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THE CORRELATION OF INTERCOSTAL MUSCLE ACTIVITY WITH RESPIRATORY AIR FLOW IN CONSCIOUS HUMAN SUBJECTS

BY J. H. GREEN AND J. B. L. HOWELL
*From the Departments of Physiology and Medicine, The Middlesex Hospital, London, W.*1.

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The mechanism by which the respiratory muscles produce respiratory movement of the thorax has been the subject of investigation for a very long time. As a result of such studies, respiratory muscles have been classified as expiratory when their activity results in forces which aid expiration and inspiratory when their activity results in forces which aid inspiration.

As a result of studies of the compliance of the thorax of anaesthetized paralysed human subjects (Howell & Peckett, 1957) we were led to suspect that the inspiratory muscles might extend their activity into expiration to oppose rather than to aid expiration. In order to explore this possibility, we have studied the electromyograms of the most accessible respiratory muscles, viz. the intercostal muscles, and have correlated their activity with the phases of the respiratory air flow.

METHODS

Six healthy young male subjects were studied in the semi-recumbent posture. Pairs of surface electrodes 1 cm in diameter and 5 cm apart were placed in the lower (6th–9th) intercostal spaces. The electromyogram (e.m.g.) of the underlying muscles was recorded with an Ediswan 4-Channel ink-writing electro-encephalograph. Respiratory air flow was recorded at the mouth with the pneumotachograph described by Green & Howell (1955), which was coupled to the last two stages of a further channel of the electro-encephalograph. With a low gain of this channel it was possible to record the complete pneumotachogram (Fig. 1), whereas at higher gain the air-flow scale was so expanded that very low rates of flow caused maximum deflexion of the pen; under these conditions the crossing of the zero flow line at the beginning of inspiration and expiration was clearly marked (Fig. 2).

RESULTS

In each subject the activity recorded from the lower intercostal spaces started shortly after the commencement of inspiration and increased in intensity through inspiration (Figs. 1, 2). This activity, however, always continued through the point of reversal of air flow, and gradually decreased during expiration. The duration of activity during expiration was variable. In one subject (Fig. 3) the activity persisted at low intensity for approximately half the duration of expiration; usually, however, no further activity could be detected after the first third of expiration.

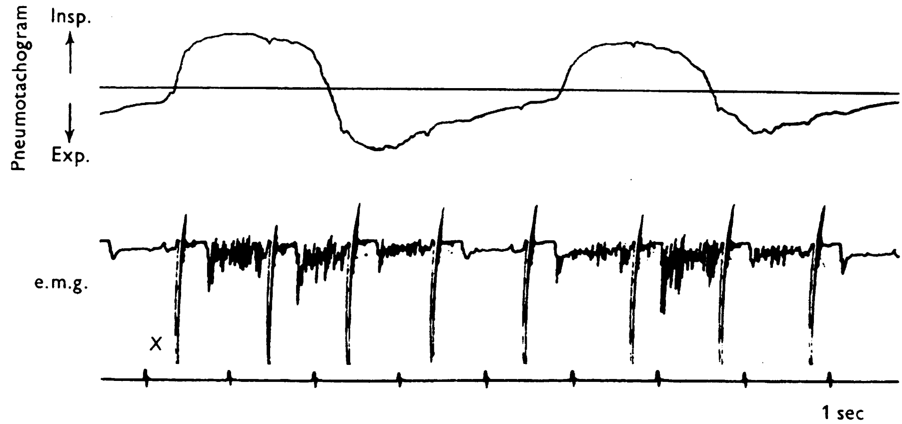

Fig. 1. Pneumotachogram (upper tracing), inspiration upwards, expiration downwards; horizontal line = zero flow. In Figs. 1–3, middle tracing = electromyogram 7th right intercostal space, anterior axillary line; X = artifact due to e.c.g. Lower tracing, time marker scale 1 sec.

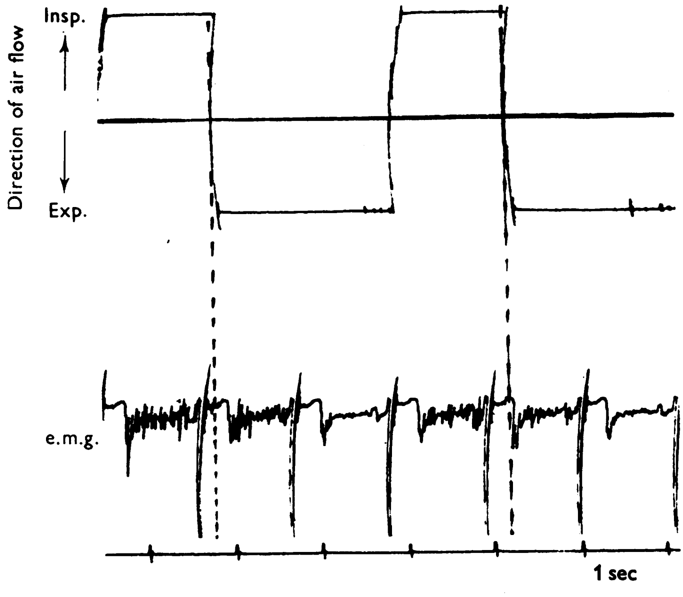

Fig. 2. Pneumotachogram (upper tracing); pneumotachograph now used as air-flow direction indicator by increasing gain.

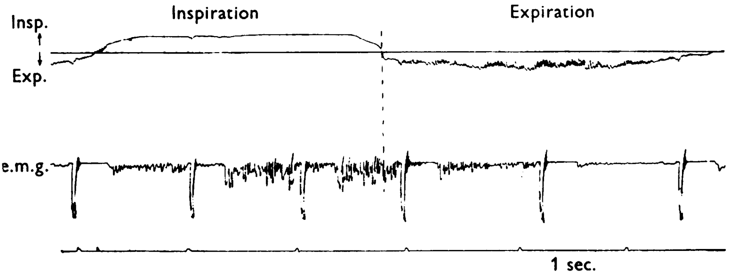

Fig. 3. Pneumotachogram (upper tracing, inspiration upwards, expiration downwards); oscillations on expiratory pneumotachogram due to artifact.

DISCUSSION

Intercostal muscle activity has been demonstrated electromyographically to continue without interruption, from inspiration into the early part of expiration. During spontaneous breathing inspiration is an active process requiring the contraction of inspiratory muscles. The potential energy stored in the elastic tissues of the lungs and thorax is available for expiration, which in quiet breathing is generally considered to be passive and does not involve activity of expiratory muscles. The recording of electrical activity from the intercostal space during the expiratory phase might suggest that the intercostal muscles had an expiratory function. However, evidence of expiratory muscle activity during quiet expiration has not been demonstrated. In a careful electromyographic study in normal supine human subjects, Campbell (1952) and Campbell & Green (1953*a*, *b*; 1955) were unable to demonstrate any activity in the abdominal muscles, which are powerful expiratory muscles, during quiet respiration. When pulmonary ventilation was greatly increased by various physiological stimuli, abdominal muscle activity could sometimes be demonstrated, but only towards the end of expiration.

The potential energy available for expiration is greatest at the onset of expiration when the stretch of the elastic tissues is greatest, and it might reasonably be expected that if additional expiratory forces were required, they would occur in the later phases of expiration. The activity which we have demonstrated in the intercostal spaces is in the earlier part of expiration and it seems improbable, therefore, that it is expiratory in function.

There is evidence that inspiratory forces are active during expiration. First, the absence of an abrupt rise in intrapleural pressure at the onset of expiration indicates that there is no sudden loss of inspiratory muscle activity. The mechanical relationships relevant to this argument are shown in Fig. 4. The horizontal co-ordinate represents intrapleural pressure, and the vertical co-ordinate lung volume above the Functional Residual Capacity (F.R.C.). At the F.R.C. (which is assumed to be the volume of the thorax when no respiratory muscle activity is present) the intrapleural pressure is due to two opposing forces, the passive recoil of the lungs attempting to reduce lung volume, and the recoil of the thorax attempting to increase thoracic volume. At the F.R.C. the magnitude of the pressure developed passively by each structure is equal and the resultant intrapleural pressure is represented by the point *A* (Fig. 4). When lung volume is increased, from *O* to *F*, by the application of an additional force by the inspiratory muscles, the recoil pressure of the lungs is increased (line *AB*), and that of the thorax, which moves towards its resting volume, is decreased (line *AE*). The pressure which is developed by the activity of the inspiratory muscles to produce the change in volume *OF* is therefore represented by the horizontal distance *BE*; and if at end-inspiration, inspiratory muscle activity were to cease abruptly, intrapleural pressure would instantaneously rise by this amount, i.e. intrapleural pressure would rise from *B* to *E*. This does not occur, and the intrapleural pressure changes approximately as indicated by the line *BDA*. The loop *ACBD* during the respiratory cycle represents the work done against non-elastic resistances of the lung. The non-elastic resistances of the thorax are not known with any accuracy and are not represented in this diagram. With this last reservation the area *ADBE* (hatched) represents the work done against the lung by the inspiratory muscles during

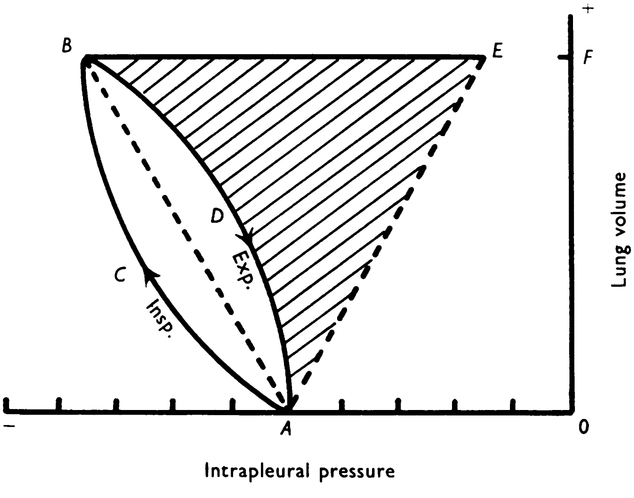

Fig. 4. Diagram to show the relationships between change in lung volume (ordinate) and intrapleural pressure (abscissa) during natural expiration (*BDA*), and completely passive expiration (*BEA*).

expiration. A further discussion of these relationships is given by Campbell (1958).

Secondly, Brody (1954) recorded the pneumotachogram of spontaneously breathing normal human subjects and compared the expiratory part of the curves obtained with the passive expiratory level theoretically deduced by using the data of Rahn, Otis, Chadwick & Fenn (1946) and of Otis & Proctor (1948). This theoretical passive expiratory flow curve is in good agreement with actual curves recorded from paralysed human subjects (Kavan & Haddy, 1956). In order to explain the absence of agreement between the theoretical curves and the pneumotachogram in all except the terminal 15–20% of the expiratory phase Brody suggested either (*a*) the presence of a resistance greater in early expiration than later, or (*b*) inspiratory muscle tonus which continues into the first part of expiration and then gradually decreases. The interruptor studies of Otis & Proctor (1948) suggest that the resistance is virtually constant during the earlier part of expiration and supports the concept that inspiratory tonus is present during expiration.

The muscle activity which we have demonstrated electromyographically occurred in the same phase of expiration as the inspiratory activity predicted by Brody (1954) and we conclude that it is inspiratory muscle activity opposing expiratory forces.

SUMMARY

1. Lower intercostal electromyograms were recorded synchronously with the pneumotachogram in six normal young male subjects during spontaneous respiration in the semi-recumbent posture.

2. Intercostal muscle activity occurring during inspiration continued into expiration for a varying length of time.

3. It is suggested from a consideration of the pressure–volume relationships of the thorax and from the shape of the expiratory flow curve that the activity recorded during expiration is acting to oppose rather than to aid the expiratory forces.

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