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# Effect of tracheostomy tube on work of breathing: Comparison of pre- and post-decannulation

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## ABSTRACT

**Objective:** To describe and compare the work of breathing (WOB) during spontaneous breathing under four conditions: (1) breathing through a tracheostomy tube with an inflated cuff, (2) breathing through the upper airway (UA) with a deflated cuff and occluded tube, (3) breathing through the UA with an occluded cuffless tube, and (4) postdecannulation.

**Patients and Methods:** Patients who tolerated an occluded cuffless tube were included. Ventilatory variables and esophageal pressure were recorded. The pressure-time product (PTP), PTP/min, and PTP/min/tidal volume (PTP/min/VT) were measured. Each condition was measured for 5 min with a 15 min time interval between evaluations. Quantitative data are expressed as mean ± standard deviation. Single-factor analysis of variance was used, and the Games-Howell test was used for *post hoc* analysis of comparisons between group means ($P \leq 0.05$).

**Results:** Eight patients were studied under each of the four conditions described above. Statistically significant differences were found for PTP, PTP/min, and PTP/min/VT. In the *post hoc* analysis for PTP, significant differences among all conditions were found. For PTP/min, there was no significant difference between Conditions 2 and 4 ($P = 0.138$), and for PTP/min/VT, there was no significant difference between Conditions 1 and 2 ($P = 0.072$) or between Conditions 2 and 3 ($P = 0.106$). A trend toward a higher PTP, PTP/min, and PTP/min/VT was observed when breathing through a cuffless tracheostomy tube.

**Conclusion:** The four conditions differed with respect to WOB. Cuff inflation could result in a reduced WOB because there is less dead space. Cuffless tracheostomy tubes generate increased WOB, perhaps due to the material deformity caused by body temperature.

**Key Words:** Airway care, airway extubation, artificial airway, decannulation, extubation methods, tracheostomy, work of breathing

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## INTRODUCTION

At long-term acute-care centers (LTACs) in Argentina, hospitalized adults are not usually discharged without having achieved certain rehabilitation objectives, such as nondependence on an artificial airway for spontaneous breathing. This process is called decannulation.[1,2] Certain steps should be followed to accomplish decannulation, such as confirming the airway permeability, evaluating



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the cough capacity to eliminate bronchial secretions, and evaluating the airway protection capacity, among others. The simplest way to evaluate the airway permeability is by deflating the tracheostomy tube cuff and occluding the tube so that the patient can breathe through the upper airway (UA). The UA permeability is guaranteed in any patient who can breathe by this method.[3] Two laboratory studies using an artificial trachea model[4,5] found higher flow resistance with an occluded tracheostomy tube and deflated cuff than with an occluded fenestrated tracheostomy tube and deflated cuff. One case report described the tolerance to exercise and work of breathing (WOB) generated while breathing through an occluded fenestrated tracheostomy tube with a tracheostomy button (which would not take UA space) and decannulation. The authors concluded that a fenestrated tracheostomy tube worsens muscle performance, resistance to exercise, and resistance to air flow.[6] There is also evidence of an increase in WOB when tracheostomized patients begin breathing through their natural decannulated airways. This variation is thought to be due to an increase in dead space.[7] However, another study[8] that compared the same conditions found a linear correlation between WOB and airway resistance, evidencing particular changes for each individual studied.

Our objective was to describe the change in WOB during spontaneous breathing under different conditions: (1) Breathing through a tracheostomy tube with an inflated cuff, (2) breathing through the UA with a deflated cuff and an occluded tracheostomy tube, (3) breathing through the UA with an occluded cuffless tracheostomy tube, and (4) postdecannulation (breathing through the UA). Our secondary objective was to describe the changes in various physiological variables: Tidal volume (VT), respiratory frequency (FR), minute ventilation (VE), and rapid shallow breathing index (RSBI).

## PATIENTS AND METHODS

The present study was performed at an LTAC in Buenos Aires City, Argentina. Patients were recruited from March 2014 to May 2014. Patients older than 16 years who tolerated breathing through the UA with a deflated cuff and occluded tracheostomy tube were consecutively selected. Patients who complied with the decannulation protocol of the facility were included. This protocol involves a ventilation stage through the UA with an occluded tracheostomy tube and deflated cuff for 3 days and another ventilation stage through the UA with a cuffless tube with an occluded inner cannula for 4 days. After overcoming these stages and having complied with the protocol, the patient is considered ready for decannulation.[2] The variables were measured the day the patients were to be decannulated. Patients who could not cooperate with measurement of the variables due to cognitive disorders (delirium, dementia, etc.) and those who refused to provide written informed consent were excluded from the study. The study protocol was approved by the Ethics Committee of CEMIC, Buenos Aires City, Argentina (865/14).

The measurements were performed with the patient in a supine position. The headboard was placed at 45°, and the patient's head and neck were kept in a neutral position. Lidocaine hydrochloride jelly USP 2% was used for local anesthesia, after which an esophageal balloon (BA-A-008MBMed, Buenos Aires, Argentina) was passed through the nose, passing the pharynx and esophagus and progressing into the stomach (55 cm). The esophageal balloon was inflated with 5.0 ml of air, 4.5 ml of which were removed so that the balloon was left with 0.5 ml.[9] The balloon's location in the stomach was verified using a sniff test, which caused a positive deflection in pressure graphs. The balloon was then retracted 20 cm, the sniff test was repeated, and a negative deflection on the pressure graph confirmed its position in the esophagus. The balloon was attached to the nose with taped dressing to prevent movement.[9] An occlusion test was performed to verify the correct position.[10] For patients breathing through a tracheostomy tube, a flow sensor was placed on the tracheostomy tube universal connector. Patients breathing using the UA received an oronasal mask. The measurements were performed for 5 min under each condition. Cuffed tracheostomy tubes (Shiley Hi-Lo Evac Tracheostomy Tube Cuff®; Covidien, Ireland) and cuffless tubes (Biesalski® Rucsh, Uruguay) were used. The inner diameter (ID) and outer diameter (OD) of the tubes used are shown in Table 1.

The four measurement conditions were those to which a patient is subjected during the usual decannulation process performed at the LTAC:

- Patient breathing through an unoccluded tracheostomy tube and inflated cuff. The tracheostomy tube ID was the same as that used before the measurement
- Patient breathing through the UA with an occluded tracheostomy tube and deflated cuff. The cuff was deflated with a 10-ml syringe until the plunger showed negative pressure, indicating a lack of air in the cuff. A button routinely used at the LTAC was utilized to occlude the tube. A 5 cm × 5 cm of Tegaderm Film® (3M) was placed between the neck

**Table 1: Inner and outer diameters of the tubes used**

| Tracheostomy | id* (mm) | od* (mm) |
|---|---|---|
| Cuffed tube | 7 | 9.7 |
| Cuffless tube | 7 | 10.85 |
| Cuffed tube | 8 | 11 |
| Cuffless tube | 8 | 11.9 |

*ID: Inner diameter, *OD: Outer diameter

plate and patient's skin; the film contained a hole for the tracheostomy tube. This procedure was performed to prevent peristomal air leakage
- Patient breathing through the UA with a cuffless tracheostomy tube with an inner cannula (Biesalski). The ID of the tube was identical to that which the patient was wearing. A 5 cm × 5 cm of Tegaderm Film® was placed between the neck plate and patient's skin; the film contained a hole for the tracheostomy tube
- Decannulated patient breathing through the UA. The Biesalski tracheostomy tube was removed, and the stoma was sealed with gauze stuck with a 5 cm × 5 cm of Tegaderm Film®. While taking the measurements, the gauze was pressed with one or two fingers on the stoma to prevent air leakage.

During each change in the patient's condition, the time interval was 15 min in a semi-seated position at 45° to allow all ventilatory variables to return to their baseline values.[7] The WOB variations were analyzed as the pressure-time product (PTP) and PTP per minute (PTP/min). The PTP/min/VT quotient was used as an efficiency determinant. The following ventilatory variables were also analyzed: FR, VT, VE, and the RSBI.[11] Ventilatory and WOB variables were collected with FluxMed® GrT (MBMed, Argentina) equipment and analyzed with FluxView® and FluxReview® (MBMed software, Argentina). Numerical variables are reported as mean ± standard deviation. Categorical variables are expressed as percentages. The primary result variable (changes in WOB during spontaneous breathing) in the different models was measured using single-factor analysis of variance (ANOVA), and the Games-Howell test was used for *post hoc* analysis of differences between group means due to the lack of equal variations. $P \leq 0.05$ was considered statistically significant.

## RESULTS

Eight patients were studied. Their mean age was 58.5 ± 17.2 years, and 62.5% were men. The diagnoses at the time of admission to the intensive care unit were cerebrovascular accident ($n = 3$), multiple injuries and cranioencephalic trauma ($n = 2$), pneumonia ($n = 1$), recovering from myocardial revascularization surgery ($n = 1$), and acute respiratory failure with pulmonary fibrosis ($n = 1$). The average duration of use of the artificial airway was 110 ± 44 days, and the average duration of use of the tracheostomy was 95 ± 42 days. Seven patients had #7 tracheostomy tubes, and one patient had a #8 tracheostomy tube. The physiological and WOB variables are shown in Table 2. ANOVA showed significant differences for all variables. *Post hoc* analysis identified significant differences in FR, RSBI, VT, and VE among all conditions except between Conditions 3 and 4 ($P = 0.945$, $P = 0.064$, $P = 0.324$, and $P = 0.927$, respectively). On analysis of WOB, esophagus pressure showed significant differences among all conditions except between Conditions 2 and 3 ($P = 0.053$). PTP showed significant differences among all conditions. PTP/min showed significant differences among all conditions except between Conditions 2 and 4 ($P = 0.138$), and PTP/min/VT was significantly different among all conditions except between Conditions 1 and 2 and between 2 and 3 ($P = 0.072$ and $P = 0.106$, respectively). Figure 1 depicts a decrease in FR and an increase in VT as a result of changing from breathing through a tracheostomy tube with an inflated cuff to breathing through the UA under Conditions 2, 3, and 4. Figure 2 depicts how Pes, PTP, PTP/min, and PTP/min/VT increased under Condition 3 compared with the other conditions.

## DISCUSSION

No previous reports have described the effects of the decannulation protocol (deflated cuff stage, occluded tracheostomy tube stage, and occluded cuffless tube stage) on WOB and respiratory variables. Our study revealed that WOB is higher when breathing through the UA than when breathing through a tracheostomy tube with an inflated cuff. This finding is consistent with that of Chadda *et al.*,[7] who hypothesized that this increase is produced by the increased dead space generated by breathing through the UA. The authors found that WOB was higher when breathing through a tracheostomy tube than when breathing through the UA once the patients were decannulated. This increase was produced at the expense of an increase in both VT and transdiaphragmatic pressure. These findings are similar to those in our study. However, our study population differs in that we did not include patients with neuromuscular disease. Unlike Chadda *et al.*,[7] we found statistically significant differences in FR and RSBI and observed a rapid, shallow pattern when breathing through a tracheostomy tube (Condition 1).

Another finding in our study was an increase in WOB when breathing through the UA with an occluded tracheostomy tube, whether cuffed or cuffless (Conditions 2 and 3, respectively). This may be related to the presence of the tracheostomy tube body in the trachea, which decreases its ID, generating more resistance to airflow. The OD of the tracheostomy tubes used in this study was slightly larger in the cuffless tubes (when compared with tracheostomy tubes with the same ID) and resulted in a significant difference in the PTP and PTP/min. The PTP/min/VT, a measurement of efficiency, was lower under Conditions 1 and 4. This may also be explained by the decrease in tracheal ID generated by the tube body under Conditions 2 and 3.

The manufacturer's specifications of cuffless tracheostomy tubes (Biesalski) refer to an OD of 10.85 mm for #7 tubes

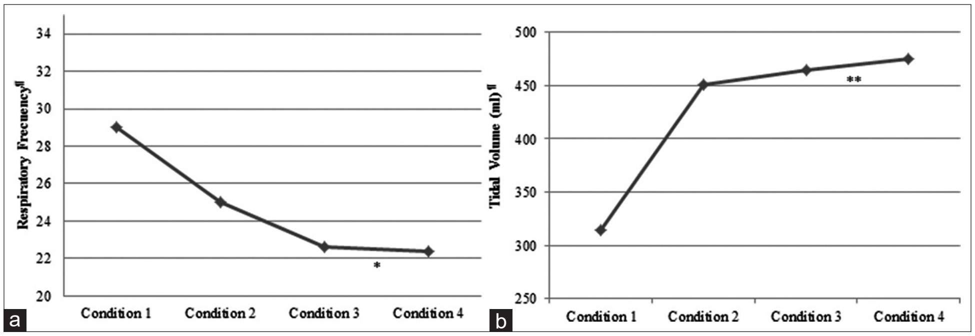


**Figure 1:** Ventilatory variables among conditions. ¶Values expressed in means; Condition 1: inflated cuff; Condition 2: deflated cuff with occluded tube; Condition 3: occluded cuffless tube; Condition 4: upper airway. In the *post hoc* analysis, all the conditions showed a statistically significant difference among each except for *Condition 3 versus Condition 4, *P* = 0.945 and **Condition 3 versus Condition 4, *P* = 0.324

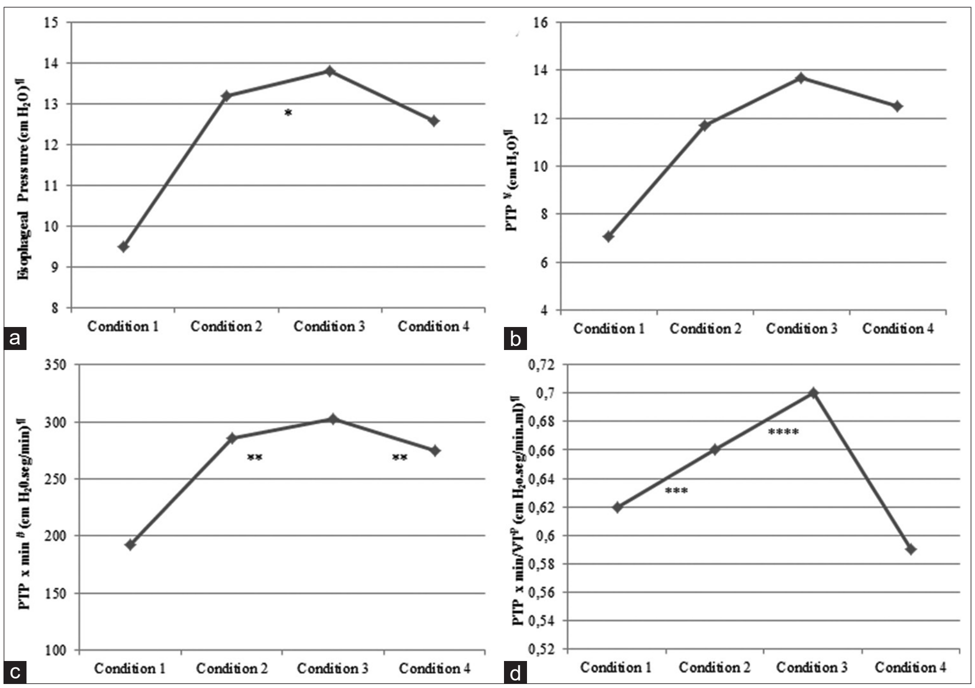


**Figure 2:** Work of breathing in different conditions. ¶Values expressed in mean; Condition 1: inflated cuff; Condition 2: deflated cuff with occluded tube; Condition 3: occluded cuffless tube; Condition 4: upper airway; ¥pressure-time product; #pressure-time product per minute; ¥pressure-time product per minute/tidal volume. In the *post hoc* analysis all the conditions showed a statistically significant difference among each except for *Condition 2 versus condition 3, *P* = 0.053; *Condition 2 versus condition 4, *P* = 0.138; *Condition 1 versus condition 2, *P* = 0.072; ****Condition 2 versus Condition 3 *P* = 0.106

**Table 2: Physiological and work of breathing variables in the four conditions measured**

| Variables | Condition 1 | Condition 2 | Condition 3 | Condition 4 | *P* |
|---|---|---|---|---|---|
| FR[a] | 29.1±7.3 | 25±5.1 | 22.6±3.5 | 22.4±3.8 | <0.001 |
| Vt[b] | 314±74 | 451±81 | 464±103 | 475±100 | <0.001 |
| VE[c] | 8.8±1.8 | 11.2±3.1 | 10.4±2.9 | 10.6±2.8 | <0.001 |
| FR/VT[d] | 100±45 | 57±18 | 51±15 | 48±12 | <0.001 |
| Pes[e] | 9.5±4.2 | 13.2±4.6 | 13.8±3.3 | 12.6±3.3 | <0.001 |
| PTP[f] | 7.1±3.6 | 11.7±4.2 | 13.7±3.5 | 12.5±3.4 | <0.001 |
| PTP/min[g] | 192±75 | 286±95 | 303±71 | 275±70 | <0.001 |
| PTP/min/vT[h] | 0.62±0.23 | 0.66±0.25 | 0.70±0.26 | 0.59±0.15 | <0.001 |

[a]Respiratory frequency (frequency min), [b]Tidal volume (ml), [c]Minute ventilation (L/min), [d]Rapid and shallow breathing index (frequency min/ml), [e]Esophageal pressure swing (cm $H_2O$), [f]Pressure-time product (cm $H_2O$/s), [g]Pressure-time product/minute (cm $H_2O$/s/min), [h]Pressure-time product/minute/tidal volume (cm $H_2O$ s/min/ml). Values expressed in means and standard deviation

and 11.9 mm for #8 tubes. Nevertheless, these models have a cone-shaped body with an OD that decreases at the distal end. Consequently, the ODs of the middle and distal parts of the tube are smaller than in cuffed tubes (#7 tube: ODs in middle and distal parts are 9 and 8 mm, respectively; #8 tube: ODs in middle and distal parts are 10 and 9 mm, respectively). This could increase the space around the tube and generate a lower resistance to airflow in the UA. There is evidence that the endotracheal tube resistance differs *in vivo* versus *in vitro* because of the thermal malleability of the material.[12] This could explain the higher WOB (PTP and PTP/min) under Condition 3 than under Condition 2, although its conical shape allows a smaller OD within the airway space.

In a study performed by Dellweg *et al.*,[8] the WOB generated while breathing through the UA once the patient was decannulated was compared with the WOB generated while breathing through a tracheostomy tube with an inflated cuff. The WOB showed individual changes in each patient (in some patients, it increased when they were decannulated, and in others it decreased), but it was correlated with the airway resistance (as resistance increased, the WOB increased and vice versa). This could explain the increased WOB and decreased efficiency (PT/min/VT) under Conditions 2 and 3 of the present study.

A laboratory study performed by Beard and Monaco[4] found greater resistance in occluded tubes with deflated cuffs than in occluded tubes without cuffs. We did not analyze the flow under the different conditions in the present study, but analysis of the WOB generated showed the opposite results. However, their study did not specify the OD of the tracheostomy tubes used, and the materials were not subject to body temperature because it was not a human trial. In our study, we found that the WOB was lower when breathing through the tracheostomy tube than when breathing through the UA. This result is different from the results obtained by Moscovici da Cruz *et al*.[13] The difference could be due to the fact that in their study, the patients had several tumors in the UA that decreased its ID, which was the reason for the tracheostomy. In our study, however, the main indication for performing a tracheostomy was associated with the duration of invasive mechanical ventilation.

The decannulation protocol of our institution includes a 72-h period of tolerance to breathing with an occluded tracheostomy tube with a deflated cuff and a 96-h period with an occluded cuffless tube. All patients studied were able to undergo decannulation on the day of the measurements, and recannulation was not required. This might support the fact that the increased WOB caused by the tracheostomy tube body and breathing through the UA is not clinically significant.

The small number of patients enrolled did not allow us to analyze other variables that might influence the WOB, such as the diagnosis on admittance to the intensive care unit, age, number of days that the artificial airway was used, and number of days that the tracheostomy tube was used.

The conditions under which the patients were studied were not randomized because we decided not to change the usual order of the protocol, which progresses from the patient breathing with an inflated cuff to breathing with a deflated cuff and occluded tube, an occluded cuffless tracheostomy tube, and finally decannulation. We decided not to randomize the order of measurements because we would have inevitably needed to cannular again the patients to perform the measurements.

## CONCLUSION

All of the conditions under which the variables were measured showed different results regarding the WOB generated. The conditions requiring the use of the UA to breathe caused an increase in WOB, possibly due to the increase in dead space. The use of occluded cuffless tracheostomy tubes generated an increase in WOB, perhaps due to a smaller peri-tube space, which may result when the tube material is at body temperature. This study should be repeated using a larger sample of patients to more fully evaluate the clinical impact.

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Nil.

### Conflicts of interest

There are no conflicts of interest.

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