Effects of tracheotomy on respiratory mechanics in spontaneously breathing patients

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ABSTRACT: Tracheotomy is a method of intubating the trachea, which is employed in several clinical settings, including the treatment of head and neck neoplasms. Tracheotomy is believed to facilitate weaning through changes in respiratory mechanics. Existing information concerning functional changes associated with tracheotomy are limited to comparisons with orotracheal intubation.

In this study, respiratory mechanics were monitored in seven spontaneously breathing patients, before and after an elective tracheotomy was performed for surgical treatment of cancer. Campbell diagrams were constructed by plotting pressure, obtained with an oesophageal balloon catheter, against volume, obtained from a pneumotachograph placed at the airway opening. Work of breathing was calculated as the internal area of the Campbell diagram and was partitioned into its elastic and inspiratory and expiratory resistive components. Oesophageal pressure was also used to quantify intrinsic positive end-expiratory pressure (PEEPi) and the pressure-time product (PTP), which is considered to be proportional to the oxygen cost of breathing. PTP was divided into its resistive and elastic components.

Inspiratory resistive work, PEEPi, inspiratory PTP, as well as its resistive and elastic components were significantly reduced by tracheotomy.

Tracheotomy significantly reduces work of breathing and pressure-time product in spontaneously breathing patients.
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Tracheotomy is a standardised and widespread procedure [1], however, its functional implications have been not been exhaustively studied. Tracheotomy is indicated in several clinical conditions, including relief of upper airway obstruction by neoplasms, inflammation or trauma, and is also performed on patients under prolonged mechanical ventilation, where it is believed to facilitate weaning [2].

Viewed from a respiratory standpoint, the physiological implications of tracheotomy are related to loss of upper airway and laryngeal function and resistance of the artificial airway. In patients with pulmonary disease these implications may be more important.

In a recent study, DIEHL et al. [3] studied mechanically ventilated patients submitted to tracheotomy because of prolonged intubation, and observed a reduction in the mechanical work of breathing (WOB) and intrinsic positive end-expiratory pressure (PEEPi) after the procedure, when compared to the condition before with an orotracheal tube. Under normal circumstances, the larynx represents a small fraction of total airflow resistance [4, 5]. However, the transition from orotracheal tube to tracheotomy cannula has a significant impact on PEEPi and mechanical WOB.

These observations suggest that it is the reduction in airway length that explains the observed variations.

The study by DIEHL et al. [3] did not evaluate spontaneously breathing nonintubated patients, as is the case in surgically treated head and neck cancer patients and individuals who have been mechanically ventilated and have been successfully weaned. Previous studies [6, 7] have reported the presence of PEEPi in stable, nonintubated chronic obstructive pulmonary disease patients. Loss of laryngeal function has not been addressed previously.

The Head and Neck Surgery Dept of the São Paulo Cancer Hospital, where this study was conducted, performs around 200 annual elective procedures that include tracheotomy. The aim of the present study was to functionally assess the mechanics of breathing of stable patients submitted to elective tracheotomy.

Methods

The study was approved by the local ethics committee, and all patients involved gave informed consent. Analysis of pressure/volume relationships was

used to assess changes in respiratory mechanics imposed by tracheotomy.

Variations in oesophageal pressure (P_{oes}) variation correlate well with variations in pleural pressure [8]. Therefore, P_{oes} was measured using an oesophageal balloon catheter (SmartCath; Allied Healthcare, Irvine, CA, USA) with a 0.8 mL inflation volume automatically delivered by a Bicore CP-100 (Allied Healthcare) pulmonary monitor. Measurements were validated before and after surgery using the technique described by BAYDUR *et al.* [9].

Flow values were obtained using a variable orifice pneumotachograph (VarFlex Flow Transducer; Allied Healthcare) held between the patient's lips. The oesophageal catheter and the pneumotachograph were connected to a Bicore CP-100 pulmonary monitor. Nostrils were occluded by a noseclip. Measurements were performed with patients in the sitting position before and after surgery.

The oesophageal catheter was kept in position during the surgical procedure. A new measurement was taken on the first day after surgery, when the patient was awake and had not required ventilatory support for at least 12 h. For this measurement the pneumotachograph was connected to a cuffed tracheotomy tube (Portex tubes with 7 or 8 mm internal diameter).

Variables were recorded in a notebook computer, using the Lab View 5.0 (National Instruments, Austin, TX, USA) program. The program generated text files relative to time from tracheal pressure, oesophageal pressure and flow. Acquisition frequency was 100 Hz. Pre- and postoperative measurements lasted 5 min. Using files developed at the Discipline of Pulmonology of the Faculty of Medicine of the University of São Paulo, the onset of each respiratory cycle was determined and on-screen visualisation allowed exclusion of spurious cycles (that could correspond to swallowing or cough) which differed from the predominant pattern. A mean cycle was then calculated to minimise artefacts.

Mean cycles were exported to Quatro Pro 7 (Corel Word Perfect Suite; Corel Corporation, Ottawa, Ontario, Canada) where the WOB and pressure-time product (PTP) were estimated from the area under the pressure/volume (Campbell diagram [10]) and pressure/times curves [11], respectively. The lung compliance line ($C_{L,dyn}$) was plotted on the Campbell diagram by linking end-inspiratory and end-expiratory points of zero flow. Chest-wall compliance (C_w) was not measured, since not all patients were routinely paralysed, but was estimated to be equal to 4% of the predicted forced vital capacity (FVC). Therefore, to avoid possible chest-wall compliance alterations induced by anaesthesia and surgical procedure, measurements were obtained within intervals >12 h before or after the operations.

$PEEP_i$ was measured as the maximal negative deflection of P_{oes} at the onset of inspiration, in which no volume increment was observed. This approach assumed no expiratory muscle activity. However, this deflection could be interpreted either as the effort necessary to overcome $PEEP_i$ or, assuming absence of $PEEP_i$, the relaxation of expiratory muscles activated during expiration. To avoid this problem, the C_w line was positioned on the Campbell diagram according to both situations, as described previously as upper bound and lower bound, respectively [12].

WOB was calculated separately in its elastic (WOB_{el}) and inspiratory-resistive (WOB_{ri}) components. WOB_{el} was defined by the area between the two compliance lines ($C_{L,dyn}$ and C_w) and limited by the maximum volume achieved. WOB_{el} was analysed considering upper and lower bound situations separately, as described above. WOB_{ri} was defined by the area inside the pressure/volume loop to the left of $C_{L,dyn}$. Therefore, WOB_{ri} corresponds to the inspiratory phase of the respiratory cycle. WOB values were expressed as joules $(J) \cdot L^{-1}$.

PTP was calculated similarly considering upper and lower bound situations and by plotting a theoretical chest-wall elastic recoil pressure ($P_{oes,CW}$) curve according to the following equation:

$$P_{oes,CW} = (E_{dyn,CW} \times V_L) + P_{oes,CW,eep} \qquad (1)$$

where $E_{dyn,CW}$ is the chest-wall dynamic elastance (the reciprocal of C_w, estimated as 4% of predicted FVC), V_L is the lung volume above the end-expiratory volume and $P_{oes,CW,eep}$ is the P_{oes} at the point of transition between the end of expiration and the beginning of inspiration. Upper bound PTP assumes that $P_{oes,CW,eep}$ equals P_{oes} when it undergoes a sharp negative deflection before the beginning of inspiratory flow, while lower bound PTP assumes $P_{oes,CW,eep}$ as equal to P_{oes} at the onset of inspiratory flow. PTP is expressed in $cmH_2O \cdot s^{-1}$.

The resistive component of PTP (PTP_r) was calculated as the area under the line of lung recoil pressure ($P_{oes,L}$) in the pressure/time curve, the curve of which was plotted according to the following formula:

$$P_{oes,L} = (E_{dyn,L} \times V_L) + P_{oes,L,eep} \qquad (2)$$

where $E_{dyn,L}$ is the calculated lung elastance (the reciprocal of $C_{dyn,I}$ as obtained from the Campbell diagram), V_L is the lung volume above the end-expiratory volume and $P_{oes,L,eep}$ is the oesophageal pressure at the onset of inspiratory flow.

The elastic component (PTP_{el}) was calculated as the integral of the area of the pressure/time curve limited by the lung elastic-recoil curve and the chest-wall recoil pressure line upper bound. The elastic component, due to the presence of $PEEP_i$, was calculated as the integral of the area limited by lower- and upper-bound derived chest-wall recoil pressure lines (fig. 1).

Variables were found to have a nonparametric distribution, and were compared using the Wilcoxon test.

Results

Twenty-three patients were eligible for the study. Eight patients refused to participate, in four patients progression of the oesophageal-balloon catheter to the necessary position for oesophageal-pressure monitoring was impossible, one patient lost the catheter
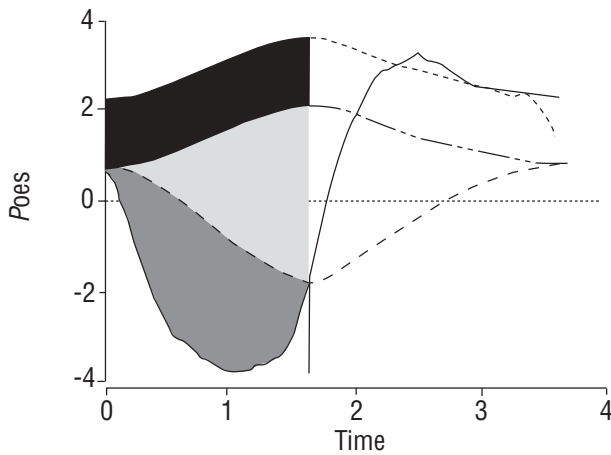
Fig. 1.–Pressure/time curve showing upper bound (- - -) and lower bound (– – – –) chest wall recoil pressure, and lung recoil pressure (– – –). Poes: oesophageal pressure; t: time; ■: elastic pressure-time product (PTP) relative to instrinsic positive end-expiratory pressure (PEEPi); ▨: elastic PTP unrelated to PEEPi; ▨: resistive PTP.

during surgery and therefore postoperative values could not be obtained, one patient had surgery cancelled and two patients had clinical syndromes at hospital admission (psychotic symptoms and alcoholic intoxication) that rendered the procedures necessary for the study impossible. Therefore, data was obtained pre- and postoperatively for seven patients.

Patient demographics are shown in table 1. Figure 2 shows the Campbell diagrams obtained from Poes and volume measurements of the mean cycles pre- and postoperatively for the seven patients.

Postoperative Campbell diagrams obtained from patients 1, 2, 4, 5, 6 and 7 showed loss of the configuration indicative of the presence of PEEPi.

Results of inspiratory resistive work, elastic work and PEEPi from all patients before and after surgery are shown in tables 2 and 3. Tables 4 and 5 show results PTP and its components before and after surgery. The main results were a significant reduction of PEEPi as well as a reduction of all components of PTP, except for PTP lower bound, and a significant reduction in WOBel. VT did not change significantly pre- and postoperatively (0.38±0.17 and 0.40±0.11, p=0.610) while respiratory rate increased significantly (15±3 and 20±6, p= 0.04).

Table 1.–Patient demographics

Patient no.	Sex	Age yrs	Tumour location[#]
1	M	61	Tonsil
2	M	45	Palate
3	M	57	Base of tongue
4	F	45	Base of tongue
5	M	64	Larynx
6	M	86	Tongue
7	M	57	Larynx

M: male; F: female; [#]: All patients had squamous-cell carcinoma.
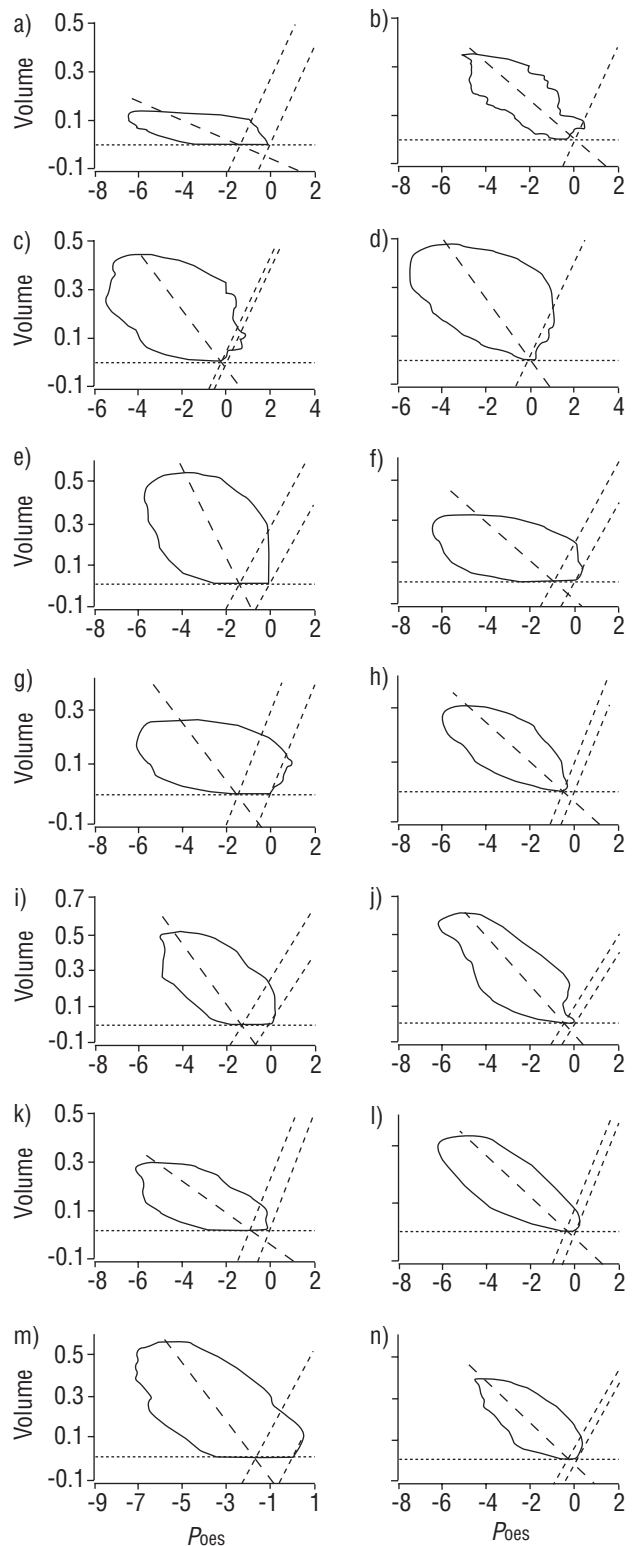

Fig. 2.–Campbell diagrams for patients 1 (a and b), 2 (c and d), 3 (e and f), 4 (g and h), 5 (i and j), 6 (k and l) and 7 (m and n). The left column shows the pre-operative diagrams and the right column shows the postoperative diagrams. Chest wall compliance lines (- - - -) are shown for both situations: upper bound on the right and lower bound on the left. Dynamic lung compliance lines (– – –) are also shown. Postoperative diagrams from patients 1 and 2 show near superposition of the two lines.

Table 2. – The resistive and elastic components of work of breathing (WOB) obtained before and after tracheotomy

Patient no.	WOBri J·L^{-1}		WOBel J·L^{-1}		WOBel′J·L^{-1}	
	Pre	Post	Pre	Post	Pre	Post
1	0.84	0.11	0.21	0.32	0.35	0.32
2	0.37	0.30	0.30	0.32	0.33	0.32
3	0.34	0.26	0.27	0.26	0.48	0.39
4	0.34	0.64	0.22	0.33	0.42	0.39
5	0.49	0.24	0.31	0.40	0.49	0.48
6	0.64	0.21	0.30	0.37	0.41	0.41
7	0.37	0.14	0.37	0.31	0.61	0.34
Mean±SD	0.48±0.19	0.27±0.18	0.28±0.06	0.33±0.05	0.44±0.10	0.38±0.06
p-value		0.13		0.11		0.03

WOBri: resistive work of breathing; WOBel: elastic work of breathing considering the *lower bound* situation; WOel′: elastic work of breathing considering the *upper bound* situation.

Discussion

The results of this study showed a significant reduction in mechanical-work parameters after tracheotomy in spontaneously breathing nonintubated patients. This trend is demonstrated best in data obtained from the PTP measurements. Oxygen consumption has been demonstrated to correlate with PTP better than with mechanical-work measurements [13] as time, a determinant of oxygen consumption by muscle, is not taken into account in WOB calculations, as it is in PTP.

Previous work [14, 15], using Bicore crude values to compare ventilation through an orotracheal tube and through tracheotomy, failed to demonstrate any reduction in WOB parameters. In the current authors view this was mainly due to the methods employed.

The use of the mean cycle as the source for calculating work values minimised artefacts and allowed the visualisation of a Campbell diagram representative of a long period of observation time. Moreover, it allowed the exclusion of spurious cycles caused by swallowing or coughing, and the treatment of the signals obtained allowed a more accurate scrutiny of the different components of WOB and PTP. SPAHIJA *et al.* [16] used mean cycles to deal with the mechanics of breathing experimentally and suggested that this procedure should be applied to clinical practice.

The current authors assumed that the same theoretical value of C_w could be used to compare the same patient before and after tracheotomy. Direct measurement of C_w would certainly yield different numerical values, but as this study compared the same patient at two different times, the difference would remain.

Using an similar approach DIEHL *et al.* [3] demonstrated a reduction in work parameters after tracheotomy in mechanically ventilated patients, in relation to the endotracheal tube. To the best of the authors′ knowledge the present report is the first to demonstrate benefit in nonintubated patients.

Results have been expressed considering two extreme situations, upper bound and lower bound. These

Table 3. – Intrinsic positive end-expiratory pressure (PEEPi) obtained before and after tracheotomy for each patient

Patient no.	PEEPi cmH$_2$O	
	Pre	Post
1	1.34	0.00
2	0.18	0.01
3	1.28	1.00
4	1.44	0.50
5	1.26	0.51
6	0.85	0.35
7	1.72	0.28
Mean±SD	1.15±0.50	0.38±0.34
p-value		0.02

Table 4. – Pressure-time product (PTP) upper bound, PTP lower bound, and PTP due to intrinsic positive end-expiratory pressure (PTPI)

Patient no.	PTP upper bound		PTP lower bound		PTPi	
	Pre	Post	Pre	Post	Pre	Post
1	8.19	7.09	6.21	7.08	1.98	0.00
2	10.40	6.49	10.06	6.47	0.34	0.02
3	12.69	6.26	10.02	5.27	2.67	0.98
4	9.30	4.66	6.96	4.22	2.35	0.44
5	10.13	9.75	7.88	8.96	2.25	0.78
6	7.18	6.08	6.17	5.69	1.01	0.39
7	19.35	8.51	15.13	8.01	4.23	0.49
Mean±SD	11.04±4.06	6.97±1.68	8.92±3.19	6.53±1.64	2.12±1.24	0.44±0.36
p-value		0.02		0.13		0.02

Table 5. – Resistive pressure-time product (PTPr) and elastic PTP (PTPel)

Patient	PTPr		PTPel	
	Pre	Post	Pre	Post
1	2.92	2.07	5.27	5.01
2	4.15	2.50	6.26	3.99
3	4.21	2.59	8.48	3.66
4	3.47	1.31	5.84	3.35
5	2.25	2.42	7.88	7.32
6	2.25	1.83	4.93	4.24
7	4.90	1.67	14.45	6.84
Mean±SD	3.45±1.03	2.06±0.48	7.59±3.30	4.92±1.57
p-value		0.03		0.02

situations occur considering that either the negative deflection of the pressure curve as due only to PEEPi (upper bound) or in the complete absence of PEEPi, considering the negative deflection observed in the pressure curve as due solely to expiratory muscle activity (lower bound). In fact it is theoretically possible that during any respiratory cycle a patient is in an intermediate situation between these extremes. The observations by CAMPBELL and FRIENDS [17] showed that under expiratory muscle activity, P_{oes} increases during expiration. Such a pattern could be seen in only one of the patients in this study (no. 4). Thus, the current authors believe that the upper bound values correctly describe the mechanical alterations observed in the patients studied. Whatever the option, a graphical change in the Campbell diagram was observed in all patients.

Expiratory muscle activity can be alternatively observed through the measurement of gastric pressure. Recent work has shown that a large part of the pressure change measured as PEEPi can be attributed to expiratory muscle activity [18]. Unfortunately, gastric pressure was not measured here and therefore the real cause of the changes observed cannot be determined. Nonetheless, a parameter independent of whether expiratory muscle activity was considered or not, i.e. upper or lower bound, namely the resistive component of PTP, was shown to decrease significantly.

Could the functional benefit observed be due to the relief of tumour-induced upper airway obstruction in this population? Only three of seven patients had tumours in structures that could be implicated in airway obstruction (larynx and tonsil), and all others exhibited numerical and graphic changes, thus the authors believe that these findings are consistent with benefit irrespective of upper airway obstruction. Similarly, observation of preoperative flow/volume curves obtained from the mean cycles (data not shown) did not disclose the usual pattern associated with variable extrathoracic obstruction. In spite of a relatively small number of patients who accepted the insertion of a naso-oesophageal catheter on the evening before surgery, consistent evidence was obtained supporting the hypothesis that tracheotomy reduces the work of breathing, probably by decreasing resistance and intrinsic positive end-expiratory pressure.

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