Immediate post-operative effects of tracheotomy on respiratory function during mechanical ventilation

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Abstract

Introduction Tracheotomy is widely performed in the intensive care unit after long-term oral intubation. The present study investigates the immediate influence of tracheotomy on respiratory mechanics and blood gases during mechanical ventilation.

Methods Tracheotomy was performed in 32 orally intubated patients for 10.5 ± 4.66 days (all results are means ± standard deviations). Airway pressure, flow and arterial blood gases were recorded immediately before tracheotomy and half an hour afterwards. Respiratory system elastance (Ers), resistance (Rrs) and end-expiratory pressure (EEP) were evaluated by multiple linear regression. Respiratory system reactance (Xrs), impedance (Zrs) and phase angle (φrs) were calculated from Ers and Rrs. Comparisons of the mechanical parameters, blood gases and pH were performed with the aid of the Wilcoxon signed-rank test (P = 0.05).

Results Ers increased (7 ± 11.3%, P = 0.001), whereas Rrs (-16 ± 18.4%, P = 0.0003), Xrs (-6 ± 11.6%, P = 0.006) and φrs (-14.3 ± 16.8%, P < 0.001) decreased immediately after tracheotomy. EEP, Zrs, blood gases and pH did not change significantly.

Conclusion Lower Rrs but also higher Ers were noted immediately after tracheotomy. The net effect is a non-significant change in the overall Rrs (impedance) and the effectiveness of respiratory function. The extra dose of anaesthetics (beyond that used for sedation at the beginning of the procedure) or a higher FiO2 (fraction of inspired oxygen) during tracheotomy or aspiration could be related to the immediate elastance increase.

Keywords: blood gases, respiratory mechanics, tracheotomy
The present study was designed as a detailed comparative evaluation of respiratory mechanics and blood gas exchange before and immediately after tracheotomy. This comparison elucidates the immediate influence of the surgical tracheotomy and TTs were made by the same manufacturer.

Tidal volume was set at 6–8 ml/kg, respiratory frequency at 0.17–0.33 Hz, and externally applied positive end-expiratory pressure (PEEP) varied from 0 to 10 hPa. The fraction of inspired oxygen (FI02) was adjusted for each patient so as to keep the oxygen tension of arterial blood (PaO2) at 60 mmHg or more. FiO2 was raised to 100% in all patients 15 min before tracheal intubation was performed.

Airway pressure (Paw) and flow (V) were recorded digitally immediately before and half an hour after the procedure. V was measured with a Lilly-type pneumotachograph (Jaeger, Würzburg, Germany); Paw was measured with a pressure transducer (Jaeger) placed between the pneumotachograph and the ET or the TT. The Paw and the V pressure transducers were matched for amplitude and phase up to 15 Hz. Paw and V signals were acquired digitally with the use of an analogue-to-digital converting board (Jaeger) at a sampling rate of 100 Hz. The humidification filter was removed during measurements. The equipment dead space (not including the ET or ET) was 25 ml.

Seven consecutive respiratory cycles under the same breathing conditions were recorded in the hard disk of a personal computer (Pentium 166 MHz, ADI) as a data file for subsequent computer analysis. The pressure signal was not corrected for the pressure drop along the ET or the TT. Data for Paw and V were treated with specifically developed software in Turbo Pascal v. 7.0 for the DOS environment, on a cycle per cycle basis.

Arterial blood samples were obtained at the same time. Both measurements were made for each patient under previously chosen ventilatory settings. Ten minutes before each measurement, tracheal secretions were aspirated conventionally. Measurements were done in the supine position.

Respiratory system elastance (Ers), resistance (Rrs) and end-expiratory pressure (EEP) were evaluated by multiple linear regression analysis (MLRA): Paw = EEP + ErsV + RrsV', where V is the lung volume above functional residual capacity, as obtained by numerical integration of the V’ signal, and EEP is the elastic recoil pressure at the end of expiration (null tidal volume and flow). The respiratory system reactance (Xrs) was calculated from the formula for a linear compliance–resistance model, namely Xrs = -Ers/2π f, where f is the breathing frequency.
frequency (in Hz). The respiratory system impedance ($Z_{rs}$) was then calculated from $Z_{rs} = \sqrt{(R_{rs}^2 + X_{rs}^2)}$, and its phase angle, expressing the pressure–flow lag, from $\phi_{rs} = \tan^{-1}(X_{rs}/R_{rs})$.

The mean values of $E_{rs}$, $R_{rs}$, EEP, $Z_{rs}$, $X_{rs}$, and $\phi_{rs}$ were used for every record because intra-cycle variation was always less than 3%.

Mechanical indices, blood gases and pH were compared between the two phases of tracheotomy with the aid of the Wilcoxon signed-rank test. Simple regression analysis was performed to investigate the correlation between (1) the percentage change in PaO$_2$/FiO$_2$ and respiratory mechanics, (2) the percentage change in PaCO$_2$ and respiratory mechanics, and (3) the percentage changes in respiratory mechanics and blood gases and the duration of the surgical procedure. The level of significance was set at 95% ($P = 0.05$).

**Results**

All measured or calculated indices during both measurements, and mean percentage changes, are presented in Table 1.

$E_{rs}$ was significantly higher after tracheotomy ($P < 0.001$), although a small decrease in $E_{rs}$ was observed in 9 of 32 patients. The highest noted percentage increase in $E_{rs}$ was 31% and the largest decrease in $E_{rs}$ was 12%. $R_{rs}$ was significantly lower ($P < 0.001$) after tracheotomy in all patients. $X_{rs}$ and $\phi_{rs}$ were significantly more negative ($P < 0.001$) after tracheotomy. Differences for $Z_{rs}$ and EEP as well as for PaO$_2$, PaCO$_2$ and pH were not statistically significant ($P > 0.05$). The mean vectors of impedance before and after tracheotomy are plotted graphically in Fig. 1 on two orthogonal axes.

The percentage change in PaO$_2$/FiO$_2$ was significantly correlated with the percentage change in $E_{rs}$ ($r = 0.4$, $P = 0.02$). None of the other mechanical indices' changes were significantly correlated with PaO$_2$/FiO$_2$. The percentage change in PaCO$_2$ was not significantly correlated with the percentage change in any of the evaluated mechanical indices. Furthermore, the duration of the tracheotomy procedure was not correlated with the percentage changes in the respiratory mechanics and blood gases.

**Discussion**

The present study suggests that immediately after surgical tracheotomy there is a favourable decrease in the respiratory system's resistance but also a significant increase in its elastance. The net result is a non-significant change in the respiratory system's impedance. The decreased $X_{rs}$ is an alternative expression of the increased $E_{rs}$ after tracheotomy. Calculating reactance is not meaningless, because although it reflects the elastance it is influenced by respiratory frequency, which in our measurements varied from 10 to 20 cycles/min. Furthermore, the shift of $\phi_{rs}$ to more negative values is the result of the synchronous increase in $X_{rs}$ and decrease in $R_{rs}$, which indicates a new elastance–resistance balance immediately after surgery (Fig. 1).

Tracheotomy is widely performed in the intensive care unit, more frequently today than a few years ago [2,4], but little is known about its influence on respiratory mechanics immediately after the procedure, which results in an improvement of respiratory function and the facilitation of weaning from mechanical ventilation [3,4,9,15]. Most previous studies have shown that the beneficial effect of tracheotomy is related to

### Table 1

| Parameter | Translaryngeal intubation | Tracheal intubation | Change from translaryngeal (%) | $P$  |
|-----------|---------------------------|---------------------|--------------------------------|------|
| $E_{rs}$ (hPa l$^{-1}$) | 27.86 ± 11.390 | 29.73 ± 12.589 | 7.05 ± 11.283 | <0.001 |
| $R_{rs}$ (hPa l$^{-1}$ s$^{-1}$) | 15.88 ± 6.381 | 13.43 ± 6.472 | -15.84 ± 18.425 | <0.001 |
| $Z_{rs}$ (hPa l$^{-1}$ s$^{-1}$) | 24.35 ± 8.694 | 23.79 ± 9.012 | 0.94 ± 9.419 | >0.05 |
| $X_{rs}$ (hPa l$^{-1}$ s$^{-1}$) | -18.00 ± 7.237 | -19.08 ± 7.853 | -6.34 ± 11.567 | <0.001 |
| $\phi_{rs}$ (degrees) | -48.73 ± 10.005 | -55.27 ± 11.547 | -14.30 ± 16.820 | <0.001 |
| EEP (hPa) | 3.90 ± 2.929 | 3.99 ± 3.084 | 10.25 ± 100.022 | >0.05 |
| PaO$_2$ (mmHg) | 104.84 ± 29.503 | 99.49 ± 32.012 | -2.79 ± 26.727 | >0.05 |
| PaO$_2$/FiO$_2$ (mmHg/% O$_2$) | 203.68 ± 72.871 | 194.11 ± 80.078 | 7.05 ± 11.283 | <0.001 |
| PaCO$_2$ (mmHg) | 39.96 ± 7.168 | 40.22 ± 8.587 | 0.94 ± 9.419 | >0.05 |
| pH | 7.39 ± 0.087 | 7.39 ± 0.105 | -0.09 ± 0.469 | >0.05 |

Results are expressed as means ± standard deviations for all patients. EEP, end-expiratory pressure; $E_{rs}$, respiratory system elastance; FiO$_2$, fraction of inspired oxygen; $\phi_{rs}$, pressure–flow phase angle; PaCO$_2$, carbon dioxide tension of arterial blood; PaO$_2$, oxygen tension of arterial blood; $R_{rs}$, respiratory system resistance; $X_{rs}$, respiratory system reactance; $Z_{rs}$, respiratory system impedance.
The results concerning $R_{rs}$ are not surprising. The recorded significant decrease in resistive losses of pressure after tracheotomy are logically expected and easily explained. They simply confirm that a shorter and more rigid tube would offer less resistance to any applied flow. However, the more important finding of the present study is the significant increase in $E_{rs}$ immediately after tracheotomy. Dead space changes were in fact minimal and could not explain the corresponding alterations in $E_{rs}$ [6,8,9]. The increase in $E_{rs}$ could be related to aspiration during or after the operation. We had no evidence of major aspiration. Nevertheless, small and invisible aspirations are inevitable during tracheotomy, especially when the cuff is deflated for tube replacement [1,9]. The impact of anaesthesia on decrease in lung volume and pulmonary compliance should not be disregarded, because an additional dose of anaesthetics was administered for the tracheotomy procedure [22]. The increased FiO$_2$ during tracheotomy might also explain the increased $E_{rs}$ through O$_2$-induced atelectasis [23]. The immediate effects of anaesthesia and increased FiO$_2$ are transient and disappear over a short period [23]. This might explain the phenomenal conflict between the currently noted immediate increase in $E_{rs}$ and the previously reported non-significant decrease in $E_{rs}$ 24 hours after tracheotomy [15]. Furthermore, comparisons with previous findings are inappropriate because they refer to static pulmonary elastance, whereas MLRA results in a rather dynamic evaluation of $E_{rs}$ [21]. This refers to the estimation during the whole cycle and not during a specifically applied flow interruption.

The percentage increase in $E_{rs}$ was smaller than the corresponding decrease in $R_{rs}$, although changes in $E_{rs}$ were not homogeneous. A small decrease in $E_{rs}$ was noted in 9 of 32 patients immediately after tracheotomy. Because the conditions and regulation of mechanical ventilation were similar during both measurements, we speculate that variations in $E_{rs}$ change could only reflect the influence of factors that varied during the surgical procedure such as the dose of anaesthetics, increase in FiO$_2$, or aspiration.

Changes in PEEP$_t$ were minimal, as reported previously. Again, we underline differences in methodology and timing. EEP decreased in 15 and increased in 17 patients after tracheotomy, indicating a varying influence on respiratory mechanical homogeneity.

Summarising, we stress that the present results do not contradict previous observations and confirm the beneficial effect of tracheotomy on the resistive load and PEEP$_t$ for a longer period after the surgical procedure. It seems reasonable that at substantially longer periods after tracheotomy any respiratory mechanical inhomogeneity induced during the surgical procedure would be abolished.

As reported previously, no significant changes have been observed in values of blood gases [9]. The non-significant...
post-operative decrease in PaO₂ could be related to the increased elastance after tracheotomy. Indeed, PaO₂/FiO₂ was significantly correlated with the percentage change in elastance. It seems probable that both the decrease in PaO₂/FiO₂ and the increase in E₉ reflect an enhanced mechanical inhomogeneity induced during tracheotomy.

Conclusion
The replacement of ETT with TT results in a decreased Rₘ. Anaesthesia, high FiO₂ and limited aspiration during the operation might explain the increased inhomogeneity induced during tracheotomy. Indeed, PaO₂/FiO₂ decreased after tracheotomy. It seems probable that both the decrease in PaO₂/FiO₂ and the increase in E₉ were significantly correlated with the percentage change in elastance. It seems probable that both the decrease in PaO₂/FiO₂ and the increase in E₉ reflect an enhanced mechanical inhomogeneity induced during tracheotomy.

Key messages
- Respiratory system elastance might be transiently elevated after tracheotomy.
- Monitoring of respiratory mechanics may be clinically useful immediately after tracheotomy.

Competing interests
None declared.

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