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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 (E_{rs}), resistance (R_{rs}) and end-expiratory pressure (EEP) were evaluated by multiple linear regression. Respiratory system reactance (X_{rs}), impedance (Z_{rs}) and phase angle (ϕ_{rs}) were calculated from E_{rs} and R_{rs}. Comparisons of the mechanical parameters, blood gases and pH were performed with the aid of the Wilcoxon signed-rank test ($P = 0.05$).

Results E_{rs} increased (7 ± 11.3%, $P = 0.001$), whereas R_{rs} (-16 ± 18.4%, $P = 0.0003$), X_{rs} (-6 ± 11.6%, $P = 0.006$) and ϕ_{rs} (-14.3 ± 16.8%, $P = <0.001$) decreased immediately after tracheotomy. EEP, Z_{rs}, blood gases and pH did not change significantly.

Conclusion Lower R_{rs} but also higher E_{rs} were noted immediately after tracheotomy. The net effect is a non-significant change in the overall R_{rs} (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 FiO_2 (fraction of inspired oxygen) during tracheotomy or aspiration could be related to the immediate elastance increase.

Keywords: blood gases, respiratory mechanics, tracheotomy

Introduction

Surgical tracheotomy is a technique that is usually applied during long-term ventilatory support in critically ill patients [1-5]. Tracheotomy is also indicated for bypassing obstructed upper airways, tracheal toilette and removal of retained bronchial secretions [1,2,4].

Previous studies have shown that tracheotomy is associated with a significant decrease in airway resistance and work of breathing compared with spontaneous ventilation through oral intubation [6-9]. The endotracheal tube (ETT) is recognised as the major site of increased respiratory system resistance (R_{rs}) during mechanical ventilation [10-12]. Replacement with a

EEP = end-expiratory pressure; ETT = endotracheal tube; E_{rs} = respiratory system elastance; FiO_2 = fraction of inspired oxygen; ϕ_{rs} = pressure–flow phase angle; MLRA = multiple linear regression analysis; $PaCO_2$ = carbon dioxide tension of arterial blood; PaO_2 = oxygen tension of arterial blood; P_{aw} = pressure measured at the airway opening (proximal part of ETT or TT); $PEEP_e$ = externally applied positive end-expiratory pressure; $PEEP_i$ = intrinsically developed positive end-expiratory pressure; R_{rs} = respiratory system resistance ; V' = flow; X_{rs} = respiratory system reactance; TT = tracheotomy tube; Z_{rs} = respiratory system impedance.

considerably shorter tube should therefore be associated with important relief of the respiratory mechanical load. Comparisons between ETT and tracheotomy tube (TT) *in vitro* (mechanical modelling) were strictly focused on pressure dissipation through the airways and on the work of breathing [7,8,13]. Previous *in vivo* results refer to measurements performed 10–24 hours after surgery. As far as we know, the influence of tracheotomy on respiratory mechanics and respiratory function efficiency has never been investigated during the immediate post-tracheotomy period. Such an investigation would not only have theoretical interest but could have implications for clinical practice.

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 in mechanically ventilated patients.

Methods

The protocol was approved by the local institutional Ethics Committee, and informed consent was obtained by the patients' relatives before the study.

Thirty-two patients, 13 women and 19 men, aged 60 ± 17.1 years (results are means ± SD throughout) and orally intubated (duration of intubation 10.6 ± 4.61 days) were included in the study. The duration of stay in the intensive care unit was 26.6 ± 16.44 days and the duration of mechanical ventilation before the tracheotomy procedure was 9.2 ± 4.72 days. The main indication for tracheotomy was long-term mechanical ventilatory support (11 patients). We also performed tracheotomy to preserve the patency of airways (11 patients) or to facilitate tracheo-bronchial toilette (10 patients).

Ten of the patients presented no respiratory involvement (in comatose status because of brain injury), 10 were hospitalised for respiratory failure because of exacerbation of chronic obstructive pulmonary disease, 7 for severe respiratory infection and 5 for acute respiratory distress syndrome in accordance with the latest criteria of the American–European Consensus Committee [14]. None of the patients were under chest intubation. Tracheotomy was performed surgically under general anaesthesia. Regardless of the type of their previous ventilatory support (synchronised intermittent mandatory ventilation, spontaneous breathing with T-piece, or intermittent positive pressure ventilator) all patients were sedated with propofol (2 mg/kg) and fentanyl (4 μg/kg) and muscle was relaxed with *cis*-atracurium (0.2 mg/kg). Mechanical ventilation (controlled mandatory ventilation mode) was set, 30 min before tracheotomy was performed, with various types of ventilator (Evita II-Drager, Servo Ventilator 900C-Siemens, Erica-Engstrom) during the procedure. The average operating time was 50 ± 20.8 min. No complications associated with tracheotomy were observed in the perioperative period. All patients presented cardiovascular stability. None of them had evidence of major aspiration during the procedure. Control of airway was discontinued for no more than 20 s and blood loss did not exceed 50 ml.

Intubation after tracheotomy was applied with a cuffed TT of the same diameter to the previously used ETT (7.0 mm, $n = 2$; 7.5 mm, $n = 6$; 8.0 mm, $n = 14$; 9.0 mm, $n = 10$). Both ETTs 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 ($PEEP_e$) varied from 0 to 10 hPa. The fraction of inspired oxygen (FiO_2) was adjusted for each patient so as to keep the oxygen tension of arterial blood (PaO_2) at 60 mmHg or more. FiO_2 was raised to 100% in all patients 15 min before tracheal intubation was performed.

Airway pressure (P_{aw}) 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); P_{aw} was measured with a pressure transducer (Jaeger) placed between the pneumotachograph and the ETT or the TT. The P_{aw} and the V' pressure transducers were matched for amplitude and phase up to 15 Hz. P_{aw} 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 ETT 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 ETT or the TT. Data for P_{aw} 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 (E_{rs}), resistance (R_{rs}) and end-expiratory pressure (EEP) were evaluated by multiple linear regression analysis (MLRA): $P_{aw} = EEP + E_{rs}V + R_{rs}V'$, 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 (X_{rs}) was calculated from the formula for a linear compliance–resistance model, namely $X_{rs} = -E_{rs}/2\pi\ f$, where f is the breathing 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 ϕ_{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 ϕ_{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 ϕ_{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

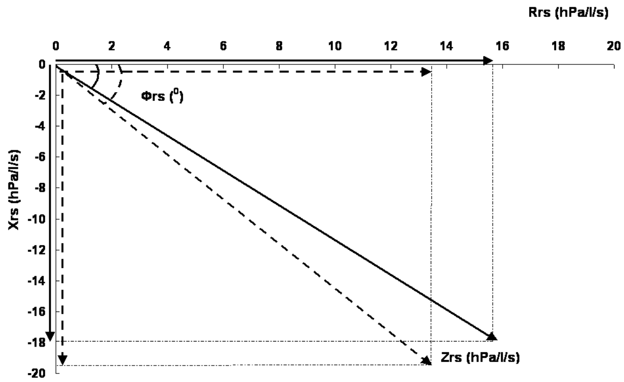
Table 1

Measured and calculated indices of respiratory function during translaryngeal and tracheal intubation

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	-2.12 ± 12.036	>0.05
X_{rs} (hPa l^{-1} s^{-1})	-18.00 ± 7.237	-19.08 ± 7.853	-6.34 ± 11.567	<0.001
ϕ_{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	-4.09 ± 26.358	>0.05
PaO_2/FiO_2 (mmHg/% O_2)	203.68 ± 72.871	194.11 ± 80.078	-2.79 ± 26.727	>0.05
$PaCO_2$ (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; ϕ_{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.

Figure 1



Respiratory mechanics before and after tracheotomy. Diagram of impedance (Z_{rs}) before (continuous arrow) and immediately after (dashed arrow) tracheotomy. The corresponding pressure–flow phase angles (ϕ_{rs}) are also depicted; respiratory system reactance (X_{rs}) and respiratory system resistance (R_{rs}) represent the polar coordinates of Z_{rs}.

the decrease in airway resistance and work of breathing under spontaneous or assisted mode of intratracheal ventilation [6-8,12,16]. A non-significant increase in static pulmonary compliance and a non-significant decrease in intrinsically developed positive end-expiratory pressure ($PEEP_i$) have also been reported 10–24 hours after tracheotomy [6,7,9,15].

ETT is recognised as the major site of resistance during mechanical ventilation owing to the thermolability of the materials, and the tortuous translaryngeal path, as well as the adherence of secretions to the inner lumen [12]. The decreased resistive load of the TT tubes has been attributed to their geometrical (shorter length) and material (more rigid) characteristics.

All previous studies confirm the long-term beneficial effect of replacing ETT with TT. The present study was specifically designed to focus on the immediate post-surgical period and to examine respiratory mechanics and pulmonary function in comparison with the immediate pre-tracheotomy situation. Therefore, similar regulation of the mechanical ventilation through ETT and TT was necessary and this condition was accomplished in our study. The duration of the surgical procedure was within the expected limits, with short variations; this duration was found to be independent of the observed changes in functional parameters.

Respiratory mechanics was evaluated by MLRA. The method is well established during various modes of mechanical ventilation, permitting the calculation of EEP, which corresponds to the sum of any externally applied plus any intrinsically developed positive end-expiratory pressure ($PEEP_e + PEEP_i$) [17-21]. The evaluation of X_{rs}, Z_{rs} and ϕ_{rs} was based on the elastance and resistance estimated by MLRA.

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 $PEEP_i$ 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 $PEEP_i$ 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 PaO_2 could be related to the increased elastance after tracheotomy. Indeed, PaO_2/FiO_2 was significantly correlated with the percentage change in elastance. It seems probable that both the decrease in PaO_2/FiO_2 and the increase in E_{rs} reflect an enhanced mechanical inhomogeneity induced during tracheotomy.

Conclusion

The replacement of ETT with TT results in a decreased R_{rs}. Anaesthesia, high FiO_2 and limited aspiration during the operation might explain the increased E_{rs} immediately after tracheotomy. The overall result is a small and non-significant decrease in respiratory system impedance. Changes in respiratory mechanics immediately after surgical tracheotomy might be important, especially in cases with an already increased elastance (for example in acute respiratory distress syndrome). In such cases, recruiting manoeuvres or transient changes in the regulation of mechanical ventilation could be considered.

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.

References

1. Heffner JE: **Timing of tracheotomy in mechanically ventilated patients.** *Am Rev Respir Dis* 1993, **147:**768-771.
2. Heffner JE: **Medical indications for tracheotomy.** *Chest* 1989, **96:**186-190.
3. Qureshi AI, Suarez JI, Parekh PD, Bhardwaj A: **Prediction and timing of tracheostomy in patients with infratentorial lesions requiring mechanical ventilatory support.** *Crit Care Med* 2000, **28:**1383-1387.
4. Heffner JE, Miller KS, Sahn SA: **Tracheostomy in the intensive care unit. Part 1: Indications, technique, management.** *Chest* 1986, **90:**269-274.
5. Kollef MH, Ahrens TS, Shannon W: **Clinical predictors and outcomes for patients requiring tracheostomy in the intensive care unit.** *Crit Care Med* 1999, **27:**1714-1720.
6. Davis K Jr, Campbell RS, Johannigman JA, Valente JF, Branson RD: **Changes in respiratory mechanics after tracheostomy.** *Arch Surg* 1999, **134:**59-62.
7. Diehl JL, El Atrous S, Touchard D, Lemaire F, Brochard L: **Changes in the work of breathing induced by tracheotomy in ventilator-dependent patients.** *Am J Respir Crit Care Med* 1999, **159:**383-388.
8. Davis K Jr, Branson RD, Porembka DA: **A comparison of the imposed work of breathing with endotracheal and tracheostomy tubes in a lung model.** *Respir Care* 1994, **39:**611-616.
9. Mohr AM, Rutherford EJ, Cairns BA, Boysen PG: **The role of dead space ventilation in predicting outcome of successful weaning from mechanical ventilation.** *J Trauma* 2001, **51:**843-848.
10. Sullivan M, Paliotta J, Saklad M: **Endotracheal tube as a factor in measurement of respiratory mechanics.** *J Appl Physiol* 1976, **40:**590-592.
11. Demers RR, Sullivan MJ, Paliotta J: **Airflow resistances of endotracheal tubes.** *JAMA* 1977, **237:**1362.
12. Wright PE, Marini JJ, Bernard GR: **In vitro versus in vivo comparison of endotracheal tube airflow resistance.** *Am Rev Respir Dis* 1989, **140:**10-16.
13. Mullins JB, Templer JW, Kong J, Davis WE, Hinson J Jr: **Airway resistance and work of breathing in tracheostomy tubes.** *Laryngoscope* 1993, **103:**1367-1372.
14. Bernard GR, Artigas A, Brigham KL, Carlet J, Falke K, Hudson L, Lamy M, Legall JR, Morris A, Spragg R: **The American-European Consensus Conference on ARDS. Definitions, mechanisms, relevant outcomes, and clinical trial coordination.** *Am J Respir Crit Care Med* 1994, **149:**818-824.
15. Lin MC, Huang CC, Yang CT, Tsai YH, Tsao TC: **Pulmonary mechanics in patients with prolonged mechanical ventilation requiring tracheostomy.** *Anaesth Intensive Care* 1999, **27:**581-585.
16. Plost J, Campbell SC: **The non-elastic work of breathing through endotracheal tubes of various sizes.** *Am Rev Respir Dis* 1984, **129:**A106.
17. Peslin R, Gallina C, Saunier C, Duvivier C: **Fourier analysis versus multiple linear regression to analyse pressure–flow data during artificial ventilation.** *Eur Respir J* 1994, **7:**2241-2245.
18. Rousselot JM, Peslin R, Duvivier C: **Evaluation of the multiple linear regression method to monitor respiratory mechanics in ventilated neonates and young children.** *Pediatr Pulmonol* 1992, **13:**161-168.
19. Nicolai T, Lanteri CJ, Sly PD: **Frequency dependence of elastance and resistance in ventilated children with and without the chest opened.** *Eur Respir J* 1993, **6:**1340-1346.
20. Vassiliou MP, Petri L, Amygdalou A, Patrani M, Psarakis C, Nikolaki D, Georgiadis G, Behrakis PK: **Linear and nonlinear analysis of pressure and flow during mechanical ventilation.** *Intensive Care Med* 2000, **26:**1057-1064.
21. Amygdalou A, Psarakis C, Vassiliou P, Dalavanga YA, Mandragos C, Constantopoulos SH, Behrakis PK, Vassiliou MP: **Evaluation of the end-expiratory pressure by multiple regression and Fourier analysis in humans.** *Respir Med* 2002, **96:**499-505.
22. Schmid ER, Rehder K: **General anesthesia and the chest wall.** *Anesthesiology* 1981, **55:**668-675.
23. Joyce CJ, Baker AB: **What is the role of absorption atelectasis in the genesis of perioperative pulmonary collapse?** *Anaesth Intensive Care* 1995, **23:**691-696.