Comparison of occlusion pressure and ventilatory responses

D. H. LEDERER, M. D. ALTOSE, S. G. KELSEN, AND N. S. CHERNIACK

From the Cardiovascular-Pulmonary Division, Department of Medicine, University of Pennsylvania School of Medicine, Philadelphia, Pennsylvania 19104, USA

Lederer, D. H., Altose, M. D., Kelsen, S. G., and Cherniack, N. S. (1977). Thorax, 32, 212–220. Comparison of occlusion pressure and ventilatory responses. The airway pressure 100 msec after the onset of an inspiratory effort against a closed airway (P_{100}, occlusion pressure) is theoretically a more accurate index of respiratory neuron motor output than ventilation. Occlusion pressure and ventilation responses to hypercapnia were compared in repeated trials in 10 normal subjects while in the seated and supine positions. During progressive hypercapnia changes in P_{100} were also compared to changes in tidal volume and inspiratory airflow. These studies show that occlusion pressure increases linearly with hypercapnia in both sitting and supine subjects. Changing from the seated to the supine position, or vice versa, had no significant effect on either ventilation or occlusion pressure responses to CO₂. Correlations between P_{100} and ventilation or airflow rate were significantly higher than correlations between P_{100} and tidal volume or breathing frequency. Intermittent random airway occlusion had no effect on either ventilation or pattern of breathing during hypercapnia. Occlusion pressure responses were no less variable than ventilation responses in groups of subjects whether studied seated or supine. However, maintenance of a constant moderate breathing frequency (20 breaths per minute) reduced the interindividual variability in ventilation and occlusion pressure responses to hypercapnia.

Respiratory sensitivity to CO₂ is generally evaluated by the change in ventilation during hypercapnia. Ventilation, however, is an imperfect measure of respiratory neural efferent activity since the level of ventilation may be affected by alterations in the mechanical properties of the lung and chest wall independently of changes in respiratory activity (Cherniack and Snidal, 1956; Eldridge and Davis, 1959; Brodovsky et al., 1960; Milic-Emili and Tyler, 1963). Even in normal individuals in whom pulmonary performance is unimpaired, ventilatory responses to hypercapnia vary markedly from person to person, and in the same individual ventilatory responses differ widely from day to day (Read, 1967; Kallos et al., 1972; Patrick and Howard, 1972; Saunders et al., 1972; Hirshman et al., 1975).

Recently, occlusion pressure, the mouth pressure during airway occlusion 100 msec after the onset of inspiration (P_{100}), has been proposed as a more accurate index of respiratory neural efferent activity (Grunstein et al., 1973; Whitelaw et al., 1975; Altose et al., 1976b; Kelsen et al., 1976). The relationship between respiratory output and occlusion pressure, determined during periods of arrested airflow, should not be affected by changes in the flow-resistive and elastic properties of the ventilatory apparatus. However, occlusion pressure, at any level of respiratory activity, may be substantially altered through changes in functional residual capacity, which in turn affect the resting length of the inspiratory muscles (Evanich et al., 1973). Changes in functional residual capacity could also alter the relationship between occlusion pressure and ventilation.

Because ventilation and not occlusion pressure determines arterial blood gas tensions, it is important to ascertain the relationship between occlusion pressure and ventilation and its various components.

In the present study, occlusion pressure and ventilatory responses to hypercapnia were compared in a group of subjects, in the same individuals on different days and at different levels of functional residual capacity achieved by changing from the supine to the seated position or vice versa.
Comparison of occlusion pressure and ventilatory responses

Since airway occlusion, a maximal load on the respiratory muscles, could excite spinal reflexes or supraspinal mechanisms which might alter the level of respiratory activity for any given chemical drive (Corda et al., 1965; Knill et al., 1976), the effect of intermittent airway occlusion on the level and pattern of ventilation during hypercapnia was also assessed.

Methods

Ten subjects, eight men and two women, ranging in age from 20 to 35 years were studied. All were in good health and none smoked cigarettes or had symptoms or physical signs of lung disease. Informed consent for the study was obtained in all subjects.

Pulmonary function tests were performed in duplicate using a 13.5 l Collins spirometer and included the determination of vital capacity (VC), forced expiratory volume in one second (FEV$_{1.0}$), and maximum mid-expiratory flow rates (MMF). Functional residual capacity (FRC) was determined with the subjects in both the sitting and the supine position by the helium dilution technique. The physical characteristics of the subjects and the results of their pulmonary function tests are shown in Table 1.

Studies were performed late in the morning, and the subjects were instructed to refrain from eating and drinking coffee for at least three hours before the tests.

Progressive hypercapnia was produced by having the subjects rebreathe from a bag containing a gas mixture of 7% CO$_2$ in oxygen (Read, 1967). The end-tidal CO$_2$ concentration was sampled at the mouth and measured with an infrared analyser (Godart Capnograph). After analysis the sampled gas was returned to the rebreathing bag. Tidal volume was recorded by electrical integration of the signal from a pneumotachograph (Fleisch Pneumotachograph 2, i/a 7320, and Statham Differential Pressure Transducer, PM-5) which was connected to the rebreathing bag by a high-velocity one-way valve (Hans Rudolf, Inc., P-308). The circuit had a resistance of 1.2 cmH$_2$O/l/sec at a flow rate of 2.0 l/sec. The pneumotachograph was linear over the range of airflows encountered.

During rebreathing the airway was periodically occluded for a single breath by closing the large-bore stopcock placed in the inspiratory line. At least 10 occlusions were performed during each rebreathing trial. The airway was occluded randomly but occlusions were presented no more frequently than every eighth breath. A screen prevented the subjects from knowing when airway occlusion would occur. The mouth pressure was recorded with a pressure transducer (Statham PM-131, TC), and the occlusion pressure 100 msec after the onset of inspiration (P$_{100}$) was measured. All tracings were displayed on an oscilloscopic apparatus and recorded on photosensitive paper (Electronics for Medicine, DR-8).

Responses to progressive hypercapnia were determined on three separate days. On the first day two rebreathing trials were performed with the subjects seated; the first with periodic airway occlusion and the second with no airway occlusion. In five of the 10 subjects the order of the rebreathing trials was reversed. The ventilatory responses during the two trials were compared.

On the second day ventilatory and occlusion pressure responses to CO$_2$ were determined with the subjects seated and then supine or vice versa, while on the third day this order in any given subject was reversed.

On another day additional studies were performed on five subjects to evaluate the effect of tidal volume and breathing frequency in contributing to the variability of ventilation and occlusion pressure responses to hypercapnia. Each subject performed five rebreathing trials: (1) adopting any breathing pattern which seemed natural to him; (2) at a fixed tidal volume of 1 litre; (3) at a fixed tidal volume of 2 litres; (4) at a constant breathing frequency of 20 breaths per minute; and (5) at a constant breathing frequency of 35 breaths per minute. To maintain

<table>
<thead>
<tr>
<th>Subject</th>
<th>Age</th>
<th>Sex</th>
<th>FVC % pred</th>
<th>FEV$_{1.0}$ % pred</th>
<th>FEV$_{1.0}$/FVC</th>
<th>FRC Sitting</th>
<th>FRC Supine</th>
<th>% Decrease in FRC sitting to supine</th>
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<tr>
<td>1</td>
<td>30</td>
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<td>M</td>
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<td>107</td>
<td>91</td>
<td>3.61</td>
<td>2.54</td>
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<td>M</td>
<td>111</td>
<td>115</td>
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<td>89</td>
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<td>3.07</td>
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<tr>
<td>7</td>
<td>32</td>
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<td>2.61</td>
<td>1.61</td>
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<td>M</td>
<td>99</td>
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<td>10</td>
<td>23</td>
<td>F</td>
<td>108</td>
<td>113</td>
<td>81</td>
<td>3.08</td>
<td>2.05</td>
<td>33</td>
</tr>
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</table>
tidal volume constant, the subject was instructed to keep his tidal volume within the limits shown on an oscilloscope. To keep breathing frequency constant subjects breathed in synchrony with the beat of a metronome.

During progressive hypercapnia, at least three breaths after occlusion, measurements were made of respiratory frequency, inspiratory duration (tI), tidal volume (VT), average rate of inspiratory flow (VT/tI), peak inspiratory flow (Vpeak), and flow 100 msec after the onset of inspiration (V100). The relationships between PCO2, PI00, and these ventilatory indices were determined from the slopes of regression lines calculated by the method of least squares. The significance of differences in correlation coefficients was tested either by Student's t test or by non-parametric techniques (Mann-Whitney test) when distribution curves were skewed (Colquhoun, 1971).

Results

RESPONSES TO HYPERCAPNIA

Minute ventilation, tidal volume, and VT/tI increased linearly with hypercapnia. Similarly, PI00, V100 and Vpeak also increased linearly with increasing PCO2 during rebreathing. Frequency distributions of the linear correlation coefficients of the relation of PCO2 and minute ventilation, tidal volume, VT/tI, PI00, V100, and Vpeak during all rebreathing trials performed in the 10 subjects are shown in Fig. 1. Linear correlation coefficients greater than 0.9 were most commonly obtained from the minute ventilation-PCO2, VT/tI-PCO2, PI00-PCO2, and Vpeak-PCO2 relations, whether measured in the sitting or supine positions.

EFFECTS OF INTERMITTENT AIRWAY OCCLUSION

The effects of intermittent airway occlusion on ventilatory responses during progressive hypercapnia are summarised for all subjects in Table 2. There was no significant effect of airway occlusion on the changes in minute ventilation, tidal volume, VT/tI, V100, and Vpeak during hypercapnia.

In two subjects, ventilatory responses to CO2 were higher in rebreathing trials which included intermittent airway occlusion, while in three other subjects ventilatory responses were lower whereas airway occlusion was performed during rebreathing.

Ventilation at a PCO2 of 60 torr averaged 3.1 1/min + 1.8 higher in the studies in which airway occlusion was performed. This increase occurred in only six of the 10 subjects and, when noted, was due to a shortening of expiratory duration with consequent increase in breathing frequency. For the group as a whole, however, these changes (t test for paired observations) were not statistically significant (p > 0.05). There was no consistent effect of the order in which the trials were performed.

Plots of the relation of minute ventilation and tidal volume as described by Hey et al. (1966) were constructed to evaluate the effects of airway occlusion on the pattern of ventilation during rebreathing. The results in a representative subject (Fig. 2) show that intermittent airway occlusion during rebreathing had no effect on the tidal volume to ventilation relationship. The mean slope of the tidal volume to ventilation relationship in all subjects was 27 ml/min ± SE during rebreathing with intermittent airway occlusion and 31 ml/min ± SE 4 in trials where the airway was not occluded. This difference was not statistically significant.
Comparison of occlusion pressure and ventilatory responses

Table 2  Effect of airway occlusion on ventilatory responses to CO₂ (mean ± SE)

<table>
<thead>
<tr>
<th>Occlusion</th>
<th>( \dot{V} ) (l/min/torr CO₂)</th>
<th>( V_T ) (ml/torr CO₂)</th>
<th>( V_T/t_i ) (ml/sec/torr CO₂)</th>
<th>( \dot{V}_{\text{peak}} ) (ml/sec/torr CO₂)</th>
<th>( V_{100} ) (ml/sec/torr CO₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Occlusion</td>
<td>2.64±0.2</td>
<td>72±8</td>
<td>78±6</td>
<td>97±8</td>
<td>63±7</td>
</tr>
<tr>
<td>No occlusion</td>
<td>2.57±0.3</td>
<td>63±10</td>
<td>76±7</td>
<td>100±11</td>
<td>60±8</td>
</tr>
</tbody>
</table>

with the subjects seated and 34 ml/l±SE 3 with the subjects supine. There was no systematic effect on the duration of inspiration or expiration. No consistent effect on the responses to hypercapnia could be attributed to the order in which the rebreathing trials were performed.

RELATION OF OCCLUSION PRESSURE TO VENTILATORY INDICES
Linear correlation coefficients of the relation of \( P_{100} \) and minute ventilation, tidal volume, respiratory frequency, \( V_T/t_i \), \( V_{100} \), and \( \dot{V}_{\text{peak}} \) as respiratory drive was increased by progressive hypercapnia are shown in Fig. 3 for all trials in all 10 subjects. The correlation coefficients of the \( P_{100} \)-ventilation relationship exceeded 0.80 in 47 of 50 trials and exceeded 0.90 in 37 of 50 trials. Similarly, the correlation coefficients of the \( P_{100}-\dot{V}_{\text{peak}} \), \( P_{100}-V_T/t_i \), and \( P_{100}-V_{100} \) relationships exceeded 0.80 in 47, 44, and 40 of the 50 trials, respectively. Correlation coefficients of less than 0.90 occurred with equal frequency in the sitting and supine positions. As determined by the Mann-Whitney test (Colquhoun, 1971), \( P_{100} \)-ventilation, \( P_{100}-\dot{V}_{\text{peak}} \), \( P_{100}-V_T/t_i \), and \( P_{100}-V_{100} \) correlations were significantly better than the correlations between \( P_{100} \) and \( V_T \) and \( P_{100} \) and respiratory frequency (p>0.01).

VARIABILITY IN RESPONSES TO HYPERCAPNIA
The variability of each response to hypercapnia in a given individual was determined from the coefficient of variation (standard deviation divided by the mean, expressed as percent). The variability of the responses during three rebreathing trials in a single subject while seated is shown in Fig. 4 where the responses are ranked in order of increasing variability. The coefficient of variation of the ventilatory response to CO₂ was 39%. The coefficient of variation of changes in \( V_T/t_i \) and \( \dot{V}_{\text{peak}} \) during hypercapnia were smaller, indicating greater reproducibility, while changes in

Table 3  Effect of body position on ventilatory and pressure responses to CO₂ (mean ± SE)

<table>
<thead>
<tr>
<th>Body position</th>
<th>( \dot{V} ) (l/min/torr CO₂)</th>
<th>( V_T ) (ml/torr CO₂)</th>
<th>( V_T/t_i ) (ml/sec/torr CO₂)</th>
<th>( \dot{V}_{\text{peak}} ) (ml/sec/torr CO₂)</th>
<th>( V_{100} ) (ml/sec/torr CO₂)</th>
<th>( P_{100} ) (cm H₂O torr CO₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sitting</td>
<td>3.03±0.4</td>
<td>65±12</td>
<td>91±8</td>
<td>111±16</td>
<td>85±15</td>
<td>0±60±0.08</td>
</tr>
<tr>
<td>Supine</td>
<td>2.98±0.3</td>
<td>85±14</td>
<td>90±7</td>
<td>115±12</td>
<td>74±11</td>
<td>0±56±0.06</td>
</tr>
</tbody>
</table>
Fig. 3 Frequency distribution of linear correlation coefficients obtained during all rebreathing trials in 10 subjects showing the relationship between ventilatory indices and $P_{100}$. $R$ = correlation coefficient.

Fig. 4 Variability of ventilatory and occlusion pressure responses to hypercapnia in all rebreathing trials in a single subject. In this subject $V_T/t_i$, $V_{peak}$, and ventilatory responses to CO$_2$ show the least day-to-day variability. $V_{100}$, $P_{100}$, $f$, and $V_T$ during hypercapnia were less reproducible.

Figure 5 illustrates the intra-individual variability of each response in all the subjects. The responses are ranked in order of increasing variability. The ranking of the responses with respect to their coefficients of variations was not the same in all subjects, but overall the variability of changes in $V_T/t_i$, $V_{peak}$, ventilation, $V_{100}$, and $P_{100}$ were relatively small (mean coefficients of variation ranged from 22 to 33%). Interindividual variability of all responses to hypercapnia on a given day was determined from the data obtained on the third test day with the subjects seated and supine. These results are summarised in Fig. 6 which shows that the coefficient of variation of ventilatory responses to CO$_2$ was 42% with the subjects seated and 30% with the subjects supine, while the interindivdual coefficient of variation of the occlusion pressure responses was 42% with the subjects seated and 43% while the subjects were supine.

**EFFECT OF BREATHING PATTERN ON VARIABILITY OF VENTILATORY AND OCCLUSION PRESSURE RESPONSES**

Table 4 shows the ventilatory and occlusion pressure...
Comparison of occlusion pressure and ventilatory responses

Fig. 6 Interindividual variability in ventilatory and pressure responses to CO₂. Bars show average values of the coefficient of variation of each index of CO₂ response measured in all 10 subjects on a single day. Striped boxes show variation of responses measured in sitting position while unshaded bars show variation of responses measured in supine position.

responses to hypercapnia during unrestricted breathing and when either tidal volume or breathing frequency was kept constant. Holding tidal volume constant at 1 litre or 2 litres and holding breathing frequency constant at 35 breaths per minute had little effect on the variability of ventilatory or occlusion pressure responses. In contrast, when breathing frequency was kept constant at 20 breaths per minute, ventilatory responses were reduced in all subjects, and interindividual variations in both occlusion pressure and ventilatory responses appreciably narrowed.

Discussion

The present study has demonstrated that periodic, random airway occlusion has little effect on breathing pattern or on ventilatory responses to CO₂. Variations in FRC produced by changing from the sitting to the supine position or vice versa have no statistically significant effect on the magnitude or linearity of ventilatory and occlusion pressure responses to CO₂. Occlusion pressure increases linearly with Pco₂ and correlates better with minute ventilation and the rate of airflow during inspiration than with tidal volume or breathing frequency. The reproducibility from day to day in a given individual as well as the interindividual variability of the occlusion pressure responses to CO₂ are similar to that of the ventilation responses; but the variability of both responses is reduced by the performance of rebreathing tests at a constant moderate breathing frequency.

RESPONSES TO HYPERCAPNIA

Although it is agreed that minute ventilation is a linear function of Pco₂, there is controversy regarding the relationship between occlusion pressure and Pco₂. Some reports have described a curvilinear relation of P100 and Pco₂ which can be linearised by plotting the logarithm of P100 against Pco₂ (Grunstein et al., 1973; Whitelaw et al., 1975). The present study and other studies consistently find linear P100–Pco₂ relationships (Cosgrove et al., 1975; Altose et al., 1976 a and b; Burki et al., 1976). The reason for this discrepancy remains unclear. It may depend on the method used to produce hypercapnia. Using a rebreathing technique, a curvilinear relationship can be obtained unless care is taken to allow the CO₂ in the blood, alveoli, and rebreathing bag to reach complete equilibrium before determinations of ventilation or occlusion pressure can be made (Read, 1967). The time required for this to occur depends on the volume of gas and the concentration of CO₂ in the rebreathing bag.

EFFECTS OF INTERMITTENT AIRWAY OCCLUSION

Mechanical loading of the ventilatory apparatus during inspiration in normal individuals increases respiratory neural efferent activity independently of any change in chemical drive. This increase is noted by the second loaded breath but respiratory activity

| Table 4 Effect of breathing pattern on ventilatory and occlusion pressure responses to CO₂ |
|----------------------------------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Subject | Control | Constant tidal volume | Constant breathing frequency |  |
|  | 1 litre | 2 litres | 20 breaths/min | 35 breaths/min |  |
| Ventilatory responses (l/min/torr CO₂) |  |  |  |  |  |
| 1 | 3·0 | 2·3 | 1·7 | 2·1 | 2·1 |
| 2 | 3·4 | 2·1 | 2·4 | 2·7 | 4·2 |
| 3 | 2·6 | 1·8 | 1·5 | 2·1 | 1·0 |
| 4 | 7·7 | 7·8 | 8·6 | 2·4 | 5·3 |
| 5 | 1·9 | 0·6 | 0·8 | 1·3 | 1·1 |
| Occlusion pressure responses (cm H₂O/torr CO₂) |  |  |  |  |  |
| 1 | 0·6 | 0·2 | 0·2 | 0·3 | 0·4 |
| 2 | 0·6 | 0·5 | 1·3 | 0·3 | 2·0 |
| 3 | 0·6 | 0·5 | 0·4 | 0·7 | 0·3 |
| 4 | 2·3 | 2·4 | 2·1 | 0·9 | 1·3 |
| 5 | 0·4 | 0·1 | 0·1 | 0·4 | 0·8 |
returns to control values within one breath after removal of the load (Altose et al., 1975). Airway occlusion, a maximal load, might be expected to produce a similar increase in respiratory efferent activity. However, since occlusions were separated by at least eight normal breaths and minute ventilation was not measured for at least five breaths after airway occlusion, any changes in respiratory activity consequent to airway occlusion would have dissipated. In infants, inspiratory efforts against an occluded airway can distort the thorax, thus producing reflex effects which could conceivably change breathing pattern. However, in the present study in adults, no effects of intermittent airway occlusion on the pattern or level of ventilation could be discerned.

CORRELATION OF \( P_{100} \) AND VENTILATION INDICES

In anaesthetised animals occlusion pressure and tidal volume are closely related (Altose et al., 1976a). The present study indicates that, in conscious man, occlusion pressure also correlates well with tidal volume. However, even better correlations were obtained when occlusion pressure was compared to inspiratory airflow. This relationship is not unexpected since \( P_{100} \), like inspiratory airflow, is a time-dependent inspiratory event.

Minute ventilation is affected by both inspiratory and expiratory events. The excellent correlation between ventilation and occlusion pressure in both the sitting and supine positions indicates that expiratory activity is usually closely linked to the preceding inspiration and that variations in expiratory duration, independent of changes in inspiration, play an insignificant role in determining the level of ventilation.

EFFECTS OF CHANGING BODY POSITION

Changing from the sitting to the supine position had little effect on ventilatory responses to \( CO_2 \). This is in agreement with the findings in a previous study by Rigg et al. (1974). Additionally, changing body position had no significant effect on the pattern of breathing during hypercapnia.

Despite considerable change in functional residual capacity with changing position, occlusion pressure responses were also essentially unaffected. These results contrast with the findings in anaesthetised animals that graded increases in functional residual capacity, in a given animal, progressively decrease occlusion pressure responses (Eldridge and Vaughn, 1976). Theoretically the occlusion pressure which reflects the isometric force of contraction of the inspiratory muscles should vary directly, at any given level of stimulation, with the initial length of those muscles. Consequently, as functional residual capacity is increased, the resting length of the inspiratory muscles decreases and the occlusion pressure should fall.

However, in groups of normal individuals of different body size and fivefold variations in FRC, occlusion pressure responses to \( CO_2 \) could not be correlated to their functional residual capacities (Cosgrove et al., 1975; Shaffer et al., 1976). Presumably differences in respiratory efferent activity in response to hypercapnia exceed variations in inspiratory muscle length produced by changes in functional residual capacity.

The lack of an effect of changing body position on occlusion pressure responses in the present study could be due to a compensatory increase in respiratory activity while in the sitting position as compared to the supine position which would serve to overcome the effects on the inspiratory muscles of the larger functional residual capacity (Grassino et al., 1973). This would allow ventilation to be kept nearly constant despite variations in body position.

VARIABILITY OF VENTILATION AND OCCLUSION PRESSURE RESPONSES

Among the 10 subjects studied, and in any given individual from day to day, the variability of ventilatory and \( P_{100} \) responses was quite similar and may be considered equally valid measures of respiratory \( CO_2 \) sensitivity. This suggests that measurement of \( P_{100} \) is no better than ventilation in evaluating respiratory motor neuron activity in normal subjects. However, in specific circumstances, during anaesthesia or in patients with lung disease, when the mechanical properties of the chest wall or the lung may be altered, measurement of the \( P_{100} \) may be more valuable than ventilation.

Recently the maximum rate of pressure development during airway occlusion (dP/dt max) has been used to evaluate respiratory neuron motor activity (Matthews and Howell, 1975). By the rebreathing technique the dP/dt max, like the \( P_{100} \), increases linearly with ventilation. The response to hypercapnia, as measured by dP/dt max, correlates with the ventilatory response and is unaffected by changes in lung volume. Unlike the \( P_{100} \), dP/dt max is unaffected in conscious individuals by experience with external flow resistive loads (Altose et al., 1976b) or by relief of asthmatic bronchospasm (Matthews and Howell, 1975). Although measurement of dP/dt max requires somewhat more sophisticated equipment than is required for measurement of \( P_{100} \), it may also show less variability from day to day in the same subject.

Our results suggest that the interindividual variability in both \( P_{100} \) and ventilatory responses to \( CO_2 \) rebreathing could be reduced by maintaining breathing frequency constant at 20 breaths per minute during the tests. This was not true at high fixed breathing.
Comparison of occlusion pressure and ventilatory responses

frequencies where even small changes in tidal volume can result in large changes in ventilation. Rebuck et al. (1974) found in four subjects that variability in response could be reduced by keeping tidal volume constant at 1 litre, but this was not observed in the present study. Both intrinsic differences in the sensitivity of the respiratory chemoreceptors and extraneous influences which produce cortical effects can influence respiratory neuron output. Arkinstall et al. (1974) showed in studies in fraternal and identical twins that tidal volume responses were genetically determined and frequency responses were determined by ‘environmental factors’. As shown in Fig. 5, the rate of increase of breathing frequency with hypercapnia in groups of individuals showed the greatest coefficient of variation. By keeping breathing frequency constant at moderate rates, extraneous cortical influences, which can influence respiratory neuron response and can increase interindividual variability, seem to be diminished.

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References


Requests for reprints to: Dr M. D. Altose, 281 Gibson Building, Hospital of the University of Pennsylvania, 3400 Spruce Street, Philadelphia, PA 19104, USA.