Removal of the Tracheal Tube after Prolonged Mechanical Ventilation: Assessment of Risk by Oscillatory Impedance

Karl-Josef Franke Georg Nilius Stefan Morgenstern Karl-Heinz Ruhle

Department of Pneumology and Critical Care Medicine, Helios Klinik Ambrock, University of Witten/Herdecke, Hagen, Germany

Key Words

Long-term mechanical ventilation · Oscillatory impedance · Tracheal obstruction · Tracheostomy decannulation · Weaning failure

Abstract

Background: Decannulation failure is usually due to tracheal obstruction. Prior to decannulation, inspection by the invasive procedure of bronchoscopy that permits morphological evaluation of a tracheal stenosis is standard practice. A non-invasive method enabling the quantification of the airway obstruction that requires little cooperation is measurement of the airway resistance by the forced oscillation technique. **Objectives:** The aim of the present study was to define oscillatory impedance thresholds which predict successful decannulation. **Methods:** A total of 131 patients were investigated prospectively. Step 1: Following probatory decannulation, measurement of the oscillatory impedance. Step 2: Blinded to the results of the impedance measurement, bronchoscopy-assisted decannulation attempt. The criteria for renewed cannulation were high-grade laryngeal or tracheal obstruction, dyspnea or stridor, or a drop in SaO_2 <90% under O_2 insufflation. **Statistics:** Determination of the ratio tracheal tube remains/tracheal tube removed (TT+/TT-) for every measured value of the oscillatory resistance at 5 Hz (Ros 5 Hz). Determination of specificity and positive pre-

dictive value for determined threshold values with respect to TT-. **Results:** The data of 126 patients were evaluated. TT+ n = 26, TT- n = 100. Decannulation on the basis of bronchoscopy criteria: Specificity and positive predictive value found out for Ros 5 Hz <0.35 kPa/l/s (n = 44) were 1.00 and 1.00, respectively, and for Ros 5 Hz <0.47 kPa/l/s (n = 71) 0.88 and 0.96, respectively. **Conclusions:** Measurement of the oscillatory airway resistance represents a practicable method prior to decannulation. Below a value of Ros 5 Hz <0.35 kPa/l/s, bronchoscopy would appear not to be necessary.

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Introduction

Especially since the introduction of percutaneous techniques performed by the intensivist at the bedside, tracheostomy has become an increasingly common intervention in patients difficult to wean [1, 2]. Late complications of tracheostomy and long-term mechanical ventilation include tracheal and laryngeal obstructions, the former due to tracheal stenosis, tracheomalacia or the development of granulation tissue [3, 4]. In as much as 16% of such cases, tracheolaryngeal obstruction leads to decannulation failure [4, 5]. After percutaneous dilational tracheostomy, in particular, the stomal and supra-stomal regions prove to be predilection sites for the de-

velopment of a tracheal stenosis, and frequently of granulation tissue. Prior to decannulation, a bronchoscopic examination that allows a morphological assessment of tracheal obstruction is standard [3, 4, 6]. In the assessment of the bronchoscopist, the tracheal tube is removed – the clinical picture and the measurement of oxygen saturation aid the decision to favor permanent decannulation.

In view of the not inconsiderable burden caused to the patient by tracheoscopy, and the time needed for the examination, we sought a non-invasive means of quantifying airway obstruction that could serve as a basis for permanent decannulation. Candidates for tracheal tube removal are not infrequently immobile, and their ability to cooperate is limited. In such cases, measurement of airway impedance by means of oscillometry – a technique that can also be applied in young children and the newborn – would appear most appropriate [7, 8].

In the present study, the technique of multifrequency impulse oscillometry described by Müller und Vogel [9] was employed. Via an external loudspeaker, flow oscillations are superimposed on the breathing, and the pressure response analyzed. Airway obstruction is identified particularly well at low oscillation frequencies. Oscillometry requires little of the patient other than simply to breathe quietly on a mouthpiece. The time needed to obtain a measurement is brief and the equipment small and easy to operate.

Objectives

We analyzed the airway resistance measured with the oscillatory method to determine whether a threshold value predictive of a successful or failed decannulation can be defined. A secondary aim of the present study was to establish a possible correlation between the bronchoscopic evaluation of the severity of the tracheal or laryngeal obstruction and the measured impedance values.

Methods

The study was approved by the Ethics Committee of the Witten/Herdecke University.

Patients

In the period between October 2006 and April 2008, we investigated 131 consecutive patients in whom, following successful weaning from prolonged mechanical ventilation, the tracheal tube was to be removed. The large majority of these patients had been referred to us from other hospitals with tracheal tubes in

place. Written permission was obtained from all the patients or their respective legally appointed guardians. The data of 126 patients were evaluated – 1 patient withdrew his consent, and in 4 others laryngoscopy revealed an elevated risk of aspiration, so that decannulation was no longer indicated.

Procedure and Materials

Impulse Oscillometry (Firma Jaeger, Germany). The patient was positioned semi-reclining with head mildly extended, and provided with a nose clamp. The mouthpiece affixed to the pneumotachograph of the oscilloresistometer was held by the patient between his teeth with his lips closed around it and his tongue below it. The patient was then provisionally decannulated by a physician, and the tracheostomy briefly closed off from the outside to prevent the passage of air. Measurement of the impedance was effected over a period of 20 s with the patient breathing normally. Thereafter, the patient was recannulated. The oscillatory airway resistance at 5 Hz (Ros 5 Hz) was evaluated.

Bronchoscopy-Directed Decannulation Attempt. The investigator was blinded to the results of the impedance measurement. In each case, sedation with 2–5 mg midazolam was applied, and pernasal or peroral inspection with a bronchoscope having an outside diameter of 5.1 mm (Pentax, Europe) performed. Recannulation criteria: subtotal laryngeal obstruction, tracheal obstruction >50–75% and/or the occurrence of dyspnea, stridor and/or a drop in SaO₂ <90% under insufflation with oxygen at 3 l O₂/min. Following the examination in the endoscopy department, decannulated patients were monitored for at least 24 h employing pulse oximetry and ECG monitoring.

Bronchoscopic Evaluation of Tracheal or Laryngeal Obstruction and Classification into One of Four Degrees of Stenosis (A, B, C, D). Grade A: obstruction 0–25%, B: 26–50%, C: 51–75%, D: 76–100%. In the event of multiple stenoses at different locations, the most severe stenosis was graded in accordance with the Hagen-Poiseuille law.

Statistical Analysis

- Threshold determination on the basis of the ratio tracheal tube remains/tracheal tube removed (TT+/TT–) for each measured value of Ros 5 Hz in ascending series. Calculation of specificity and positive predictive value for the established threshold values in relation to the parameter TT– on the basis of bronchoscopic-clinical criteria.
- Calculation of the percentage of TT– for each of the grades A–D of the tracheolaryngeal obstruction.
- Calculation of the mean Ros 5 Hz values for each of the grades A–D of the tracheolaryngeal obstruction.

Results

The mean age of the 126 patients investigated (TT+ n = 26, TT– n = 100) was 65.9 ± 11.8 years, and the group comprised 80 men and 46 women. Table 1 shows the percentage distribution of the main diagnoses of the patients, all of whom were multimorbid. The indication for decannulation was established on day 41.7 ± 29.8 of their

Fig. 1. Ratio tracheal tube left in place/tracheal tube removed (TT+/TT-) for every value of the oscillatory resistance at 5 Hz (Ros 5 Hz) in order to determine threshold values with respect to TT-.

Table 1. Main diagnoses of the patients investigated (n = 126)

Main diagnosis	n (%)
Pneumonia	17 (13.5)
Guillain-Barré	2 (1.6)
Cerebral hemorrhage	7 (5.6)
Chronic obstructive pulmonary disease	24 (19)
Chest wall disorders	2 (1.6)
Ischemic heart disease	13 (10.3)
Coronary artery bypass surgery/grafting of the aortic or mitral valve	23 (18.3)
Peritonitis	2 (1.6)
Spinal cord disease	5 (4.0)
Embolism of the lung	3 (2.4)
Ischemic stroke	9 (7.1)
Carbon monoxide intoxication	1 (0.8)
Gastrointestinal hemorrhage	2 (1.6)
Encephalomyelitis disseminata	1 (0.8)
Polyneuropathia	4 (3.2)
Carcinoma of the colorectum	3 (2.4)
Thyroid carcinoma	1 (0.8)
Carcinoma of the esophagus	2 (1.6)
Central pontine myelinolysis	1 (0.8)
Cerebral injury	1 (0.8)
Grafting of the thoracic aorta	2 (1.6)
Cerebral toxoplasmosis	1 (0.8)

stay in our facility, the total duration of which (including rehabilitation measures where necessary) was 76.6 ± 38.2 days.

The TT+/TT- ratio for each measured value of Ros 5 Hz in ascending sequence can be seen in figure 1. The cutoff value for the threshold values of Ros 5 Hz <0.35 kPa/l/s was selected at the point of the curve where its gradient no longer comes to 0. The cutoff value for the threshold values of Ros 5 Hz <0.47 kPa/l/s was selected at the point where the curve shows its strongest gradient. For the threshold values of Ros 5 Hz <0.35 kPa/l/s (n = 44) and Ros 5 Hz <0.47 kPa/l/s (n = 71), a specificity of 1.0 and 0.88, and a positive predictive value of 1.0 and 0.96, respectively, were calculated (tables 2, 3). Table 4 shows the percentage contribution of TT- for each of the stenosis grades A–D of tracheolaryngeal obstructions. The mean values of Ros 5 Hz for each stenosis grade A–D of the tracheolaryngeal obstruction are shown in figure 2.

Discussion

On the basis of bronchoscopic-clinical criteria, decannulation proved possible in all of the cases with a measured Ros 5 Hz <0.35 kPa/l/s, as also in 88% of the cases with a measured Ros 5 Hz <0.47 kPa/l/s. The airway resistance Ros 5 Hz correlated well with the bronchoscopically assessed degree of stenosis: for grade A it was 0.36 ± 0.14 kPa/l/s and for grade B 0.45 ± 0.19 kPa/l/s, and

Fig. 2. Values of the oscillatory resistance at 5 Hz (Ros 5 Hz) in relation to the degrees of tracheolaryngeal obstruction.

thus corresponded with the measured threshold values of oscillatory impedance predictive of successful decannulation. As was to be expected, the probability of decannulation was a calculated 95% for grade A stenosis, and 89% for grade B.

Tracheal Stenosis and Failed Decannulation

Following prolonged tracheotomy, a respiratory obstruction of more than 20% has been described in 67% of the cases, with the obstruction being located proximal to the stoma in every case [3]. Not infrequently, the technique of percutaneous dilatational tracheostomy leads to cartilage damage and the formation of granulation tissue with the development of stomal or suprastomal stricture [5, 10, 11]. As a rule, circumferential, fibrotic stenoses arising somewhere along the length of the tracheal tube, due to cuff-related ischemia, are less often reported [6]. The presence of tracheolaryngeal obstruction, however, must be considered the major cause of decannulation failure in 6–16% of the cases [3–5]. In the present study, the percentage of patients failing decannulation – 21% (26/126) – is only a little higher than the figures reported in the literature, although the overall published data on this are sparse.

Risk Assessment prior to Scheduled Decannulation Bronchoscopy

In view of the above-mentioned findings, pernasal or peroral bronchoscopy should be considered prior to the removal of a tracheal tube [3–6, 10, 11]. The advantage of bronchoscopy is that it enables direct visualization of the nature and extent of the tracheolaryngeal obstruction.

Table 2. Calculation of specificity and positive predictive value for the cutoff values Ros 5 Hz 0.35 kPa/l/s and 0.47 kPa/l/s, respectively

		Real	
Test	n	TT- (n = 100)	TT+ (n = 26)
<i>Ros 5 Hz <0.35</i>			
TT-	44	(A) 44	(B) 0
TT+	82	(C) 56	(D) 26
<i>Ros 5 Hz <0.47</i>			
TT-	71	(A) 68	(B) 3
TT+	55	(C) 32	(D) 23

Test = Number of patients with TT– and TT+ predicted by impedance measurement; Real = TT– and TT+ on the basis of bronchoscopic-clinical criteria. Specificity = $D/(B + D)$; positive predictive value = $A/(A + B)$.

Table 3. Specificity and positive predictive values for the threshold values of the airway resistance in relation to the safety of decannulation based on bronchoscopic-clinical criteria¹

Ros 5 Hz	Specificity	Positive predictive value
<0.35	1.00	1.00
<0.47	0.88	0.96

¹ Ros 5 Hz = Oscillatory airway resistance at 5 Hz.

Table 4. Number of patients with the tracheal tube removed (TT–) for each degree of tracheolaryngeal obstruction

Degree of stenosis	TT– (%)
A	95
B	89
C	35
D	0

Narrowing of the airway >50–75% may be expected to cause symptoms [3, 12] – which corresponds to our stenosis grades C and D. In accordance with the defined criteria for recannulation, the probability of decannulation failure was 65% for stenosis grade C, and 100% for grade D (table 4). A disadvantage of bronchoscopy is the fact that it is an invasive procedure. The technique of im-

pulse oscillometry employed by us is non-invasive, and also enables a quantitative determination of airway obstruction. We observed a good correlation between the stenosis grade assessed morphologically during bronchoscopy, and the results of impedance measurement (fig. 2), with the airway resistances associated with grades A and B being considered normal and mildly elevated, respectively.

Comparison of Non-Invasive Methods

As a non-invasive technique for investigating the possibility of achieving successful decannulation, 24-hour capping of a fenestrated tracheal tube can be employed [4, 13]. An additional endoscopic inspection to check the position of fenestration within the tracheal lumen would however appear to make good sense. At a sensitivity and a positive prediction value of 1.0 for the impedance measurement and a value of $R_{os} 5 \text{ Hz} < 0.35 \text{ kPa/l/s}$, it may be assumed that bronchoscopy can be forgone (table 3). In contrast to capping, measurement of the impedance is associated with a brief loss of airway control, so that the associated decannulation attempt was performed by physicians with expertise in airway management. On the other hand, measurement of impedance provides a relevant assessment of the risk associated with decannulation within approximately 1 min.

In comparison with the investigation by Rumbak et al. [4], the time elapsed between successful weaning from the ventilator and the indication for decannulation in our patients was appreciably more than 48 h, since rehabilitative measures were following directly after weaning in our ward. When decannulation is followed by symptoms of airway obstruction, the latter usually occurs within 6 weeks in more than 50% of the cases [14]; this might ex-

plain the somewhat large percentage of patients failing to decannulate in our study (21 vs. a maximum of 16% in the literature) [4, 5]. But comparing our results to the literature remains difficult, because decannulation failure may also be due to worsening respiratory mechanics; especially with regard to the fact that our patients were multimorbid. Also in this context the results depend on the time of the indication for decannulation. Nevertheless, it might be a good idea to allow more time to elapse between successful weaning and decannulation, in particular since, for the most part, the most common tracheal obstruction with stomal or suprastomal location is caused by the application of percutaneous dilatational tracheostomy itself, rather than by the tracheal tube remaining in place [10, 11, 15–18]. Stenoses close to the distal tip of the tracheostomy tube caused by impingement of the tip of the tube against either the anterior or the posterior tracheal wall occur appreciably less often [19]. Following decannulation, impulse oscillometry can then readily be repeated and enables the risk of a significant tracheolaryngeal obstruction weeks to months after decannulation to be identified.

Conclusions

Impedance measurement can readily be done at the patient's bedside, and requires but little cooperation on his/her part [20]. Its advantages include quantifiability of the stenosis and the possibility of making more frequent observations. Our investigations show that at a $R_{os} 5 \text{ Hz} < 0.35 \text{ kPa/l/s}$ decannulation can be performed at no risk to the patient and with no need for an invasive bronchoscopic assessment of the risk.

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