid paper, and the outer layer of the scalene was thus calculated to shorten only 4.5% during a full vital capacity maneuver (see Fig. 2).

Volume changes were measured by a 40-liter bag-in-box system connected to a Wedge Spirometer (Med-Science Electronics, St. Louis, Mo.). This system allowed

TABLE 1. *Scalene and sternomastoid activity onset related to percent vital capacity during active maximal inspiration*

Subj No.	Onset of Scalene as % VC		Onset of Sternomastoid as % VC		No. of Attempts	*P* Value From *t* Test
	Mean	SD	Mean	SD		
1	26.4	8.5	75.2	25.8	5	<0.01
2	29.8	6.0	83.1	13.7	5	<0.01
3	22.4	12.1	77.9	19.2	6	<0.01
4	23.1	8.2	82.5	5.9	8	<0.01
5	28.2	12.3	59.6	15.5	5	<0.01
6	53.2	9.7	77.9	8.4	10	<0.01
7	38.4	7.8	70.7	12.6	7	<0.01

Scalene activity began at a lower percentage of vital capacity by a significant amount, $P < 0.01$ in all cases.

inspiration of room air from an airtight bag and expiration into an airtight box containing the bag. A vital capacity maneuver was done each time the system was filled to establish 0 and 100% vital capacity reference points.

Transpulmonary pressure was estimated by the use of a Mead-type intraesophageal balloon, 1.2 by 15 cm, attached over multiple perforations made in the end of an 80-cm length of polyethylene tubing (PE 200), with 1.5 cc of air placed in the balloon. The catheter was connected to one side of a differential strain gauge (Statham PM I 131 TC ± 7.5 psi 5v), and the pressure at the mouthpiece was delivered to the other side.

Airflow was measured by a screen pneumotachograph appropriately attached to a Statham (911 p5a-0.2D — 350, 0 to 0.2 psid) strain gauge. Using this method a 90% response to a sudden change of flow occurred within 0.01 sec.

The subjects performed a variety of respiratory maneuvers, including resting respiration, vital capacity, maximum voluntary ventilation (MVV) with and without expiratory resistors, abnormally rapid breathing, gradual voluntary hyperventilation and slow stepwise inhalation with the glottis open, and attempted inhalation against a closed glottis.

Expiratory resistance was produced by resistors of 3.5- or 7.5-mm internal diameter placed in the expiratory line.

EMG's, integrated scalene EMG, transpulmonary pressure, air volume and airflow were simultaneously recorded at varying paper speeds up to 75 mm/sec.

RESULTS

Scalene Strength and Static Chest Position

The slope of the integrated EMG, i.e., strength of scalene contraction (as percentage of maximum observed in the same subject) increased with the increase in percentage of vital capacity toward the full inspiratory position. Each measurement was made while the chest was held static, airflow zero, with the glottis open.

Figure 3 represents the values in *subject 3*. It can be seen that as the lung volume is progressively increased, the contraction becomes increasingly strong. In all subjects the curve showed a gradual rise, and as 100% vital capacity was approached, the integrated EMG increased sharply. The curves of all subjects showed similar characteristics, but were not identical. The major differences were in the slope of the initial and final portions. The sternomastoid tracing showed activity beginning later in the inspiratory maneuver and appeared to increase similarly, although actual electrical integration was not performed.

Scalene Strength and Intrathoracic Pressure

Attempted inspiration against a closed glottis, on repeated attempts of varying intensity, gave the data shown in Fig. 4. These data were obtained from *subject 3*. Three subjects were so tested. When subjected to linear regression, these correlation coefficients for the three subjects were obtained: $r = 0.59$ ($P < 0.05$), $r = 0.83$ ($P < 0.05$), and $r = 0.73$ ($P < 0.01$).

When respiratory position was closely controlled and the glottis open, the data shown in Fig. 5 were obtained in *subject 3*.

Onset of Muscular Activity

During quiet breathing five of the seven subjects showed scalene EMG activity. None used the sternomastoids. The scalene activity appeared after inspiration had begun.

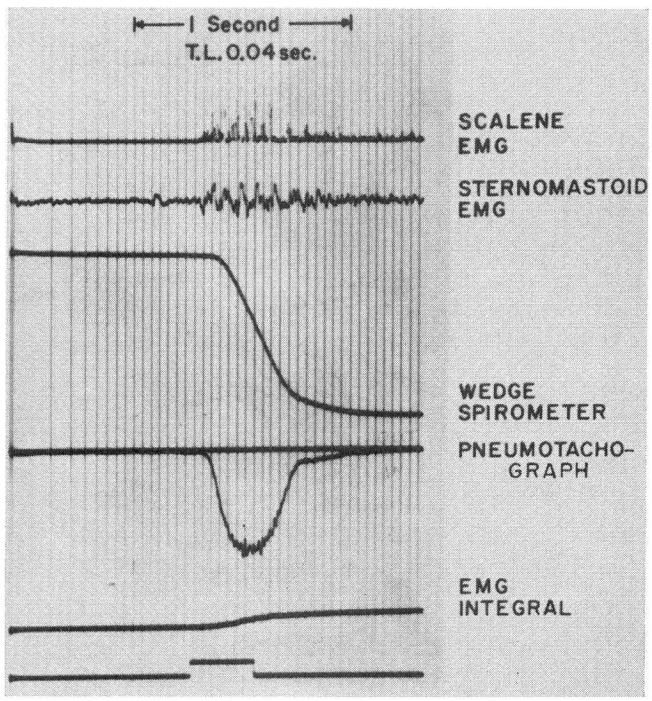

FIG. 6. MIFR maneuver recorded at 50 mm/sec paper speed. Note simultaneous onset of scalene and sternomastoid activity.

TABLE 2. *Onset of muscle activity during maximal voluntary ventilation (MVV)*

Subj	Mean Time Before Onset of inspiration, sec	No. Breaths Measured	SD, sec
1	0.19	44	0.04
2	0.07	43	0.04
3	0.07	57	0.03
4	0.08	24	0.03
5	0.09	41	0.03
6	0.09	32	0.04
7	0.10	22	0.06

The scalene and sternomastoid muscles' onset was simultaneous.

TABLE 3. *Subject 6 data during gradual increase in voluntary ventilation*

Respiratory Rate	Scalene Onset, sec	Sternomastoid Onset, sec	Airflow, liters/min
15	+0.6		76
15	+.15		132
23	+0.1		132
24	0.0	0.0	132
26	+0.1	+0.1	171
30	0.0	0.0	190
33	−.04	−.04	201
40	−.03	−.03	265
50	−.07	−.07	295
60	−.08	−.08	295
63	−.08	−.08	362
75	−.09	−.09	362

Both ventilatory rate and respiratory rate increased. Onset is shown in seconds after (+) and before (−) onset of inspiration.

Onset of muscle activity was related to percentage of vital capacity during active inspiration, as shown in Table 1. In each subject the activity of the scalenes began at a lesser fraction of vital capacity and the sternomastoids later, usually at or beyond 65% vital capacity. When subjected to the paired t test this difference was significant in all subjects, P in each case = <0.01.

Onset was also related to rapidity of inspiration. Figure 6 shows a maximum inspiratory flow rate maneuver (MIRF) recorded at high paper speed. The patient exhaled to residual volume, then inhaled as rapidly and completely as possible. The inward movement of air and onset of scalene and sternomastoid activity occurred simultaneously. This pattern was found in all subjects. During slow inspiration with low flow rates scalene and sternomastoid activity began well after the onset of inspiration.

Defining the onset of inspiration as the first inward movement of air as detected by the pneumotachograph, the onset of scalene and sternomastoid activity preceded inspiration during performance of the MVV in all subjects. This "anticipation" varied from 0.05 to 0.22 sec. The mean and standard deviations for each subject are given in Table 2.

Subjects were asked to gradually increase ventilatory rate. At slow rates (approximately 10–20 liters/min) scalenes first showed activity late in inspiration. As ventilation and airflow increased scalene acitivity appeared

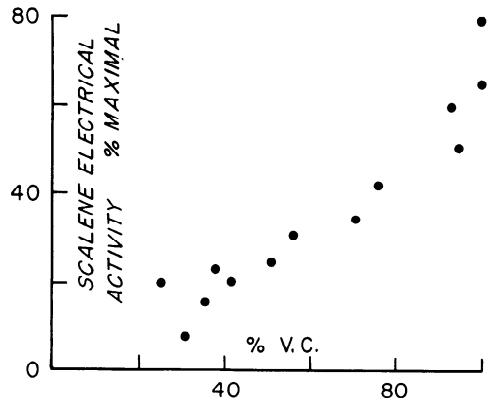

FIG. 7. Values obtained during performance of vital capacity, integrated EMG against percent VC.

progressively earlier in inspiration, until at maximum ventilation anticipation occurred as mentioned above. Table 3 gives data from *subject 6*. The pattern was not identical in each case.

Integrated EMG During Dynamic Maneuvers

Integrated EMG was found related to percentage of vital capacity during active inspiration. Figure 7 shows results in *subject 5*. The integrated EMG is simply expressed as percentage of maximum electrical activity (see DISCUSSION). All subjects showed curves of this general configuration, although they were not identical.

Airflow was measured during quiet breathing and maximal voluntary ventilation, but did not correlate well with integrated electrical activity.

Increased expiratory lung volume in response to expiratory obstruction was not seen in all subjects. In each of the three subjects in which it was seen a consistent progressive increase of electrical activity also occurred. Figure 8 represents such an occurrence in *subject 3*. Successive breaths are numbered.

DISCUSSION

Use of the scalenes during quiet respiration by five of the seven patients was noted; none used the sternomastoids. The scalene activity began after the onset of inspiration. These findings are in agreement with those of Campbell obtained with surface electrodes (2). The actual contribution of these muscles to airflow and tidal volume during resting respiration is uncertain.

During slow vital capacity maneuvers the scalenes of six of the subjects showed activity soon after the estimated neutral point of the thorax was passed (see Table 1). They differed significantly in this respect from the sternomastoids, which began to contract later, well after the midpoint of maximal inspiration. Thus the scalenes are active in some degree in the range encompassed by the normal or slightly increased tidal volume, whereas the sternomastoids assist inspiration at lung volumes not usually utilized in health except during exercise, singing, sighing, or in deliberate respiratory maneuvers. It therefore appears justified to omit the qualifying adjective "accessory" in describing the scalenes, whereas the sternomastoids are truly accessory.

In each case, when ventilatory and respiratory rate were voluntarily increased, the scalene activity occurred progressively earlier in the inspiration. During maximum voluntary ventilation (MVV), the scalenes and sternomastoids were active, and the onset of activity preceded inspiration by 0.05–0.22 sec (see Table 2). This time interval is too great to be explained by the response time of the pneumotachograph system used. That this anticipation of inspiration is related to chest or air movement of the previous breath is suggested by its uniform absence during performance of the maximum inspiratory flow rate maneuver (MIFR), in which the chest is static prior to a maximal inspiratory effort. Since the actual mass of inspired air during the MVV is very small (approximately 1 g/liter), and that of the chest and lung is very much greater, it appears likely that this anticipation of inspiration is in reality utilized to decelerate the expiratory chest and lung movement, and then to reverse it. This is not unlike the action of many other muscle groups in performing rapid alternating movements, as in running.

The scalenus medius muscle acts close to the axis of rotation of a relatively long lever arm, the first rib. Measurements taken externally indicate that its outer layers shorten by about 5% during full inspiration. This essentially isometric contraction, rare in the skeletal muscles, permits use of the integrated electromyogram to

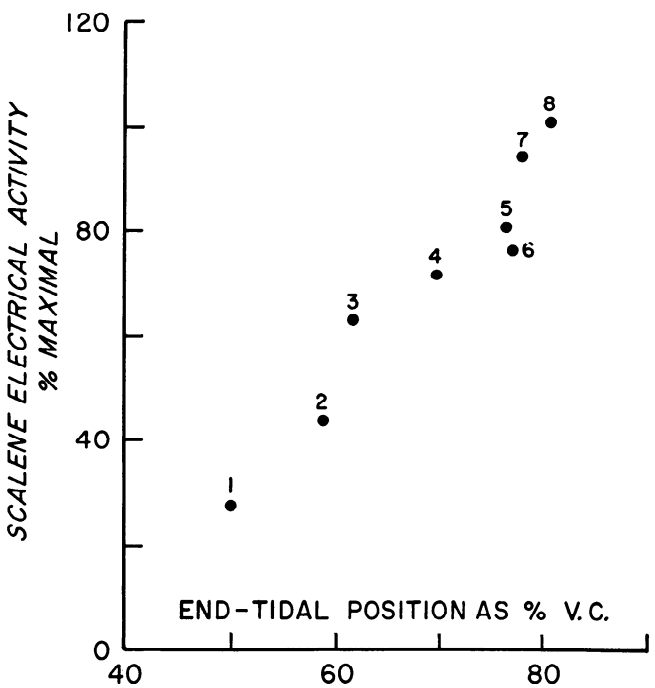

FIG. 8. Effect of increased expiratory lung volume on integrated EMG during performance of maximum voluntary ventilation with expiratory resistance. Percent maximal integrated EMG is plotted against percent vital capacity at end-expiratory volume. Successive breaths are numbered. Note increasing electrical activity as expiratory lung volume increases.

estimate its isometric force. There is, of course, error introduced by doing so; however, this error is most likely small in view of the small length change of the muscle.

Needle electrode depth, thickness of subcutaneous tissue, and exact distance between electrodes represent variables which could not be controlled with precision. Thus, the integrated EMG is related in each case to the maximum seen in that subject, and represents isometric strength as a percentage relative to the maximum produced by that subject.

During static maneuvers the increase in isometric scalene force was found related to increase in lung volume, the scalene contracting more strongly as the opposing elastic force of the lungs and thorax increases. The final steep portion of the curve (see Fig. 3) was seen in all subjects. Lippold (8) found that the linear relationship between isometric force and integrated EMG disappeared at extremes of force, using the human gastrocnemius muscle. This we also observed, using the human biceps muscle. This finding would adequately explain the final steep portion, which occurred as the subject was asked to inspire with maximum effort.

Attempted inspiration against a closed glottis was used to produce static negative intrathoracic pressure. Only those maneuvers producing a stable plateau of negative pressure were utilized in the calculations. The increasingly negative intrathoracic pressure, as estimated by intraesophageal pressure, was associated with an upward trend in the integrated EMG, though the data were scattered. This scatter is probably present because chest position was not controlled in every experiment. When chest elastic forces were eliminated by having one subject inspire against a closed airway with glottis open, and respiratory position was closely controlled, the values shown in Fig. 5 were obtained.

Use of the integrated EMG to estimate scalene force during actual muscle movement is probably not justified, because of the unpredictable electrical potentials induced by gross movements of the needle shaft and point within the muscle. It is therefore not surprising that the integrated EMG did not correlate well with airflow. Nevertheless, the integrated EMG did show directional changes during dynamic maneuvers similar to those seen with the chest static (see METHODS), these changes increasing as the chest was raised toward full inspiration. This pattern was seen in all subjects. Whenever increased expiratory lung volume occurred, a stepwise increase in the integrated EMG also occurred. (See Figs. 7 and 8.) It appears very likely that these increases in electrical activity reflect to a degree an increase in the contractile activity and metabolic demands of the muscle.

The pattern of abnormally high functional residual capacity and end-expiratory position is present in severe chronic obstructive lung disease even at rest (4). Thus these muscles, in constant use during inspiration in such patients, often hypertrophied and contracting with greater force, would be expected to contribute to the increased oxygen requirement and carbon dioxide production characteristic of the breathing in these patients.

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