

Influence of posture on mechanical parameters derived from respiratory impedance

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ABSTRACT: The influence of posture on respiratory mechanics was investigated in 10 healthy volunteers, using the forced pseudorandom noise technique. Subjects were studied in four randomly selected positions: sitting; sitting with the head turned sideways; supine; and prone with the head turned sideways. Respiratory compliance (Crs), inertance (Irs) and resistance estimated at 4 Hz (R_4), were calculated by fitting respiratory impedance by a 4 parameter model with a frequency dependent resistance.

When subjects changed from sitting to lying, whilst maintaining the head in the same position in relation to the body, Irs increased and Crs decreased, probably due to gravitational effects. R_4 was significantly higher in the supine position than in either of the sitting or the prone positions.

These results demonstrate that changes in lung volume cannot completely explain the influence of posture on respiratory resistance, and indicate upper airway geometry as a determinant factor of respiratory resistance.

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The effects of body position on lung, chest wall and respiratory mechanics measured by conventional methods have been previously investigated. Results for the static elastic properties are conflicting. Shifting from the seated to the horizontal posture has been reported to decrease lung static compliance [1], or to leave chest wall and respiratory static compliance unchanged [2, 3]. Under dynamic conditions, pulmonary compliance has been demonstrated to decrease [1, 4-8], and pulmonary resistance to increase [1, 4-7], in the supine posture. The latter results are in agreement with most of those obtained by the forced oscillation technique for respiratory impedance measurement. Indeed, changing from sitting to supine has been reported to increase respiratory resistance (Rrs) [9-11] and inertance (Irs) [11], and to decrease respiratory compliance (Crs) [11]. This postural influence on respiratory mechanics has been attributed mainly to the effects of lung volume changes.

Compliance and resistance have been studied in the upright and supine postures, but, surprisingly, they have never been examined in the prone position, which is a natural physiological position taken for sleep. Therefore, it appeared of interest to further investigate the effect of posture on these respiratory parameters. Because prone subjects naturally turn their head sideways, we decided to study four different positions:

sitting; sitting with the head turned about 90° to the right; supine; and prone. Thus, we aimed to examine the respective influences of airway geometry and lung volume. We used the forced oscillation technique, which allows easy measurement of respiratory parameters in any position.

Materials and methods

Experimental protocol

The study was performed in 10 healthy young volunteers (4 females and 6 males), aged 17-25 yrs. Eight were nonsmokers, two were light smokers, and none had a history of pulmonary disease. Each subject was studied, in a random sequence, in the following four positions: sitting; sitting with the head turned about 90° to the right ("lateral sitting"); supine; and prone in the most natural posture, *i.e.* with the head turned. Care was taken to keep the same orientation of the head in relation to the body in the sitting and supine positions on the one hand, and in the sitting lateral and prone positions on the other. The cheeks were carefully supported with the hands in the sitting and supine positions. In the prone position, the left

cheek rested on the investigating table and, thus, only the right cheek was supported. In each position, a 5 min stabilization period was observed, and resistance, compliance and inertance values were calculated from the measured respiratory impedance, as described below.

Forced noise technique

The forced pseudorandom noise used in this study was composed of 27 harmonics (4–30 Hz) of the fundamental (1 Hz), with enhanced amplitudes at the lower frequencies to limit the influence of spontaneous breathing. The phases were calculated in order to minimize the peak-to-peak amplitude of the excitation signal. The forced signal, generated by a digital-to-analogue converter, excited, through a power amplifier, two 60 W loudspeakers attached to a 12 l rigid chamber. The amplitude of the resulting pressure oscillations was limited to 2 cmH₂O peak-to-peak, which resulted in approximately 0.2–0.5 l·s⁻¹ peak-to-peak amplitudes of superimposed flow. The forced pressure excitation was applied at the mouth of the subject, who was wearing a noseclip and supporting his cheek(s). Mouth pressure was measured with a differential pressure transducer (Sensym SCX 01D, ±70 cmH₂O), and mouth flow, through a screen pneumotachograph (Jaeger Lilly, internal resistance=0.35 cmH₂O·s·l⁻¹) connected to a similar transducer. Pressure and flow signals were low-pass filtered (Butterworth, 8th order, cut-off frequency=32 Hz), and sampled at 128 Hz for 16 s. The data were then high-pass filtered (3rd order, cut-off frequency=3.5 Hz) to eliminate the low harmonics of the breathing noise.

Data processing

A Fast Fourier Transform (FFT) algorithm was applied to adjacent 4 s periods. Impedance data were calculated from the auto- and cross-spectra obtained by averaging the spectra of three consecutive manoeuvres. Impedance data corresponding to a coherence value >0.9 were retained for analysis. The real part of impedance was submitted to linear regression analysis, which yielded the respiratory resistance estimated at 4 Hz (R₄), and the slope (S) of the linear relationship of resistive impedance vs frequency. Respiratory compliance (Crs) and inertance (Irs) were estimated by multilinear regression analysis of the imaginary part of impedance, and resonant frequency (FR) was calculated as FR=(1/2π)(IrsCrs)^{-0.5}. The quality of the fit was assessed by calculating the mean relative difference (RD) between the response of the model and that of the subject, according to the following equation proposed by OOSTVEEN *et al.* [12]:

$$RD = \frac{1}{n} \sum_{i=1}^n \frac{[(\text{Re}, m, i - \text{Re}, s, i)^2 + (\text{Im}, m, i - \text{Im}, s, i)^2]^{0.5}}{[(\text{Re}, s, i)^2 + (\text{Im}, s, i)^2]^{0.5}}$$

where n is the number of data points, and Re and Im are the real and imaginary parts of the impedance of the model (index m) and of the subject (index s).

Statistical analysis

For each subject in each position, the values of R₄, Crs, Irs and FR were respectively expressed as the percentage of the corresponding value obtained in the sitting position. Statistical analysis was performed using one way analysis of variance for repeated measures, completed as necessary by modified paired t-test.

Results

The mean values obtained for respiratory inertance, compliance and resistance in the sitting position are listed in table 1. The mean relative differences between the response of the model and that of the subject obtained in each of the four positions are given in table 2.

As shown in figure 1, respiratory inertance did not change significantly when moving from one vertical position to another, or from one horizontal position to another. Irs was higher in the supine position.

Table 1. — Values obtained for respiratory mechanics in the sitting position

Irs cmH ₂ O·s ² ·l ⁻¹	Crs l·cmH ₂ O ⁻¹	R ₄ cmH ₂ O·s·l ⁻¹
0.013 ±0.001	0.038 ±0.003	2.53 ±0.30

Values are means±SE (n=10). Irs: respiratory inertance; Crs: respiratory compliance; R₄: resistive impedance estimated at 4 Hz.

Table 2. — Index of the quality of the fit, resonant frequency and frequency dependence of resistance of the respiratory system in the four positions

	Sitting	Lateral sitting	Supine	Prone
RD %	6.6 ±1.7	6.0 ±1.9	5.6* ±1.0	5.3* ±0.7
FR Hz	7.3 ±0.3	8.9** ±0.6	8.2* ±0.3	9.5** ±0.4
S cmH ₂ O·l ⁻¹ ·s·Hz ⁻¹	0.026 ±0.004	0.010** ±0.006	0.006** ±0.006	-0.001** ±0.006

Values are means±SE (n=10). RD: residual value of difference; FR: respiratory system resonant frequency; S: slope of the linear relationship between respiratory resistive impedance and frequency. * and **: significantly different from sitting position (p<0.05 and p<0.01, respectively); *: significantly different from prone position (p<0.05).

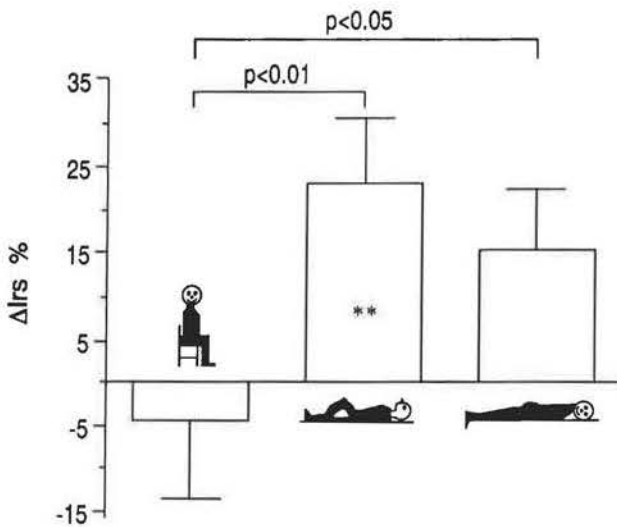


Fig. 1. - Mean changes (n=10) in respiratory inertance (ΔI_{rs}), expressed as the percentage of the sitting value, observed in the lateral sitting, supine and prone positions. Bars indicate se. **: significantly different from zero ($p < 0.01$).

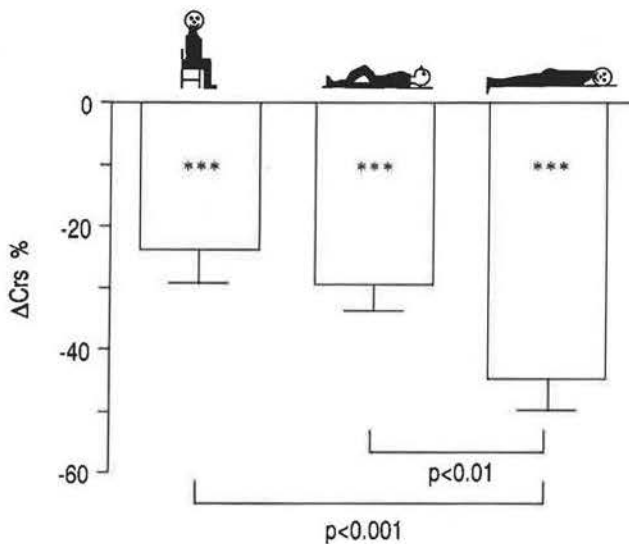


Fig. 2. - Mean changes (n=10) in respiratory compliance (ΔC_{rs}), expressed as the percentage of the sitting value, observed in the lateral sitting, supine and prone positions. Bars indicate se. ***: significantly different from zero ($p < 0.001$).

Posture dependency of respiratory compliance is illustrated in figure 2. The highest C_{rs} value (100%) was found in the sitting position. C_{rs} decreased significantly when moving from supine to prone.

Mean values of resonant frequencies of the respiratory system are presented in table 2. FR was significantly lower in the sitting position ($p < 0.05$). When lying, moving from supine to prone induced an increase in FR.

The effects of postural changes on respiratory resistance are shown in figure 3 and table 2. When shifting from the sitting to either the supine or prone positions, R_4 increased (fig. 3), whereas the frequency dependence of resistive impedance decreased (table 2).

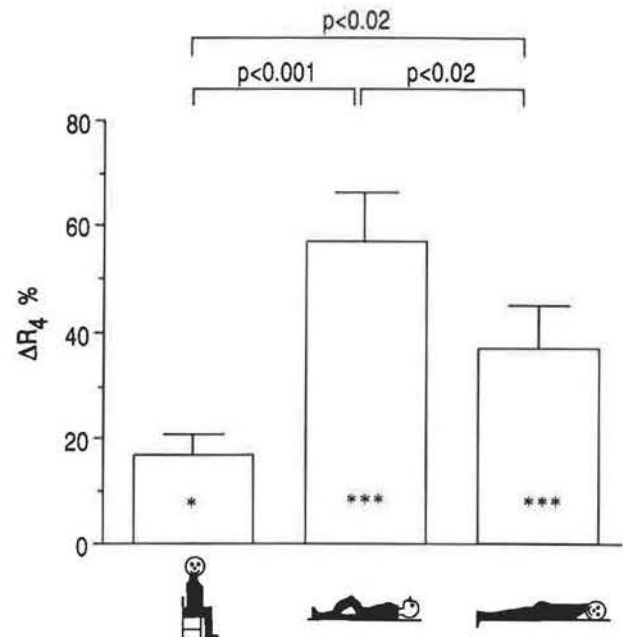


Fig. 3. - Mean changes (n=10) in respiratory resistance estimated at 4 Hz (ΔR_4), expressed as the percentage of the sitting value, observed in the lateral sitting, supine and prone positions. Bars indicate se. * and ***: significantly different from zero ($p < 0.05$ and 0.001, respectively).

R_4 was significantly higher in the supine position than in either of the sitting positions or the prone position (fig. 3).

Discussion

The influence of lung volume on respiratory mechanics has been widely documented, and it has been proved that a decrease in lung volume lowers compliance and increases resistance. The influence of posture on respiratory mechanics has been studied in the sitting and supine positions in particular [1-11], and the changes in compliance and resistance were attributed to a lung volume effect. However, changes in upper airway mechanics may occur in the supine position, when the gravity-induced retrodisplacement of the tongue may increase airway resistance. Hence, the interest in investigating respiratory mechanics in the prone position, when the displacement of the tongue is abolished. To assess the respective effects of lung volume and upper airways, subjects were also studied sitting with their head turned sideways, as in the prone position. As the variety of positions made the simultaneous measurement of lung volume difficult, it was assumed, according to previous results [11, 13-15], that: 1) functional residual capacity (FRC) remained unchanged in the two sitting positions; 2) FRC remained unchanged in the two horizontal positions; 3) FRC decreased by about 20-30% when shifting from a vertical to a horizontal position. In order to avoid the interference of decreases in resistive impedance and in reactance [16, 17], particular care was

taken to correctly support the cheeks in each position. Respiratory impedance data were fitted by a 4 parameter model with frequency dependent resistive impedance, which has proved able to detect early airway abnormalities [18]. Whatever the position, the quality of the fit was fairly acceptable (table 2). In the sitting position, the mechanical parameters (table 1) were very similar to those reported for normal subjects [11].

Respiratory inertance

The increase in I_{rs} observed when shifting from a vertical to a horizontal position (fig. 1), is in accordance with previous data [11]. Respiratory inertance reflects airway, gas and tissue inertance. In the prone and supine positions, the gravitational effects are abolished, which increases pulmonary blood volume and raises the lung weight and, thus, tissue inertance. As tissue inertance is <10% of I_{rs} [12], it is likely that airway and gas inertance have also contributed to the I_{rs} increase. Since I_{rs} remained unchanged in both sitting positions, and did not change when moving from supine to prone (fig. 1), a lung volume effect could be indicated. However, it has been reported that: 1) the I_{rs} increase noted in the horizontal position could not be due to the reduction in intrathoracic airway calibre [11]; 2) in the sitting position, I_{rs} did not vary with lung volume [12]. Thus, the rise in airway inertance in the horizontal position probably reflects that of the upper airway. As airway inertance is proportional to the length and to the reciprocal of cross-section and depends on the velocity profile, this suggests changes in upper airway geometry.

Respiratory compliance

C_{rs} takes into account tissue compliance, airway distensibility and gas compressibility. C_{rs} was lower in the lateral sitting than in the sitting position (fig. 2), which probably reflects a diminution of upper airway compliance, and thus a lesser upper airway artefact. Indeed, lateral rotation of the head may be assumed to result in a neck extension, which increases the stiffness of the pharyngeal wall [19, 20]. But, as upper airway compliance is not more than 5% of C_{rs} , it cannot account for the observed decrease in C_{rs} , for which we have no ready explanation.

As previously reported [1, 4-11], shifting from sitting to supine decreased C_{rs} (fig. 2), probably due to the reduction in FRC resulting from a cephalad displacement of the diaphragm and an increase in pulmonary blood volume [1, 13]. Similar influences of lung volume on C_{rs} have been reported in the sitting position, when FRC was artificially lowered [21, 22]. The diminution in C_{rs} observed when moving from lateral sitting to prone (fig. 2) is probably due to the same effects.

Shifting from supine to prone decreased C_{rs} (fig. 2), which may be attributed to the reduction in chest wall

compliance resulting from impediment to the displacement of the rib cage and abdominal wall, and/or to a decrease in pharyngeal compliance induced by the rotation of the head.

Respiratory resistance

R_4 reflects resistance at low frequency, and S , tissue rheological properties and/or flow distribution [23]. Since airway resistance is the main component of respiratory resistance (R_{rs}) [22, 24], R_4 will be interpreted in terms of airway resistance. As posture affects extrathoracic airway resistance directly and intrathoracic airway resistance *via* lung volume, their respective contributions to total resistance changes could be estimated.

The slight increase in R_4 observed in the lateral sitting position (fig. 3) probably reflects that in the upper airway. Rotating the head may increase R_4 by lengthening the extrathoracic airways and/or reducing their calibre, as already observed for neck flexion [25-27]. As no concomitant increase in I_{rs} was observed, one may assume that the velocity profile was blunter in the lateral position, thus tending to decrease airway inertance and to increase flow resistance, which then becomes flow dependent [23].

Shifting from sitting to supine resulted in a mean increase in R_4 of about 60% (fig. 3). Such increases in lung resistance have already been measured by conventional methods [1, 4-7]. Our increase in R_4 is higher than that already reported for mean resistive impedance [11], which suggests that R_4 is a more sensitive index, probably because R_{rs} is frequency dependent. Although the increase in resistance observed in the supine position is commonly attributed to intrathoracic airway narrowing [1, 4-7, 11], changes in upper airway geometry due to the retrodisplacement of the tongue may be advocated. Indeed, the supine position reduces pharyngeal cross-sectional area [25, 26] without changing laryngeal or tracheal area [26].

At comparable lung volume, R_4 was lower in the prone than in the supine position (fig. 3), and for similar changes in lung volume, the increase in R_4 was smaller when shifting from lateral sitting to prone than from sitting to supine (fig. 3), which proves the involvement of upper airway geometry in the influence of posture on R_{rs} . The respective contributions of intrathoracic and upper airway to the increase in R_4 observed when shifting from sitting to supine (about 60%) may then be evaluated. The former may be assessed by the increase in R_4 between the lateral sitting and prone positions (about 20%), when upper airway influence is abolished, and the latter, by the additional increase between the sitting and supine positions (about 40%) (fig. 3). Thus, in contrast to what is often suggested, the increase in R_{rs} observed in the supine position appears to result more from upper airway geometry than from lung volume.

There was little frequency dependence of resistive impedance, whatever the posture (table 2). The

increase in Rrs observed when changing from the sitting to any other position was slightly more marked at the low frequencies (table 2), probably due to changes occurring in the shunt impedance of the upper airways [28], rather than in the distribution of flow among intrathoracic parallel inhomogeneities [29].

In conclusion, the investigation of the lateral sitting and prone positions has provided new information about postural effects on respiratory mechanics. Posture mainly influences respiratory resistance via upper airway geometry, and, compared to the supine position, the prone position appears to appreciably limit the increase in upper airway resistance.

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