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An electromyographic study of the abdominal muscles during postural and respiratory manoeuvres

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SUMMARY A method was developed for making EMG recordings from the four individual muscles of the anterior abdominal wall. It was then demonstrated that these muscles have different and distinguishable actions on trunk movement, but act together in breathing. The level of ventilation at which the abdominal muscles become active in expiration was shown to be posture dependent.

Previous studies of the EMG activity of the abdominal muscles in man have used recordings made from surface electrodes[1] or needle electrodes[2] placed in rectus abdominis and external oblique muscles. The EMG activity of the external oblique muscles during breathing has been assumed to be representative of the antero-lateral muscle group as a whole, though there is no evidence for this assumption. The antero-lateral musculature consists of three layers comprising external oblique outermost, internal oblique next, and transversus abdominis innermost. These layers are in such close proximity that it has been difficult to separate their electrical activities.[3,4] The fibres of the four muscles of the anterior abdominal wall run in different directions, thus these muscles may have different actions. The aim of this study was to develop a method of sampling EMG activity from individual abdominal muscles, and to record their activity during breathing.

Methods and materials

Subjects

Six normal volunteers took part in the study; none was suffering from any acute or chronic, neurological or respiratory illness. Three subjects were male, and the group had a mean age of 28 years.

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Apparatus

EMG recordings from the abdominal muscles were made with bipolar fine wire electrodes manufactured in the manner of Basmajian,[5] from 0·06 mm stainless steel wire insulated with Diamel. Ventilation was measured as flow with a conical pneumotachograph, accurate to flow rates of 300 l/min. This was connected to a differential pressure transducer (Elema-Schonander EMT 32c), and the signal generated processed by a purpose built integrating amplifier (with a time lag in response to a square wave of 0·01s). The ventilation signal in the form of volume was displayed with the EMG signals on a "Medelec MS6" EMG module fitted with four AA6 amplifiers, and recorded on light sensitive paper run at 5 cm/s. Recordings from the wire electrodes were made at a gain of 200 mA. The high pass filter was set to 16 HZ (−3 dB cut off) and the low pass filter to 1·6 KHZ (−3 dB cut off). Both filters rolled off at 12 dB/octave.

Method for location of individual muscle layers

Computed tomographic (CT) scans of the abdomens of 20 patients were performed with an Elscint 2002 whole body scanner at Brompton Hospital. These subjects were selected at random, they represented 20 consecutive referrals for abdominal CT scan. The scan taken at the mid-point between xiphisternum and pubis was selected from a "scout" view, and on this the individual muscle layers of the antero-lateral abdominal wall were clearly visible (fig 1). The cursors available on the viewing module were used as electronic calipers to measure the distance from the skin surface to each muscle layer. The measurements were made at the point of maximum thickness of the abdominal muscles. This point was located using a metal marker at 3 cm medial to the mid-axillary line. The mean distance from surface to external oblique was 9·2 mm (SD = 2·6 mm), to internal oblique 14·6 mm (SD = 3·1 mm) and to transversus abdominis 21·2 mm (SD = 2·8 mm). A 27 gauge needle was marked at these distances, and in a series of pilot studies was inserted into the antero-lateral abdominal muscles of the six subjects

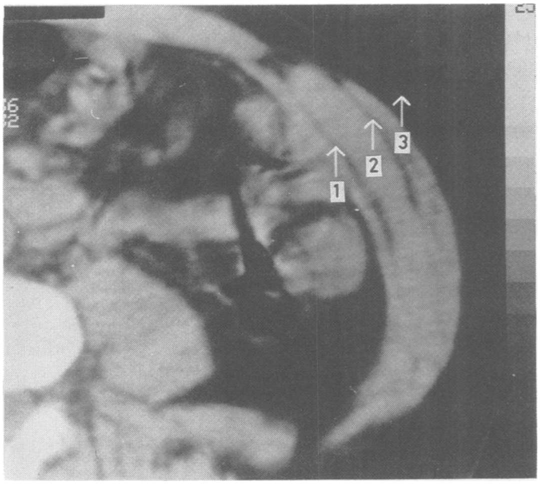

Fig 1 *CT scan of the abdominal muscles. The three layers of the antero-lateral muscle group are clearly seen, as is rectus abdominis medially. The arrows represent electronic calipers. 3 is positioned at the skin, 2 at the surface of internal oblique and 1 at the surface of transversus abdominis.*

mid-way between xiphisternum and pubis, 3 cm medial to the anterior axillary line. As each layer of fascia was penetrated it was possible to feel a decrease in resistance or "give", and on some occasions there was reflex muscular contraction. With experience, the operator became confident as to the position of the needle within the muscle layers.

Insertion of electrodes into the abdominal muscles

In each of the six normal subjects studied a bipolar fine wire electrode was placed into rectus abdominis, 3 cm to the left of the mid-line, mid-way between pubis and xiphisternum. Three electrodes were placed within 0·5 cm of each other at the surface, into the antero-lateral muscle group. The entry point was on the left 3 cm medial to the mid-axillary line, mid-way between xiphisternum and pubis. The objective was to place an electrode into each of external oblique, internal oblique and transversus abdominis muscles. The electrodes were mounted in 27 gauge needles with shaft length corresponding to the expected depth of the muscle. To insert electrodes into external oblique a 1·0 cm needle was used, for internal oblique a 1·5 cm needle and for transversus abdominis a 2·0 cm needle.

Validation of technique for electrode insertion

In order to demonstrate that the electrodes had been inserted into the muscle at which they were aimed, a series of manoeuvres were performed which were designed to produce EMG activity predominantly in a single muscle layer (table 1).

Table 1 *Manoeuvres designed to elicit EMG activity predominantly from an individual abdominal muscle*

Muscle activated	Movement
External oblique	Lift left shoulder and point it towards right hip
Internal oblique	Lift right shoulder and point it towards left hip
Transversus abdominis	Pull "belly" in
Rectus abdominis	Lift both legs. (This movement is not specific, but activates rectus abdominis to ensure the wire is in place. The electrode is in a visibly different position from the other three electrodes)

Respiratory manoeuvres

Each subject performed a series of respiratory manoeuvres with four intra-muscular electrodes in place. Recordings were made with subjects breathing at resting tidal volume; they then voluntarily increased the rate and depth of their breathing up to maximum hyperventilation. Cough, "strain" and Valsalva manoeuvres were performed. "Strain" was defined as expulsive effort against a closed glottis. This series of manoeuvres was performed with each subject lying supine and horizontal on a tilt table, then at 10° head down and at 40° head up.

Results

Validation of technique for electrode insertion

The results of the validation procedure are displayed in table 2. The manoeuvres performed were successful in eliciting EMG activity predominantly from an individual muscle (figs 2, 3, 4, and 5). A total of 24 electrodes were inserted; of these the evidence suggested that 20 were positioned in the muscle for which they were aimed.

Respiratory manoeuvres

In all six subjects the abdominal muscles were inactive during quiet breathing in the supine posture. As ventilation increased, phasic expiratory EMG activity was detected in the abdominal muscles. This activity was similar in timing and duration in all four muscles

Table 2 *Results of the validation procedure for placement of fine wire electrodes into the abdominal muscles of six normal subjects (+ = satisfactory placement)*

Subject	*Sex*	*Age (yr)*	*External oblique*	*Internal oblique*	*Transversus abdominis*	*Rectus abdominis*
1	M	27	+	+	+	+
2	M	21	+	+	+	+
3	F	31	+	+	+	+
4	M	35	−	−	+	+
5	F	32	+	+	+	+
6	F	25	+	−	−	+

examined (fig 6). The amplitude of the EMG signal increased with minute volume. During cough, strain and Valsalva manoeuvres all four abdominal muscles acted together.

Effects of posture

The pattern of abdominal muscle activation was identical when the respiratory manoeuvres were carried out with the subject horizontal, at 10° head down, and at 40° head up. The mean minute volume at which abdominal muscle EMG activity was first detected was 102 l/min (SD = 17 l/min) at 10° head down, 88 l/min (SD = 13 l/min) horizontal, and 82 l/min (SD = 9 l/min) at 40° head up. Wilcoxon Ranked Sum tests showed that the minute volume at which the abdominal muscles became active was significantly greater at 10° head down than when flat or at 40° head up ($p < 0.05$).

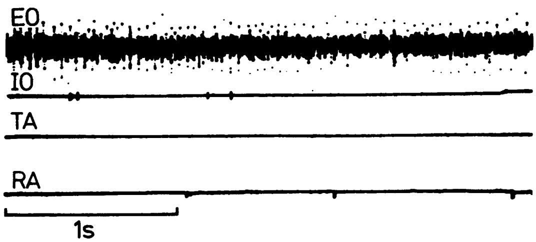

Fig 2 EMG recordings from electrodes placed in the four individual abdominal muscles (as described in the text), on lifting the left shoulder and pointing it towards the right hip. There is EMG activity from the electrode placed in the external oblique muscle which is distinguishable from the recordings from the other muscles. EO = External Oblique, IO = Internal Oblique, TA = Transversus Abdominis, RA = Rectus Abdominis.

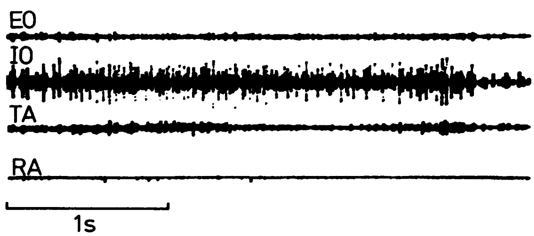

Fig 3 EMG recordings from electrodes placed in the four individual abdominal muscles (as described in the text), on lifting the right shoulder and pointing it towards the left hip. There is EMG activity from the electrode placed in the internal oblique muscle which is distinguishable from recordings from the other muscles.

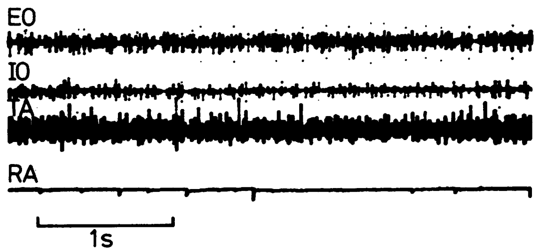

Fig 4 EMG recordings from electrodes placed in the four individual abdominal muscles (as described in the text), on "pulling the belly in". There is EMG activity from the electrode placed in the transversus abdominis muscle, which is distinguishable from recordings from the other muscles.

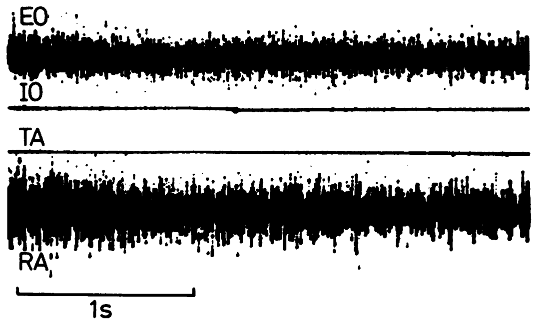

Fig 5 EMG recordings from electrodes placed in the four individual abdominal muscles (as described in the text), on raising the legs. This confirms that the electrode placed in rectus abdominis is working. It is positioned distant from the other three electrodes, and so must be recording a signal from a separate muscle.

Fig 6 EMG recordings from electrodes placed in the four individual abdominal muscles (as described in the text), during increased ventilation. Phasic expiratory EMG activity is of similar onset and duration in all four channels.

Discussion

The results of this study suggest that it is possible to record EMG activity from the individual muscles of the abdominal wall. Ideal ways of validating the method of electrode insertion would have been to image the wires within the muscle layers with CT scanning, or dissect the muscles to observe the electrodes directly. It was not ethical to attempt either of these options in normal volunteers. High resolution ultrasound was a possible solution to this problem, but the fine calibre of the wires made them invisible to this imaging system. Attempts were made to image a bipolar electrode placed in the abdominal muscles of a patient undergoing a CT scan, but again the wires could not be visualised. It was therefore decided to validate the insertion technique indirectly by using manoeuvres designed to elicit EMG activity predominantly from a single muscle. Since the electrodes were placed within 5 mm of each other at the skin surface, the separation of EMG activity as shown in figs 2 to 5 was considered good evidence that the wires were in different muscles. Twenty out of 24 electrodes were thought to have been inserted into the muscles at which they were aimed, the remaining four were displaced by only one muscle layer. This provided an adequate opportunity to study the activation of individual abdominal muscles during breathing.

Previous EMG studies have suggested that the individual abdominal muscles have separate actions. Campbell[2] in 1952 noted that on lateral trunk flexion EMG activity came predominantly from the external oblique muscle. Detailed studies by Carman *et al*[3] confirmed the presence of EMG activity mainly in external oblique on ipsi-lateral trunk flexion, and in internal oblique on contra-lateral trunk flexion. Strohl *et al*[4] placed three fine wire electrodes into the antero-lateral abdominal muscles, at depths corresponding to ultrasound measurements of the distance from the skin to each individual muscle. They demonstrated EMG activity predominantly from the deepest electrode on voluntarily "pulling the belly in", which suggested that this manoeuvre was carried out mainly by transversus abdominis. The manoeuvres performed in our study to activate individual abdominal muscles were designed considering the direction in which their muscle fibres run, and the experience of previous authors.

During quiet breathing there was no EMG activity detected from the abdominal muscles. When minute volume increased the abdominal muscles became active in late expiration, as in the studies of Campbell and Green.[7] We also concurred with their finding of abdominal muscle activity during coughing, straining and Valsalva manoeuvres.[6] Thus no new observations were made on the timing of abdominal muscle EMG activity during the respiratory cycle. There was no detectable difference between the timing and duration of EMG activity from the four individual muscles during respiratory manoeuvres. We therefore suggest that the role of the individual abdominal muscles is to modulate trunk movement, and that they act together during breathing.

Posture influenced the minute volume at which the abdominal muscles were recruited for expiration. At 10° head down the effect of gravity on the abdominal contents is expiratory, pushing the diaphragm into the thorax. Thus the abdominal muscles are recruited relatively later than in the horizontal posture. At 40° head up the effect of gravity on the abdominal contents and diaphragm is inspiratory, and the abdominal muscles are recruited to assist expiration at a lower level of ventilation than in the 10° head down position. However, comparison of data from the 40° head up and horizontal postures failed to reach statistical significance. In the 40° head up position the level of ventilation at which the abdominal muscles were recruited was lower than when flat in five out of six subjects. The variation of the pattern in the remaining subjects may have been due to variability in the pattern of voluntary hyperventilation.

In conclusion it is possible to record EMG activity from individual abdominal muscles. These muscles have distinguishable effects on trunk movement but act in concert during breathing. The level of ventilation at which they become active in expiration varies with posture.

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