Comparative analysis of respiratory system compliance in three different positions (lateral, supine and sitting) of patients on long-term invasive mechanical ventilation

**ABSTRACT**

Objectives: This study is justified due to in clinical practice, positioning of the bedfast patient is constantly changed during stay in the intensive care unity. A better understanding is needed to ascertain the possible adverse effects that such changes might cause, mainly in the respiratory system condition. The objective of this study was to evaluate if patient’s positioning in bed may interfere with pulmonary compliance.

Methods: All patients included were submitted to mechanical ventilation and were sedated and curarized. Respiratory system compliance was assessed in three different positions: lateral, dorsal and sitting. After an alveolar recruitment maneuver, patients were placed in a position for two hours, and during the last five minutes data was collected from the mechanical ventilator display.

Results: Twenty eight patients were prospectively assessed. Values of the respiratory system compliance in lateral decubitus were $37.07 \pm 12.9$ in dorsal decubitus were $39.2 \pm 10.5$ and in the sitting position were $43.4 \pm 9.6$ mL/cmH$_2$O. There was a statistical difference when the sitting and dorsal positions was compared with the lateral for respiratory system compliance ($p = 0.0052$) and tidal volume ($p < 0.001$). There was a negative correlation between mean values of positive end expiratory pressure and respiratory system compliance ($r = 0.59$, $p = 0.002$). The FIO$_2$ administered was 0.6 for the lateral decubitus and 0.5 for the supine and sitting positions ($p = 0.049$).

Conclusions: Positioning of bedfast patients submitted to invasive mechanical ventilation induces oscillations of pulmonary compliance, tidal volume and SpO$_2$. Pulmonary compliance is higher in the sitting position than in the others.

Keywords: Pulmonary compliance; Artificial respiration

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**INTRODUCTION**

An important aspect that must be assessed before ventilator weaning is compliance of the respiratory system, because mechanical ventilation weaning may be impaired by the patient’s poor pulmonary condition.\(^1\)\(^2\) Compliance of the respiratory system is defined as the slope of the pressure-volume curve or the volume variation per unit of pressure change. The lungs and chest are formed by tissue with elastic properties, therefore compliance of the respiratory system is a measure of its elasticity and resistance to deformation by any force represented by variable degrees of effort.\(^3\)

Compliance of the respiratory system may be measured with the patient
under mechanical ventilation and sedation and its measurement is expressed by dividing tidal volume by peak pressure less the positive end expiratory pressure (PEEP). To carry out measurement of the respiratory system’s compliance with a patient under mechanical ventilation a previous alveolar recruitment maneuver is recommended, aiming to homogenize all pulmonary areas.

One of the factors that may interfere, reducing or increasing compliance of the respiratory system is the patient’s positioning in bed. Currently, it is recommended that positions be changed every two hours for patients in an intensive care unit (ICU).

Studies show that compliance of the respiratory system undergoes significant changes between the sitting position and lateral decubitus, as well as increase in the inspiratory peak pressure. This same group showed that compliance of the respiratory system changes when the patient remains on mechanical ventilation for a prolonged period and increases the patient’s risk of reintubation.

The purpose of this study was to evaluate the patient’s positioning in the hospital bed that offers better pulmonary compliance in patients under invasive mechanical ventilation aiming at successful ventilator weaning.

METHODS

After approval by the Teaching and Research Commission of the hospitals, this study was carried out in two private hospitals in the city of São Paulo, from February to December of 2006.

Patients admitted at the ICU, submitted to prolonged mechanical ventilation, with ages varying from 18 to 81 years, hemodynamically stable and with no previous diagnosis of acute respiratory distress syndrome (ARDS) and pulmonary fibrosis were included.

Data collected were: age, clinical diagnosis of the patient, ventilatory and hemodynamic parameters. Ventilation data were collected from the display of the mechanical ventilator Raphael - Hamilton Medical.

The medical team was asked to provide sedation and analgesia to inhibit the patients’ respiratory drive. All patients were being ventilated in the pressure controlled ventilation (PCV) mode where all ventilation cycles were generated and controlled by the mechanical ventilator; precluding any alternative cycling mechanism.

Data collection was carried out in three positions: lateral decubitus (LD), sitting position (SP) and dorsal decubitus (DD). The sequence of the positions was randomized.

After randomization, the patient was comfortably positioned in bed. Two hours thereafter the inspired fraction of oxygen (FiO₂) was set at 100% and a pulmonary homogenization was performed by increasing PEEP by 2 cmH₂O up to 20 cmH₂O and maintained for 2 minutes. Afterwards, PEEP was reduced by 2 cmH₂O until the initial PEEP level was reached. After homogenization, data was collected. Patients remained in the recommended position for 5 minutes more with the minimal FiO₂ to keep arterial oxygen saturation (SaO₂) above 93%. After two hours in the next position, performance of pulmonary homogenization and data collection, SaO₂ should remain the same, but if the patient presented a desaturation higher than 3% or SaO₂ lower than 90%, the FiO₂ would be increased.

Values of the tidal volume, inspiratory peak pressure, inspiratory flow, minute-volume, respiratory rate, inspiratory plateau pressure, PEEP, inspiratory flow, mean airways pressure, dead space/tidal volume ratio were obtained directly from the ventilator display. These values were monitored breath by breath for one minute. For assessment of the respiratory mechanics, the respiratory circuit humidifier was removed and statistical compliance of the respiratory system (mL/cm-H₂O) lung resistance (cmH₂O/L/m) and dead space/tidal volume ratio were measured.

An analysis of static compliance was achieved dividing tidal-volume by the plateau pressure from which PEEP value was subtracted. Total airways resistance was calculated dividing the difference between inspiratory peak pressure and plateau pressure by inspiratory flow.

Mechanical ventilation software allowed indirect calculation of pleural and alveolar pressure data. This data was monitored breath by breath on the mechanical ventilator display. Transpulmonary pressure was calculated subtracting alveolar pressure from pleural pressure. Dynamic compliance of the respiratory system was measured by the formula: tidal-volume/inspiratory peak pressure subtracted from the PEEP value. Respiratory rate, PEEP and FiO₂ were maintained during the entire procedure. For statistical analysis the maximum value obtained for each parameter was considered.

After data collection, patient was placed in the next adopted position and the procedures were repeated.

Statistical Analysis
Data are expressed as mean± standard deviation,
minimum and maximum. Analysis of variables in three moments was carried out using variance analysis of repeated measurements (ANOVA RM) with the Bonferroni post-test. For analysis of associative strength among variables, Pearson’s correlation was used. A $p<0.05$ value was considered as statistically significant.

**RESULTS**

This study had the participation of 28 patients, 17 of the male gender, with a mean age of 51.1 ± 17.4 years (18 and 81). The most frequent diagnosis was intestinal neoplasia found in 28.5% of patients while the most frequent complication was respiratory failure in 60.7% of them. There were no side effects during data collection procedure, except for five patients who had a SaO$_2$ lower than 90% in lateral decubitus and one in the dorsal.

All patients in the study were under invasive mechanical ventilation in PCV. Data are shown in Chart 1.

Mean values of respiratory system compliance in LD were $37.07 \pm 12.9$ mL/cmH$_{2}$O, in DD $39.2 \pm 10.5$ mL/cmH$_{2}$O and in the SP $43.4 \pm 9.6$ mL/cmH$_{2}$O, respectively. Statistically significant differences were found in the mean values of the respiratory system compliance, when comparing the sitting position and the dorsal decubitus to the lateral decubitus ($p=0.0052$ (Figure 1). Regarding pulmonary compliance, no statistically significant differences were found for the three positions (Figure 2).

Mean values of exhaled tidal volume in LD was $670 \pm 202$ mL, in DD was $690 \pm 229$ mL in SP $705 \pm 269$ mL. There was a statistical significance between DD and SP in relation to LD ($p<0.001$) (Figure 3).

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**Chart 1 – Demographic characteristics, diagnosis and clinical complications in the patients studied (n = 28)**

<table>
<thead>
<tr>
<th>Gender</th>
<th>Age</th>
<th>Diagnosis</th>
<th>Complications</th>
</tr>
</thead>
<tbody>
<tr>
<td>M</td>
<td>59</td>
<td>Ischemic stroke + hepatic failure</td>
<td>Pneumonia, ARF</td>
</tr>
<tr>
<td>F</td>
<td>61</td>
<td>Colon neoplasia, medullar aplasia</td>
<td>Septic shock, ARF</td>
</tr>
<tr>
<td>F</td>
<td>59</td>
<td>Endometrial neoplasia</td>
<td>Septic shock</td>
</tr>
<tr>
<td>M</td>
<td>74</td>
<td>Acute pulmonary edema, CHF</td>
<td>ARF shock, ARF pneumonia,</td>
</tr>
<tr>
<td>M</td>
<td>64</td>
<td>CHF</td>
<td>Pleural effusion</td>
</tr>
<tr>
<td>M</td>
<td>65</td>
<td>Cardiomegaly, Chagas</td>
<td>ARF, sepsis</td>
</tr>
<tr>
<td>F</td>
<td>26</td>
<td>Cranioencephalic traumatism, polytrauma</td>
<td>Hemothorax, ARF</td>
</tr>
<tr>
<td>M</td>
<td>74</td>
<td>Diabetic ketoacidosis</td>
<td>Sepsis</td>
</tr>
<tr>
<td>M</td>
<td>22</td>
<td>Cranioencephalic trauma</td>
<td>Pneumonia</td>
</tr>
<tr>
<td>M</td>
<td>47</td>
<td>Polytrauma</td>
<td>Septic shock</td>
</tr>
<tr>
<td>F</td>
<td>30</td>
<td>Intestinal cancer</td>
<td>Pleural effusion</td>
</tr>
<tr>
<td>F</td>
<td>18</td>
<td>High thoracic medullary injury</td>
<td>Pneumonia</td>
</tr>
<tr>
<td>M</td>
<td>53</td>
<td>Acute myocardial infarction</td>
<td>Cardiogenic shock</td>
</tr>
<tr>
<td>F</td>
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<td>Renal failure</td>
<td>Pulmonary edema</td>
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<tr>
<td>F</td>
<td>31</td>
<td>Sepsis</td>
<td>Septic shock</td>
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<tr>
<td>M</td>
<td>70</td>
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<td>ARF</td>
</tr>
<tr>
<td>M</td>
<td>55</td>
<td>Cranioencephalic trauma</td>
<td>Pneumothorax</td>
</tr>
<tr>
<td>M</td>
<td>81</td>
<td>Lung neoplasia</td>
<td>ARF</td>
</tr>
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<td>M</td>
<td>52</td>
<td>Rectum resection due to neoplasia</td>
<td>None</td>
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<tr>
<td>M</td>
<td>41</td>
<td>Pulmonary thromboembolism</td>
<td>ARF</td>
</tr>
<tr>
<td>M</td>
<td>61</td>
<td>Choledochoplasty due to neoplasia</td>
<td>Sepsis</td>
</tr>
<tr>
<td>M</td>
<td>69</td>
<td>Rectosimyotomy</td>
<td>None</td>
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<tr>
<td>M</td>
<td>63</td>
<td>Antero-lateral acute myocardal infarction</td>
<td>Cardiogenic shock</td>
</tr>
<tr>
<td>M</td>
<td>45</td>
<td>Renal failure, metastatic neoplasia in the left lung</td>
<td>ARF</td>
</tr>
<tr>
<td>F</td>
<td>35</td>
<td>Sepsis</td>
<td>Septic shock</td>
</tr>
<tr>
<td>F</td>
<td>30</td>
<td>Respiratory failure</td>
<td>None</td>
</tr>
<tr>
<td>F</td>
<td>31</td>
<td>Respiratory failure</td>
<td>None</td>
</tr>
<tr>
<td>F</td>
<td>55</td>
<td>Respiratory failure</td>
<td>None</td>
</tr>
</tbody>
</table>

CHF – cardiac heart failure, ARF – acute renal failure, ARF – acute respiratory failure
Mean peak pressure in LD was 24.6 ± 4.5 (14 to 31); in DD mean was 24.6 ± 4.7 (14 to 30) cmH₂O. While in SP mean was 25.3 ± 4.7 (16 to 35) cmH₂O. Therefore no difference was found in the peak pressure in the different positioning (p = 0.81).

Alveolar pressure was significantly higher in SP (21 cmH₂O) in relation to LD (18 cmH₂O) p = 0.0067, but no difference was found between DD, SP and LD. Transpulmonary pressure was higher in SP (p<0.001) and DD (p < 0.01) than in LD (Figure 4).

Mean values of airways pressure in LD and DD respectively were 15.9 ± 5.7 and 16.4 ± 6.6; and in SP was of 16.9 ± 7.3, with no statistical difference among them (p = 0.34). Mean PEEP values in the three positions were similar, with no statistical difference (p=0.99). There was a negative correlation between the mean values of PEEP and pulmonary compliance (r = -0.59, p = 0.002).

Mean values of respiratory rate in the three positions were similar, with no statistically significant difference (p=0.99).

Mean values of inspiratory flow in LD and DD were 65.8 ± 21.3 and 63 ± 19 L/s, respectively; in SP was 65.7 ± 6.8 L/s. A statistically significant difference was found when LD was compared with the other positions (p=0.044).

There was a statistically significant difference (p=0.049) regarding mean values of the FI O₂ in the sitting and dorsal positions in relation to LD, considering that the given FIO2 would be minimally sufficient to keep a SpO₂ higher or equal to 93%. For LD, FIO2 was 0.6; for DD and SP it was 0.5.

Figure 5 shows results achieved in the three positions in relation to mean values of minute-volume. It was verified that minute-volume was lower in the lateral decubitus when compared with dorsal decubitus and the sitting position (p< 0.0002).
DISCUSSION

As a priority, the present study analyzed the influence of body positioning on the physiological changes of pulmonary pressures, volumes and flows. The essential finding is that the sitting position provided the highest value of compliance of the respiratory system, although the same situation was not found for pulmonary compliance, higher tidal volume and consequently minute-volume. However, it did present a lower pulmonary inspiratory flow.

Some authors report that under normal conditions the lower regions of the lungs ventilate better than the upper.7,8 However, it was noted that in patients in LD during controlled mechanical ventilation, the contralateral lung ventilated better, as its alveolar units are more distensible and less resistant to the airflow than the homolateral lung (dependent pulmonary zone).9

Pulmonary functions may be affected by position changes.7 The importance of position change in specified periods (at each 2 hours) is not only to avoid dermatological lesions, but also to improve respiratory and vascular functions.10

In this study it was observed that patient positioning in the bed greatly interferes with compliance of the respiratory system, as well as with the PEEP level to be used. It was noted that the higher the PEEP value used, the worse was the pulmonary compliance found. Since PEEP fosters oxygenation by increasing the cross-sectional area of the alveolus, a situation of pulmonary hyperinsufflation is ensured. This situation allows a modest volume increase due to pressure generated by the respiratory muscles, that is to say, a small increase of pulmonary compliance; on the other hand, the highest force vector generated is that of elastic recoil, that is, of greater elastance.

Some studies showed a greater compliance of the respiratory system in lateral decubitus and established that in this position, the weight of the mediastinum and the displacement of the abdominal content contributed to the gradient of vertical pleural pressure11-13, therefore suggested that only LD provides greater compliance to the respiratory system. As a counterpart, another study showed that compliance of the respiratory system is greater in the SP and DD when compared to LD; possibly because alveolar units are less distensible and offer greater resistance to the airflow due to the mechanical disadvantage presented by the patient when in LD.9

In this study, greater compliance of the respiratory system was observed in the sitting position in relation to the lateral and dorsal decubitus (p=0.0052). This was ascribed to the dependent zone in the sitting position, which is the area of the pulmonary base. Indeed, this is smaller than the areas of the dependent regions in the other positions. Therefore this allows the remaining non dependent zones to be more compliant. Time constant may also be altered by change of position causing discrepancies in the distribution of ventilation, the lower compliance units fill more quickly than the others. Pulmonary units with high compliance and normal resistance of the airways have a large expansion, while those with poor compliance have a shorter filling time.14

It was further observed that tidal volume was greater in the sitting position than in the dorsal and lateral decubitus (p=0.001). This was related to compliance of the respiratory system, which is a measure of elasticity and resistance to deformation when facing any force represented by varied degrees of effort.15,16 It was also seen that the pulmonary flow is lesser in dorsal decubitus than in the lateral and sitting position (p=0.044). This is probably due to a greater mechanical compression in the chest when in dorsal decubitus, thereby reducing respiratory flow.

Specifically regarding the sitting position, inspiratory flow was smaller, probably because of increased resistance of the airway. This position is the same one that assured greater compliance of the respiratory system when compared to the other positions and therefore greater pulmonary ventilation. In general, this may have taken place due to the great distensibility that took place because of the large quantity of air filling the alveoli and bringing about a decrease of the inspiratory flow, that is to say close to the maximum alveolar capacitance.

Consequently, there is an exponential increase in the...
resistance of the airway and in the pulmonary parenchyma. Resistance is expressed by the amount of intrathoracic pressure produced, divided by the pulmonary flow. Therefore, in this condition, a large increase of muscular pressure would be needed to generate a minimum inspiratory flow, because of the large alveolar distensibility and resistance.\textsuperscript{17,18}

Limitations of this study are due to the fact that data were not collected in a continuous manner, for two hours as suggested by the studies; that changes in decubitus must be carried out every two hours, and thus changes in pulmonary compliance in the different positions could have been much better quantified, as well as reading of pleural and alveolar pressure by an indirect method, which would be more reliable if obtained by introducing an esophageal balloon which is a reliable method.

We concluded that body positioning of patients submitted to invasive mechanical ventilation produces variation in the compliance of the respiratory system. In the sitting position compliance of the respiratory system is greater when compared to the dorsal and lateral decubitus.

In the sitting position a lower inspiratory flow than in lateral and dorsal decubitus takes place. And, notwithstanding the body positioning there is progressive reduction of pulmonary compliance when a progressive increase of the positive pressure at the end of expiration takes place.

These conclusions lead us to suggest that when changing the positioning of patients in bed, alterations of the patient’s ventilatory mechanics must be carefully assessed.

REFERENCES

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RESUMO

Objetivos: A realização deste estudo se justifica pelo fato que na prática clínica ocorrem constantes mudanças de decúbito do paciente no leito durante a hospitalização na terapia intensiva, sendo que necessita melhor entendimento sobre possíveis efeitos adversos principalmente sobre as condições do sistema respiratório que tais mudanças podem ocasionar. O objetivo deste estudo foi avaliar se o posicionamento do paciente no leito pode interferir na complacência pulmonar.

Métodos: Todos os pacientes incluídos neste estudo estavam em ventilação mecânica, e foram sedados e curarizados. Verificou-se a complacência do sistema respiratório de todos os pacientes em três diferentes posicionamentos: decúbito lateral (DL), decúbito dorsal (DD) e sentado (PS), para tanto, após a manobra de recrutamento alveolar os pacientes ficavam no posicionamento definido por 2 horas e nos últimos 5 min os dados eram colhidos do display do ventilador mecânico.

Resultados: Vinte e oito pacientes foram prospectivamente analisados, Os valores de complacência do sistema respiratório no DL foram 37,07 ± 12,9 no DD 39,2 ± 10,5 e na PS 43,4 ± 9,6 mL/cmH\textsubscript{2}O Houve diferença estatisticamente significativa quando a PS e a DD foram comparadas com a DL para complacência do sistema respiratório (p < 0,0052) e volume corrente (p < 0,001). Houve correlação negativa entre os valores médios de pressão expiratória final positiva e complacência do sistema respiratório (r = 0,59, p = 0,002). Para o DL a FIO\textsubscript{2} foi 0,6, para o DD e posição sentada foi 0,5. (p = 0,049).

Conclusões: O posicionamento dos pacientes no leito, em ventilação mecânica invasiva, ocasiona variação na complacência do sistema respiratório, volume corrente e saturação de oxigênio. Na posição sentada a complacência do sistema respiratório é maior quando comparada aos decúbitos dorsal e lateral.

Descritores: Complacência pulmonar; Respiração artificial


