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Use of a single pair of magnetometer coils to monitor breathing patterns in an intensive care unit

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ABSTRACT The use of a single pair of magnetometer coils placed centrally on the trunk to record tidal volumes and breath times has been evaluated in five normal subjects in five positions. Breath times were accurate in all positions tested but tidal volumes were only reliable with the subjects lying and the backrest raised to 45° or in the supine position only for volumes up to 1000 ml. Using this system, recordings have been made in seven patients with barbiturate overdose, five with salicylate overdose, and five undergoing anaesthesia with thiopentone. The single pair of coils was satisfactory for measuring changes in the pattern of breathing in these patients. In barbiturate overdose in five patients there was initially an increase in respiratory frequency with a decrease in tidal volume. As these patients recovered the tidal volume increased and the respiratory rate slowed. In two patients who had a raised $PaCO_2$ there was initially reduction of both tidal volume and respiratory rate, both increasing as the patients recovered. Monitoring respiratory rate appears to be a useful guide in barbiturate overdose; a slowing of the rate without recovery of consciousness warrants further investigation to assess the need for ventilatory support. The single pair of coils were also satisfactory for measuring the increased tidal volume in salicylate overdose. As after other respiratory stimuli in man, increased ventilation occurred predominantly through changes in tidal volume and expiratory time while inspiratory time changed very little.

At present there are no simple, accurate methods of monitoring breathing in general use for patients in whom respiratory insufficiency may occur. Methods which involve the airway or mouthpiece are unsuitable for long periods of observation and the use of such apparatus itself produces alterations of breathing pattern.[1 2] We have examined a simple method of measuring tidal volume and breath times and have used it to investigate the respiration of patients admitted to hospital with barbiturate and salicylate overdose and during induction of anaesthesia with thiopentone.

The method uses a single pair of magnetometer coils attached to anterior and posterior body surfaces. Mead *et al*[3] first described the use of two pairs of magnetometers to measure the changes in anteroposterior diameters of ribcage and abdomen during breathing and these movements may be used to obtain tidal volume.[4] The usual calibration procedure is a rocking movement of ribcage and abdomen, the "isovolume" manoeuvre, produced by diaphragmatic contraction with a closed glottis.[5] The manoeuvre is often difficult for untrained subjects to perform and in unconscious subjects can only be approximated with airway occlusion. Other computerised methods of calibration[6] are available but for routine use a simpler method is desirable.

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Methods

ASSESSMENT OF A SINGLE PAIR OF MAGNETOMETER COILS

Five normal male subjects, aged 24-33 years, were studied using a single pair of linearised magnetometer coils (constructed in the Department of Bio-Engineering and Clinical Physics, Guy's Hospital). The coils were attached to the skin with double-sided adhesive tape. The coils were positioned at a level just below the xiphisternum at the point of no movement in the "isovolume" manoeuvre. It is considered that this point is representative of anterior chest wall and abdominal movement during breathing.[7] The signal obtained from movement of the magnetometer coils was then compared with an integrated pneumotachograph signal. The subjects were asked to breathe through the pneumotachograph via a mouthpiece wearing a noseclip, at six tidal volumes in random order from 200 to 1200 ml, judging the volume from the pneumotachograph signal displayed on an oscilloscope screen. Recordings were made in five different positions in random order—standing, supine, lying with the backrest of the couch raised to 45°, lying on left side, and lying on right side. The time of inspiration and volume signal obtained from pneumotachograph trace and magnetometer trace were taken from six to eight breaths at each of the six volume steps. A regression analysis was performed on these. It has been assumed that breathing through the pneumotachograph does not significantly alter the body wall configuration so that the magnetometer signal represents the same volume with and without the pneumotachograph. This is likely to be true in view of the negligible obstruction provided by the pneumotachograph.

OVERDOSED PATIENTS

Twelve patients, aged 18-48 years, admitted to the intensive care ward were studied. Seven (four female, three male) had taken overdoses of medium-acting barbiturates, and five (four female, one male) had taken salicylates. At intervals through their recovery a single pair of magnetometer coils was positioned with the patient supine and the head of the bed raised 45°. A recording of magnetometer movement was obtained for at least 60 breaths. At the end of this recording a volume recording was performed using a pneumotachograph attached either to an endotracheal tube or facemask. The recordings were only accepted if the relationship between magnetometer movement and volume appeared linear with a coefficient of correlation of +0·95 or greater. Recordings were repeated at intervals of 12-24 hours during recovery.

ANAESTHETISED PATIENTS

After giving informed consent five patients undergoing general anaesthesia for minor genitourinary operations were similarly studied. Each had received premedication with an opiate and an anticholinergic agent. They were studied before, during, and after the intravenous injection of 300–400 mg of thiopentone. All five subjects had been anaesthetised for similar procedures previously.

The magnetometer coils were positioned as described above and calibrated against a pneumotachograph several minutes before the recording. In each patient, during induction of anaesthesia, the chin was gently supported to avoid any upper airway obstruction.

Results

RELIABILITY OF A SINGLE PAIR OF MAGNETOMETER COILS

All five subjects showed a close correlation between times of inspiration and expiration measured by magnetometer and by pneumotachograph (table 1). The coefficient of variation of the magnetometer assessment of inspiratory time was 5% or less in all subjects in all positions except for two subjects lying on their right sides.

The accuracy of the magnetometer measurement of tidal volume was dependent upon

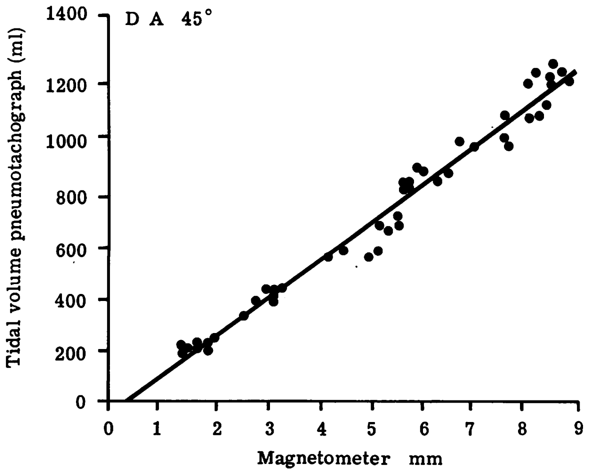

Fig 1 *Tidal volume measured by integrated pneumotachograph plotted against magnetometer movement for one normal subject lying with the backrest raised to 45°. The solid line is the line of regression.*

Table 1 *Coefficients of correlation between integrated pneumotachograph signal and magnetometer for volume and time of inspiration in five normal subjects studied in five positions*

Position	*Volume Subjects*					*Inspiratory Time Subjects*				
	1	*2*	*3*	*4*	*5*	*1*	*2*	*3*	*4*	*5*
45°	0·91	0·98	0·93	0·99	0·99	0·97	0·98	0·99	0·99	0·96
Lying	0·95	0·97	0·90	0·98	0·92	0·99	0·99	0·99	0·99	0·95
Standing	0·88	0·91	0·93	0·94	0·94	0·99	0·98	0·99	0·99	0·99
On left	0·95	0·89	0·68	0·89	0·96	0·99	0·98	0·98	0·99	0·86
On right	0·80	0·97	0·78	0·94	0·45	0·98	0·95	0·99	0·99	0·69

position. Close correlation was only found throughout the tidal volume range studied with the backrest at 45° (fig 1). In this position in all five subjects only 15% of breaths deviated by more than 100 ml from the regression line. A high correlation was found in the supine position up to tidal volumes of 1000 ml, but the magnetometer was of little use in either right or left lateral positions. For any given volume the magnetometer movement was different in each position and in each subject.

BARBITURATE OVERDOSE

In all seven patients with overdoses of barbiturates the lowest tidal volume was obtained on the first recording made when their level of consciousness was lowest (table 2). The tidal volume increased with recovery and in five patients this was associated with a progressive decrease in respiratory rate. In the other two patients (6 and 7 in table 2) the respiratory rate was lowest in the initial recording and increased with recovery. These two were the only patients with a raised arterial PCO_2 level at the time of the recording. The lowest respiratory rate found during unconsciousness in the other five patients was 19 breaths per minute. Inspiratory and expiratory time generally changed together, most of the change in rate being explained by changes in times of expiration.

There was less variation in tidal volume from breath to breath at deeper levels of coma, as shown by an increase in the coefficient of variation of tidal volume with recovery (table 2). All of the patients showed an increase in mean inspiratory flow rate (Vt/Ti) with recovery and there were also changes in timing within the respiratory cycle. In the five patients showing a decrease in respiratory rate with recovery, inspiratory time as a fraction of total cycle time (Ti/Ttot=Ti/Ti+Te) progressively decreased also with the exception of one recording in patient 3 (table 2).

Table 2 *Details of breathing pattern recorded with a single pair of magnetometer coils in seven patients with overdoses of barbiturates. The last column shows coefficients of variation of tidal volumes (ie standard deviation divided by mean tidal volume). Level of consciousness was assessed on the following scale: 0=fully conscious, 1=drowsy, appropriate response to verbal stimuli, 2 = inappropriate response to verbal stimuli and pain, 3=response only to painful stimuli, 4=no response to painful stimuli*

Patient	*Level of consciousness*	*Mean tidal vol (Vt) (ml)*	*Respiratory rate (breaths per min)*	*Mean inspiratory time (Ti) (s)*	*Mean expiratory time (Te) (s)*	*Mean inspiratory flow rate Vt/Ti (ml/s)*	*Ti/Ti+Te (%)*	*Coefficient of variation (Vt) (%)*
1	3	261	20	1·32	1·69	198	44	11
	1	339	18	1·52	1·75	223	46	35
	0	325	15	1·35	2·77	241	33	22
2	3	253	36	0·82	0·86	309	49	7
	2	267	33	0·87	0·95	307	48	8
	0	344	18	1·04	2·29	331	31	35
3	4	138	21	0·77	2·09	179	27	14
	3	243	19	1·30	1·86	187	41	21
	0	391	16	1·16	2·59	337	31	22
4	3	176	31	0·73	1·21	241	38	14
	3	276	25	0·68	1·72	406	28	10
	1	316	14	1·01	3·18	313	24	39
	0	420	10	1·44	4·56	292	24	22
5	4	229	26	0·93	1·38	246	40	4
	0	265	18	0·98	2·35	270	30	47
6	4	94	14	1·50	2·79	63	35	17
	1	440	18	1·27	2·06	346	38	26
	0	343	19	1·30	1·86	264	41	23
7	4	326	13	1·25	3·37	261	27	21
	0	742	22	1·11	1·62	618	41	34

The addition of a pneumotachograph to an endotracheal tube or facemask regularly produced changes in the pattern of breathing. The predominant change was an increase in tidal volume. In conscious patients the mean increase was 25% (range 0%–60%) and this was associated with a decrease in respiratory rate. In unconscious patients the mean increase in tidal volume was 33% (range 13%-55%) while rate increased as a result of shortening of expiratory time. Since the pneumotachograph was attached after the recording used for analysis the changes did not affect the patterns analysed but served to help in the volume calibration of the magnetometer.

ANAESTHETISED PATIENTS

In all five patients tidal volume decreased after the intravenous injection of thiopentone. In four patients this was preceded by one to three deep sighing breaths and a variable period of apnoea (fig 2). The effect on respiratory frequency was variable (table 3). In the three patients who

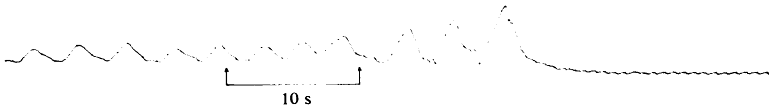

Fig 2 *Breathing pattern recorded by a single pair of magnetometer coils in one subject during injection of thiopentone. Sighing breaths are immediately followed by apnoea.*

showed the most marked period of respiratory depression immediately, with apnoea lasting 15-170 seconds, respiratory rate was slowed when a stable pattern of respiration returned but in the other two patients the rate was increased. The changes in rate were caused by times of inspiration and expiration changing in the same direction.

SALICYLATE OVERDOSE

Recordings in five patients with salicylate overdose indicated that the method was also applicable to situations in which the tidal volume was increased. Tidal volume usually decreased progressively as salicylate levels fell (table 4). Variations in frequency were caused predominantly by changes in expiratory time while inspiratory time remained relatively constant in each patient during recovery.

Discussion

The evaluation of the single pair of magnetometer coils in normal subjects indicates that, with some limitations, it is likely to be useful for monitoring breathing in patients. As might be expected, measurement of breath times is accurate but tidal volume measurements are more variable and dependent on position. Volume measurement was found to be reliable with the backrest at 45° and for a normal range of tidal volumes in the supine position. The results are comparable with those of Ashutosh *et al*[8] who contrasted magnetometers with the impedance pneumograph. Magnetometer coils are small and easily attached and do not interfere with standard nursing care. Indeed, two of our patients with barbiturate overdose were undergoing haemoperfusion at the time of the recordings.

The calibration of the magnetometer for volume is different in each position, and movements which will occur as part of the nursing of patients in coma necessitate recalibration if an accurate volume is required. Without changes in posture calibration can be maintained for several hours. Even with movement the volume record remains semiquantitative and the technique may be used in this way with periodic volume calibration to allow more detailed study of the pattern of breathing as illustrated here.

The advantage of magnetometry is that there is no interference with the airway, except during calibration. When a facemask was used in conscious subjects we found an increase in tidal volume with decrease in rate as described by Gilbert.[1] In unconscious subjects the increase in tidal volume was associated with a slight increase in respiratory frequency. These changes were greater when a larger dead space was used and probably represent the response to the chemical stimulus of an added dead space.

The findings in barbiturate overdose and in thiopentone anaesthesia indicate that there may be two stages of respiratory depression by barbiturates in man. The initial change is a decrease in tidal volume with an increase in respiratory frequency while in the second stage there is a further decrease in tidal volume with a slowing of respiratory rate to produce slow, shallow breathing. The two patients with barbiturate overdose and a slow respiratory rate had hypercapnia, and in thiopentone anaesthesia a slow rate was associated with periods of marked respiratory depression. This indicates that in the management of barbiturate overdose it is important to observe the respiratory rate carefully. Slowing of breathing is an indication that arterial blood

Table 3 *Thiopentone dose and change in respiration in five patients undergoing anaesthesia for minor genitourinary operations*

Patient	*Mean tidal volume pre-thiopentone (ml)*	*Mean respiratory rate pre-thiopentone (breaths per min)*	*Dose of thiopentone (mg)*	*Immediate response to thiopentone*	*Mean tidal volume after thiopentone (ml)*	*Mean respiratory rate after thiopentone (breaths per min)*
1	288	22	350	Sigh and 15 seconds apnoea, 80 seconds virtual apnoea	170	16
2	293	17	400	Sigh and 25 seconds apnoea	124	12
3	353	20	300	Sigh and 170 seconds apnoea	90	17
4	381	17	300	Sigh and 12 seconds apnoea	254	24
5	230	14	350	No sigh or apnoea	140	18

Table 4 *Salicylate level, tidal volume, respiratory rate, and breath times in five patients during recovery from salicylate overdose*

Patient	*Salicylate level (mg/l)*	*Mean tidal volume (ml)*	*Respiratory rate (breaths per min)*	*Mean inspiration time (s)*	*Mean expiration time (s)*
1	520	494	27	1·23	1·00
	0	499	15	1·55	2·34
2	590	481	23	1·15	1·41
	0	224	16	1·39	2·35
3	790	699	18	1·01	2·34
	588	722	16	1·18	2·53
	171	376	13	1·15	3·65
	0	395	22	1·15	1·60
4	450	639	22	1·19	1·55
	317	516	29	0·98	1·10
	167	340	28	0·97	1·21
	50	223	24	1·00	1·53
5	500	680	24	1·12	1·38
	317	451	26	1·01	1·30

gases should be measured to assess the need for ventilatory support.

Gautier and Gaudy[9] have recently studied the effect of intravenous thiopentone in cats and man. In man they found a decrease in tidal volume and an increase in rate when thiopentone was injected intravenously as part of general anaesthesia. They only saw apnoea at the time of induction in one case and were probably observing the first stage of barbiturate effects seen in our patients. Higher levels of thiopentone would probably have produced slowing of respiration. With barbiturate overdose both Vt/Ti and Ti/Ttot changed indicating alteration in both the drive to respiration and the timing of events within the respiratory cycle.

In salicylate overdose the main finding was a decrease in tidal volume as salicylate levels fell. Inspiratory time remained relatively constant so Vt/Ti decreased, indicating a decrease in respiratory drive with recovery. The increase in tidal volume without changing inspiratory time is similar to the findings with other respiratory stimuli in man.[10]

Although the method was assessed in males initially it was also used in female overdose patients and considered valid since a satisfactory volume calibration was a criterion for accepting the recordings. The single pair of coils positioned centrally provides a simple method for monitoring breathing in acutely ill patients although it is unlikely to measure volumes accurately in the presence of marked airflow obstruction. The results obtained can provide information for more detailed study of breathing patterns in situations such as drug overdose.

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References

1 Gilbert R, Auchincloss JH, Brodsky J, Boden W. Changes in tidal volume, frequency and ventilation induced by their measurement. *J Appl Physiol* 1972; **33**:252–4.

2 Gillam PMS. Patterns of respiration in human beings at rest and during sleep. *Bull Physiopath Respir* 1972; **8**:1059–70.

3 Mead J, Peterson N, Grimby G, Mead J. Pulmonary ventilation as measured from body surface movement. *Science* 1967; **156**:1383–4.

4 Konno K, Mead J. Measurement of the separate volume changes of rib cage and abdomen during breathing. *J Appl Physiol* 1967; **22**: 407–22.

5 Higenbottam T, Allen D, Loh L, Clark TJH. Abdominal wall movement in normals and patients with hemidiaphragmatic and bilateral diaphragmatic palsy. *Thorax* 1977; **32**:589–95.

6 Stagg D, Goldman M, Newsom-Davis J. Computer aided measurements of breath volume and time components using magnetometers. *J Appl Physiol* 1978; **44**:623–33.

7 Peyrot AH, Hertel GA, Stevens AA. Pulmonary ventilation measured by a single linear displacement transducer. *Med Biol Eng* 1969; **7**:233–4.

8 Ashutosh K, Gilbert R, Auchincloss JH, Erlebacher J, Peppi D. Impedance pneumograph and magnetometer methods for monitoring tidal volume. *J Appl Physiol* 1974; **37**:964–6.

9 Gautier H, Gaudy JH. Changes in ventilatory pattern induced by intravenous anaesthetic agents in human subjects. *J Appl Physiol* 1978; **45**:171–6.

10 Clark FJ, Von Euler C. On the regulation of depth and rate of breathing. *J Physiol* 1972; **222**:267–95.