Effect of positive expiratory pressure on breathing pattern in healthy subjects


Effect of positive expiratory pressure on breathing pattern in healthy subjects. C.P. van der Schans, W. de Jong, G. de Vries, D.S. Postma, G.H. Koeter, Th.W. van der Mark.

ABSTRACT: The purpose of this study was to register breathing patterns, in healthy subjects, during breathing with a positive expiratory pressure. Integrated electromyographic (EMG) activity of the following muscles was assessed: scalene muscle, parasternal muscle and abdominal muscles, using surface electrodes. Inspiration time, expiration time, total breathing cycle time, tidal volume and breathing frequency were measured using a water-sealed spirometer. Functional residual capacity was measured using a body plethysmograph. Oxygen uptake and carbon dioxide output were measured using an automatized ergometry set-up. All measurements were performed during undisturbed breathing and during breathing with positive expiratory pressures of 5 and 15 cmH₂O.

Phasic activity, but not tonic activity, of the scalene muscles and the abdominal muscles increased significantly during breathing with the expiratory pressures. No significant change was observed in phasic or tonic activity of the parasternal muscle. Mean (SD) tidal volume increased significantly from 0.8(0.2) l during undisturbed breathing to 1.1(0.3) l and 1.5(0.7) l during breathing with the expiratory pressures of 5 cmH₂O and of 15 cmH₂O, respectively. Respiration times, breathing frequency, oxygen uptake, carbon dioxide output and functional residual capacity remained unchanged.

It can be concluded that, in healthy subjects, positive expiratory pressure increases tidal volume by activity of both expiratory and inspiratory muscles, while functional residual capacity remains unchanged. The changes appeared to be pressure dependent.

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Many studies have focused on the effect of positive expiratory pressure breathing in patients with pulmonary diseases [1-4]. Physiological changes have been related to positive expiratory pressure breathing in patients with chronic obstructive pulmonary disease (COPD), e.g. decreased respiratory rate, increased tidal volume, and increased arterial oxygen saturation (SaO₂) [5-7]. These changes can be explained by a diminution of the airway collapse [5], which may arise in some patients with severe airflow obstruction. This implies that the beneficial effects of positive expiratory pressure breathing are related to pathological changes in the lung and that these changes would not arise in healthy subjects. However, no data are as yet available with regard to the effect of positive expiratory pressure breathing in healthy subjects.

Our purpose was to study breathing patterns in healthy subjects with and without positive expiratory pressures, by recording respiratory muscle activity and pulmonary function.

Subjects

Ten healthy subjects took part in this study after informed consent. Some characteristics of the subjects are summarized in table 1. The study was approved by the Medical Ethics Committee of our University Hospital.

Methods

Electromyography

Myoelectrical activity of several respiratory muscles was recorded by a pair of Ag/AgCl paediatric surface monitoring electrodes with solid gel (Red Dot 3M) for each muscle. The midline distance between the electrodes was 4 cm. Electrode position was not changed during the measurements. The following muscles were measured: the scalene muscle, the parasternal muscle, the diaphragm and the abdominal muscles.
The electrodes for registration of the myoelectrical activity of the scalene muscle were located in the right supraclavicular fossa, just behind the sternocleidomastoid muscle. These electrodes may also have registered some activity of the sternocleidomastoid muscle, but this muscle probably has more or less the same respiratory action as the scalene muscle [8]. The electrodes for registration of the myoelectrical activity of the parasternal muscles were placed on the right second intercostal space, directly lateral to the sternum. One pair of electrodes was placed on the right axillary line in the eighth intercostal space, to register the myoelectrical activity of the diaphragm. The above-mentioned muscles were chosen because they are thought to be primary inspiratory muscles [9-11]. The electrodes for registration of the myoelectrical activity of the abdominal muscles were placed on the right midclavicular line, at the height of the umbilicus. The abdominal muscles were chosen as they are thought to have an expiratory function during expiratory loading. De Kroeyer and co-workers [12] showed that the transversus abdominal muscle is preferentially recruited during expiration but that the oblique abdominal muscle also has an expiratory action. The surface integrated electromyographic (IEMG) signal will be dominated by the activity of the oblique abdominal muscle when this muscle is very active but will probably also register activity of the transversus abdominal muscle, especially when this muscle has a relatively high activity. Activity of these respiratory muscles does not necessarily reflect respiratory action but may, in theory, also reflect postural activity. However, position of the subjects was similar between the measurements and no regular head, shoulder or trunk movements were observed. It has been shown that the use of surface electrodes in the registration of myoelectrical activity is a reliable method, especially when the different measurements are performed on the same day [13].

The myoelectrical signal was amplified 10,000 times and filtered using a band pass filter (6 dB/octave, 3 dB points at 50 and 900 Hz). An additional 50 Hz notch filter was used to suppress hum. Thereafter, the signal was led into an integrator with a time constant of 0.25 s as described by Gottlieb and Agarwal [14]. All settings, including band width and amplification, were held constant during the different measurements. The signal was printed out and analysed by a modified method as described by Druzd and Sharp [15]. The burst deflection of the IEMG activity was considered to reflect phasic activity of the muscles involved. The deflection between the bursts was considered to reflect tonic activity or absence of IEMG activity. Changes in deflection between the bursts were thought to reflect changes in tonic activity. Phasic and tonic IEMG activity were expressed as cm deflection. The IEMG signal also holds some electrocardiographic signal, which was recognized as a regular stable signal throughout the registration, with a small amplitude and a frequency of about 60-80 per min. The amplitude of the electrocardiographic signal was considered to be constant during our measurements. Differences in deflection of the registered signal between the three measurements are, therefore, thought to reflect differences in phasic and/or tonic IEMG activity. The absolute values of the surface EMG signal are dependent on many factors, such as condition of the skin and electrode placement [16]. In this study, we analysed intra-individual changes in IEMG activity and not inter-individual differences. Reproducibility of the EMG measurements was measured in five healthy subjects; in each subject, three measurements for each muscle were performed during one session. IEMG activity of the four muscle groups of interest was simultaneously registered during 20 s. Measurements were carried out three times. Firstly, the subjects breathed through a face-mask, with an inspiratory and an expiratory outlet, each with a one way valve. A pressure valve (Vital Signs) [17] was attached to the expiratory outlet, creating a relatively flow-independent positive expiratory mouth pressure of 15 cmH₂O. The face-mask was attached to the face of the subjects using two bands over the head. Care was taken that no air leaked between face and mask. Thereafter, the subjects breathed undisturbed without the mask for a few minutes, in order to normalize their breathing pattern. During the second measurement, the subjects breathed through the same face-mask, but now with an expiratory pressure valve inducing a positive expiratory mouth pressure of 5 cmH₂O. Thereafter, the subjects again breathed for a few minutes undisturbed, without the mask. During the third measurement, the subjects breathed undisturbed through the face-mask without any expiratory pressure. Mean phasic and tonic activity during each registration was taken for analysis. The registrations were carried out

### Table 1. - Characteristics of the subjects

<table>
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FEV₁: forced expiratory volume in one second; % pred: as a percentage of the predicted value; TLC: total lung capacity; FRC: functional residual capacity.
in fixed order and not at random. We expected that the deflection of the signal was the highest during the expiratory pressure of 15 cmH\textsubscript{2}O; the amplification was set according to this signal. Therefore, we always started with the highest expiratory pressure.

**Pulmonary function**

Inspiration time, expiration time, breathing cycle time and tidal volume (V\textsubscript{T}) were measured three times using a water-sealed spirometer. Inspiration time was defined as the time within one breathing cycle during which inspiratory flow could be detected. Expiration time was defined as the time during which expiratory flow could be detected. These definitions differ from the commonly used definition, in which inspiration time is defined as the time between the onset of the inspiration and the onset of expiration, and expiration as the time between the onset of expiration and the onset of inspiration. However, using this latter method, small breathing pauses are, in our opinion, wrongly considered as part of expiration or inspiration.

Measurements were first made during undisturbed breathing. During the second measurement, the facemask with a positive expiratory pressure valve was attached to the expiratory outlet, outside the body plethysmograph. Three measurements for each expiratory pressure were subsequently performed, and the mean values were taken for analysis.

After the subject was accustomed to breathing with the expiratory pressure (usually one minute), oxygen uptake (V\textsubscript{O\textsubscript{2}}) and carbon dioxide output (V\textsubscript{CO\textsubscript{2}}) were measured over 3 min, in intervals of 30 s. The values obtained in the 30 s intervals were checked for stability to ensure a steady-state condition. This procedure was performed three times, without and with positive expiratory pressure (5 and 15 cmH\textsubscript{2}O), using an automatized ergometry set up (Jaeger EOS-sprint). The first measurements were taken during undisturbed breathing. Thereafter, a positive expiratory pressure valve was connected to the expiratory outlet, outside the body plethysmograph. Three measurements for each expiratory pressure were subsequently performed, and the mean values were taken for analysis.

IEMG registration, pulmonary function testing using a water-sealed spirometer, V\textsubscript{O\textsubscript{2}} and V\textsubscript{CO\textsubscript{2}}, and pulmonary function tests in the body plethysmograph were performed at separate sessions. Conditions between the measurements were held as constant as possible. All measurements were started when the subjects felt accustomed to breathing with a positive expiratory pressure, and a stable breathing pattern was reached (after one minute). The only instruction the subjects were given during all measurements, was that a resistance would be attached to the expiration. They were not told how to respond to this stimulus.

**Statistical analysis**

Statistical analysis was performed using the "Statistical package of the social sciences" (SPSS-Pc+) [18]. Distribution of the variables was tested using the Kolmogorov-Smirnov Goodness of Fit test. There were no indications that the distribution differed from the normal distribution. Tonic and phasic activity of respiratory muscles, inspiration and expiration time, total breathing cycle time, V\textsubscript{T}, FRC, V\textsubscript{O\textsubscript{2}} and V\textsubscript{CO\textsubscript{2}}, all with and without positive expiratory pressure, were compared using analysis of variance (ANOVA). When appropriate, the Student's t-test for paired samples was used to compare differences between two measurements. A significant difference was defined as p<0.05.

**Results**

**Integrated electromyographic activity**

During undisturbed breathing, phasic activity could be registered by the "diaphragm" electrodes during inspiration. However, during breathing with an expiratory pressure phasic activity, which was similar to the tracings of the abdominal muscles, was recorded between the phasic bursts of the diaphragm. Differences in tonic or phasic activity of the diaphragm could, therefore, not be reliably detected. Therefore, we decided not to take the "diaphragm" recordings for analysis.

Variation coefficient (intra-individual) during three sessions of undisturbed breathing was: phasic activity of the abdominal muscles 6%; tonic activity of the abdominal muscles 12%; phasic activity of the parasternal muscle 19%; tonic activity of the parasternal muscle 15%; phasic activity of the scalene muscle 19%; tonic activity of the scalene muscle 9%.

An example of IEMG activity of one subject during undisturbed breathing and during breathing with positive expiratory pressures is shown in figure 1. Phasic activity of the abdominal muscles synchronized with tonic activity of the parasternal muscle and the scalene muscle. This can be explained by different respiratory actions. The abdominal muscles probably act phasically mainly during expiration, and the parasternal muscle and the scalene muscle mainly during inspiration. Mean (±SD) phasic IEMG activity of the abdominal muscles and the scalene muscle, expressed in arbitrary units as cm deflection, with and without positive expiratory pressure is shown in figures 2 and 3.
POSITIVE EXPIRATORY PRESSURE IN HEALTHY SUBJECTS

There were no significant differences in tonic IEMG activity of the abdominal muscles, the scalene muscles and the parasternal muscles, with and without breathing with the expiratory pressures.

Phasic IEMG activity of the abdominal muscles increased significantly during breathing with the expiratory pressures ($p=0.02$) (undisturbed versus $5 \text{ cmH}_2\text{O}$ expiratory pressure $p=0.04$; undisturbed versus $15 \text{ cmH}_2\text{O}$ expiratory pressure $p=0.01$; expiratory pressure $5 \text{ cmH}_2\text{O}$ versus expiratory pressure $15 \text{ cmH}_2\text{O}$ $p=0.19$). Phasic activity of the parasternal muscles was not significantly different during breathing with the expiratory pressures. Phasic activity of the scalene muscle was significantly higher during breathing with the expiratory pressures ($p=0.005$) (undisturbed versus expiratory pressure $5 \text{ cmH}_2\text{O}$ $p=0.046$; undisturbed versus expiratory pressure $15 \text{ cmH}_2\text{O}$ $p=0.002$; expiratory pressure $5 \text{ cmH}_2\text{O}$ versus expiratory pressure $15 \text{ cmH}_2\text{O}$ $p=0.01$).

Ventilation (table 2)

No significant changes were seen in inspiration time, expiration time, and total breathing cycle time with and without expiratory pressure. Consequently breathing frequency also did not change significantly during positive expiratory pressure breathing as compared to undisturbed breathing. Mean (sd) Vr measured using a watersealed spirometer was significantly higher during breathing with the expiratory pressure (undisturbed versus expiratory pressure $5 \text{ cmH}_2\text{O}$ $p=0.006$, undisturbed versus expiratory pressure $15 \text{ cmH}_2\text{O}$ $p=0.009$,
spiratory muscle tension. They found an increased expiratory muscles led to an increased reflex activity of expiratory muscles. This can be explained by reflex muscles. In their model, an increased load for the inspiratory muscles increases activity of the expiratory as well as the inspiratory muscles. Our observation in healthy subjects is to some extent similar to the observation of Roa et al. [23]. In an animal study, they also found that an expiratory load increased expiratory as well as inspiratory muscle activity. Bishop et al. [24, 25] also found, in studies in anaesthetized cats, that expiratory loading increased inspiratory muscle activity. The latter authors stated that man and cat differ in their ventilatory response to pressure breathing. Therefore, the results of our study cannot be explained by data obtained from animal studies.

The augmentation of phasic muscle activity due to positive expiratory pressure breathing was more evident than the increase in tonic muscle activity. Tonic respiratory muscle activity is employed to maintain a certain lung volume. Phasic respiratory muscle activity brings about a change in the volume of the thorax and thus to airflow. The results of our study in healthy subjects indicate that the changes in respiratory phasic muscle activity, induced by an expiratory pressure, influence ventilation by increasing flow and not functional residual capacity leading to hyperinflation. This is consistent with our observation that VT increased but FRC did not. The increase of VT and of phasic activity of the scalene muscle and the abdominal muscles appeared to be dependent on the strength of the positive expiratory pressure imposed. In general, VT may increase due to an increased ventilatory demand, as a result of increased oxygen necessity or increased carbon dioxide output [26]. The results of our study are consistent with that of Suzuki et al. [27]. They found that expiratory loading during 60 min increased VT and decreased breathing frequency. As a result of the expiratory loading, they found signs of fatigue of the expiratory as well as the inspiratory muscles. The expiratory loading and the period during which the expiratory loading was applied was, however, much higher than in our study. The increase of VT in their study may, at least partly, be explained by metabolic changes due to exertion.

We considered the ventilatory response to be in a steady-state during our measurements of oxygen uptake and carbon dioxide output. Steady-state condition was defined, according to Åstrand and Rodahl [28], as the work situation where oxygen uptake equals the oxygen requirement of the tissues. Ventilation during this state is considered to be at a fairly constant level. This steady-state condition is reached within one minute for workloads up to 50 W [28]. The workload of breathing with expiratory pressures described in our study is considerably less than 50 W. Therefore, it can be assumed that the subjects in our study were in a steady-state. The changes in breathing pattern found were not accompanied by
a measurable increase of oxygen uptake or carbon dioxide output. Since VT increased during expiratory pressure breathing, end-tidal CO₂ concentration tended to decrease. We expect the arterial carbon dioxide tension (Paco₂) to be in the horizontal part of the CO₂ response curve. Therefore, we think it unlikely that the changes in breathing pattern in our study were caused by chemosensory activation due to increased work of breathing. In view of an immeasurable change of oxygen uptake, we assume that the energy expenditure due to the breathing system is so small that it is unlikely that the change in breathing pattern is caused by an increased work of breathing. The changes in breathing pattern are more likely to be induced by reflex activity by the positive expiratory pressure. No data are available concerning the course of the response when positive expiratory pressure is maintained over a longer period.

Urbach et al. [19] found that VT increased due to continuous positive airway pressures of 10, 20 and 30 cmH₂O. This effect was explained by these authors by increased expiratory activity as a reaction to the inspiratory support to compensate for overinflation of the lungs. The results of our study show that breathing with a positive expiratory pressure induces reflex activity of the respiratory muscles, leading to a higher tidal volume. This is in contrast with the results of the study of Garrard and Lane [29], who observed a decrease of VT and an increase of FRC during breathing with an expiratory pressure in combination with carbon dioxide rebreathing. They suggested that breathing pattern may be altered due to the secondary result of the expiratory pressure in their study, namely an increased FRC. The differences from our study may be explained by the carbon dioxide rebreathing in the study of Garrard and Lane [29], since an increase of Paco₂ itself may increase inspiratory activity [30]. The results of our study show that breathing pattern may be influenced directly by the expiratory pressure, without a significant change in FRC. Green et al. [31] found a decrease of VT during continuous positive pressure breathing, using an inversed vacuum cleaner, in combination with moderate hypercapnia. Differences between their study and ours, however, do not allow a true comparison.

The increase of VT in our study, as a result of the expiratory pressure imposed, was not accompanied by a significant change in inspiration time. This corresponds with the results of a study of Clarke and von Euler [32]. They found that inspiration time did not change with an increase of VT 1.5-2 times the euclidean value (so-called range 1), which is within the range in our study. Inspiration time may decrease only when the increase of VT is higher (so called range 2).

The results of our study, therefore, show that in healthy subjects positive expiratory pressure breathing induces a breathing pattern which is characterized by an increased VT, due to increased activity of both inspiratory and expiratory muscles, without a change in FRC. The changes appeared to be dependent on the expiratory pressure imposed.

References