TRACHEOSTOMY DECANNUATION: IMPLICATION ON RESPIRATORY MECHANICS

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Accepted 19 February 2007
Published online 8 August 2007 in Wiley InterScience (www.interscience.wiley.com). DOI: 10.1002/hed.20653

Abstract: Background. Tracheostomy decreases airway resistance and work of breathing. No comprehensive data are available on respiratory mechanics after tracheostomy decannulation. We evaluated respiratory mechanics after decannulation.

Methods. Twenty-five patients with tracheostomy were included. Measurement of arterial blood gases, air-flow, and esophageal pressure during spontaneous breathing were evaluated.

Results. Overall arterial blood gas parameters as well as flow and pressure measurements including work of breathing and airway resistance were not affected by the intervention. Inspiratory time fraction increased from 40.0 ± 0.04 to 43.0 ± 0.05% (p = .007). We observed marked individual differences. Postdecannulation change in work of breathing is best predicted by change in airway resistance (R = 0.869, R² = 0.755, p < .0001)

Conclusion. Inspiratory time increased after decannulation, and arterial blood gas levels and respiratory mechanics did not change for the whole cohort. Individual changes in work of breathing are considerable and correlate closely to changes in airway resistance. ©2007 Wiley Periodicals, Inc. Head Neck 29: 1121–1127, 2007

Keywords: tracheostomy; airway resistance; airway obstruction; work of breathing; tracheal stenosis

First descriptions of tracheostomies date back to the time around 3000 B.C. Today tracheotomy is a standardized and widespread procedure. Data from small studies suggest that work of breathing, pressure-time product, airway resistance, and auto–positive end-expiratory pressure (PEEP) decrease after tracheostomy in ventilated and spontaneously breathing patients. Sequelae from tracheostomy include tracheal stenosis and upper as well as lower tracheal obstruction. These complications potentially interfere with the decannulation process. The resistance of the upper airway may vary over time for reasons such as anatomy, position, muscular tone, secretions, infection, edema, the upper airway resistance syndrome, and local complications from artificial airways. Therefore, one cannot conclude that tracheostomy removal automatically reverses the observed mechanical changes seen during tracheostomy placement. The only study investigating physiological changes after decannulation excluded upper airway pathology by endoscopic visualization before decannulation was performed. This study demonstrated a 30% increase in the work of breathing, which was caused by an increase in dead space only.

The objective of our investigation was to evaluate the mechanical changes after decannulation.
PATIENTS AND METHODS

The study protocol was approved by our institutional review board, and informed consent was obtained from every patient.15

Patient Population. Twenty-five consecutive tracheostomized patients admitted to our weaning center were studied. Patients had undergone tracheostomy in their referring hospitals after they had failed extubation at least once. Table 1 provides information about basic patient data as well as information about the time of invasive ventilation, the tracheostomy size, and arterial blood gas (ABG) data prior to decannulation. The primary reason for weaning failure was structural lung disease (chronic obstructive pulmonary disease [COPD]) in 18 patients and disease of the chest wall and the respiratory muscles in 7 patients. Additional comorbidities contributed to the failure to wean in various degrees. Table 2 summarizes the comorbidities of the cohort.

Patients were deemed appropriate for decannulation when they were able to breathe spontaneously without showing the following signs of distress16: respiratory rate above 35 breaths per minute, arterial oxygen saturation below 90%, heart rate above 140 beats per minute or a sustained decrease or increase in the heart rate of more than 20%, systolic blood pressure above 180 mm Hg or below 90 mm Hg, diaphoresis, or anxiety. The pH was required to be above 7.25.

Patient baseline data are presented in Table 1.

Experimental Protocol. Patients were positioned in bed with their upper body at a 45° upright angle in a quiet room. Respiratory flow and esophageal pressure were recorded during spontaneous breathing through the tracheostomy tube while the cuff was inflated, and during mouth-breathing after the tracheostomy site was occluded with a tracheostomy retrainer (TPS Multiflex, Rüsch, Kernen, Germany) (Figure 1). The chest physician who inserted the tracheostomy retrainer had to cut the silicon plate at the end of the device to achieve secure fitting and avoid compromise of the tracheal lumen. Placement was validated by endoscopic inspection through the upper airways. During mouth-breathing, patients were asked to breathe through a mouthpiece (Jaeger 892 100, Hoechberg, Germany) while the nostrils were occluded with a nose clip. Measurements were taken under steady state conditions (variation less than 5%); blood gas samples had to be collected parallel to flow and pressure measurements. After tracheostomy retrainer placement, patients were continuously monitored, and reininsertion of the tracheostomy tube was performed if 1 or more of the above defined failure criteria occurred.16

Measurements. Analysis of pressure, volume, and time were used to assess changes in respiratory mechanics. Esophageal pressure (\(P_{oes}\)) was measured using an esophageal balloon catheter (SmarCath 700-3-300, Viasys Healthcare, Palm Springs, CA) with an inflation volume of 0.8 ml automatically delivered by a Bicore CP-100 (Allied Healthcare, Irvine, CA) pulmonary monitor. Measurements were validated using the method described by Baydur et al.17 Flow values were obtained using a flow sensor (VarFlex Flow Transducer 700-2-300, Viasys Healthcare). The flow sensor was either directly connected to the blocked tracheal tube (Rüsch, Kernen, Germany) or to a mouthpiece. The Bicore pulmonary monitor is capable of measuring resistive (\(W_{obr}\)) and elastic (\(W_{obel}\)) work of breathing. Both values add up to total work of breathing. Principles of measurements are as described hereafter. The inspiratory portion of the flow-pressure integral, which moves in a clockwise direction, represents inspiratory resistive work of breathing. Chest wall compliance was estimated to be 4% of the predicted vital
capacity per centimeter of water\textsuperscript{18} and entered into the Bicore monitor. For calculation of elastic work of breathing, the line of chest wall compliance is fitted to the pressure volume curve by passing it through the end-expiratory elastic recoil pressure of the chest wall,\textsuperscript{19} which corresponds to end-expiratory $P_{oes}$ at zero flow.\textsuperscript{20} Dynamic pulmonary compliance is represented by a line between the 2 points of zero flow (at end-inspiration and end-expiration) of the flow-pressure curve. Elastic inspiratory work of breathing is then represented by the area between the dynamic compliance line and the line of chest wall compliance within the volume range of the corre-
sponding breath. Work is given per unit of ventilated volume and expressed in joules per liter.

Airway resistance (Raw) was calculated from the delta in transpulmonary pressure divided by the difference in flow taken at the same volume during the entire respiratory cycle. Thus having a flow, time, and pressure signal, the CP 100 Monitor is capable of measuring the following parameters: respiratory rate (RR in breath/min), tidal volume (TV in L), minute ventilation (VE in L/min), peak inspiratory flow (PIF in L/s), peak expiratory flow (PEF in L/s), total work of breathing (WOB in J/L), airway intrinsic end expiratory pressure (PEEPi in hPa), expiratory airway resistance (RAW in hPa*s/L) and inspiratory time fraction (TI as a fraction of 1). Tidal volume (TV) was calculated by dividing VE by RR. The Bicore system has been validated previously; the procedure is based on a close correlation between esophageal and pleural pressure.

Statistics. The average of each 40-breath cycle was calculated and entered into the SPSS statistical software package version 12.0. Within-subject comparison was analyzed by paired t test. Significance was assumed when p was less than .05. Differences (delta) in RR, VE, TV, PEF, PIF, WOB, PEEP, RAW, and Ti/Ttot were calculated by subtracting the corresponding values (mouth-breathing minus tracheal-breathing) and labeled RRd, VEd, TVd, PEFd, PIFd, WOBd, PEEPd, RAWd, and Ti/Ttotd. Stepwise linear regression was performed to predict WOBd by the other delta values.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Tracheal-tube</th>
<th>Mouth-breathing</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>RR</td>
<td>26.7 ± 6.8</td>
<td>26.2 ± 7.4</td>
<td>&gt;.05</td>
</tr>
<tr>
<td>VE</td>
<td>8.1 ± 1.9</td>
<td>8.1 ± 2.3</td>
<td>&gt;.05</td>
</tr>
<tr>
<td>TV</td>
<td>320 ± 108</td>
<td>332 ± 120</td>
<td>&gt;.05</td>
</tr>
<tr>
<td>PIF</td>
<td>0.51 ± 0.14</td>
<td>0.51 ± 0.14</td>
<td>&gt;.05</td>
</tr>
<tr>
<td>PEF</td>
<td>0.37 ± 0.09</td>
<td>0.42 ± 0.13</td>
<td>&gt;.05</td>
</tr>
<tr>
<td>WOB</td>
<td>1.07 ± 0.61</td>
<td>1.19 ± 0.67</td>
<td>&gt;.05</td>
</tr>
<tr>
<td>PEEPi</td>
<td>4.8 ± 1.6</td>
<td>5.9 ± 1.6</td>
<td>&gt;.05</td>
</tr>
<tr>
<td>RAW</td>
<td>12.5 ± 10.3</td>
<td>13.7 ± 10.5</td>
<td>&gt;.05</td>
</tr>
<tr>
<td>Ti/Ttot</td>
<td>0.40 ± 0.04</td>
<td>0.43 ± 0.05</td>
<td>.007</td>
</tr>
</tbody>
</table>

Abbreviations: RR, respiratory rate in breath per minute; VE, minute-ventilation in liters; TV, tidal volume in milliter; PIF, peak inspiratory flow in liters per second; PEF, peak expiratory flow in liters per second; WOB, total work of breathing in Joules per liter; PEEP, intrinsic PEEP in cm H2O; RAW, airway resistance in hPa * seconds per liter; Ti/Ttot, inspiratory time as a fraction of one.

RESULTS

Patients were ventilated for 43.2 ± 23.6 days before admission to our hospital. The decision for tracheostomy removal was made on average on hospital day 6.2 ± 4.2 days (Table 1) according to the criteria listed in the method section. At this time, patients had their tracheostomy tubes for 37.3 ± 20.2 days in place. Overall, the only significant change in respiratory mechanics detected after tracheal tube removal and tracheostomy retrainer placement was a slight increase of the inspiratory time. All other parameters remained unchanged on a significant level (Table 3). The same applies for parameters of arterial blood gas analysis (Table 4). The individual development of the airway resistance and work of breathing before and after decannulation varied substantially. The differences arranged in ascending order are shown in Figures 2 and 3. Two patients developed clinically significant increase of WOB within 1 hour of placement of the tracheostomy retrainer (1.2 to 2.81 J/L and 0.92 to 2.63 J/L respectively). The causes were a protruding broken tracheal cartilage with granulation tissue in the first patient and laryngeal edema in the second. Exclusion of these 2 patients from analysis did not result in a significant reduction of the WOB after tracheostomy retrainer placement (1.19 to 1.05 J/L, p = .74).

Regression analysis was performed to investigate which variables impact WOBd. RAWd was found to be the best single predictor (R = 0.869, R² = 0.755, p < .0001). Stepwise addition of RRd and VEd to the calculation improved the model slightly to (R = 0.9, R² = 0.81 and R = 0.919, R² = 0.845, all p < .0001) respectively. The correlation of WOBd and RAWd is shown in Figure 4.

DISCUSSION

The transition from spontaneous breathing through a tracheal tube to mouth-breathing was
accomplished by decannulation and insertion of a tracheostomy tube retrainer (Figure 1). This device keeps the tracheostomy site open for potential reinsertion of a tracheostomy tube.

Other than tracheostomy buttons, the retrainer does not compromise the lumen of the trachea, since the silicon plate lines up tightly with the anterior portion of the trachea and is held in place by an adjustable counter-plate. Tracheostomy retrainer placement resulted in a slight increase in inspiratory time fraction without change in the remaining mechanical parameters (Table 1). Significance calculation of a t test is based on the comparison of group means and the sum of the squared individual distances to the group mean. If a number of individuals increase their values while a similar number decrease their values in a comparable range, there will be no change overall. This phenomenon is clearly visible in our patient cohort (Figures 2 and 3). For this reason, we want to emphasize the importance of the individual course of the patients, including 2 individuals who had to be recannulated because of respiratory distress on account of marked increase in airway resistance and work of breathing. Previous studies clearly showed a reduction in work of breathing, airway resistance, and intrinsic PEEP after tracheostomy tube placement for intubated patients as well as patients who previously used their natural airways. While endotracheal tubes are usually longer than tracheostomy tubes, their resistance, given the same inner diameter and curvature, is expected to be higher according to the law of Hagen-Poiseuille. Thus the observed changes are expected and easily explained. The resistance of a tubular system is directly proportional to its length and inversely proportional to the radius of the system raised to the 4th power for laminar flows and to the 5th power for turbulent flows. Because the

![Figure 2](image1.png)

**FIGURE 2.** Individual changes in airway resistance (RAW hPa s/L); positive bars represent increases after decannulation, negative bars represent decreases.

![Figure 3](image2.png)

**FIGURE 3.** Individual changes in total work of breathing (WOB, J/L); positive bars represent increases after decannulation, negative bars represent decreases.

![Figure 4](image3.png)

**FIGURE 4.** Changes in work of breathing (WOB, J/L) after decannulation are closely related to changes in airway resistance (RAW, hPa s/L), $r = 0.869, p < .0001$. 

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inner morphology of the upper airway is depend-ant on anatomy, position, muscular tone, secre-tions, infection, edema, and local complications from an artificial airway, it becomes obvious that the resistance of the natural airways might vary over time. The 2 published studies comparing mouth-breathing to tracheal-tube-breathing are both special in terms of their patient cohort. Moscovici da Cruz et al investigated a group of patients with head and neck cancer. At least 3 of the 7 patients exhibited cancer invasion into the tonsils or larynx, possibly impacting upper airway resistance. Not surprisingly, this study observed a reduction in intrinsic PEEP, pressure time product, and work of breathing according to upper bound calculation. Chadda et al compared similar parameters in 9 neuromuscular patients after the upper airways were confirmed to be free of obstructing pathology by indirect laryngoscopy and fiberoptic bronchoscopy. The increase in work of breathing when switched to mouth-breathing was due only to increased dead space that forced the patient to generate higher tidal volumes. In our patient group, observed changes in WOB (WOBd) are best predicted by RAWd explaining more than 75% of the variance of WOBd (Figure 4). Parameters of breathing pattern (RRd and VEd) improved prediction by only another 9%.

Other than the previous studies, we do not see a uniform difference in WOB in favor of tracheostomy when comparing it to mouth-breathing. We rather observe individual differences that correspond to changes in airway resistance after decannulation. According to our data, decannulation can result in increased or decreased respiratory burden depending on upper airway morphology and pathology.

We see a considerable variability of certain parameters such as RAW, WOB, and the markers of respiratory pattern. The high standard deviation of these parameters however can be explained by the pathophysiology of the underlying diseases (Table 2). Different severities of obstructive airway disease will impact the RAW and the breathing pattern differently, while parenchymal and pleural diseases can substantially impact lung compliance and therefore WOB.

**CONCLUSION**

We conclude that decannulation (removal of the tracheostomy tube) did not change the respiratory burden overall; however, there is considerable variability and patients might experience relevant decrease or increase in airway resistance and work of breathing possibly resulting in respiratory distress with the need for recannulation. Changes in work of breathing are closely related to changes in airway resistance.

**Acknowledgments.** The authors thank Dr. Glenn Eiger (Albert Einstein Medical Center, Philadelphia, PA) for expert editorial assistance and linguistic advice. The measurement equipment was property of the conducting institution. No external support was given; no grants were received.

**REFERENCES**


