Influence of the cuff pressure on the swallowing reflex in tracheostomized intensive care unit patients

R. Amathieu1,2, S. Sauvat1,2, P. Reynaud1,2, V. Slavov1,2, D. Luis1,2, A. Dinca1,2, L. Tual1,2, S. Bloc1,2 and G. Dhonneur1,2*

1 Anaesthesia and Intensive Care Unit Department, Jean Verdier University Hospital of Paris, Av du 14 Juillet, 93143 Bondy, France
2 Paris 13 University School of Medicine, Bobigny, France
* Corresponding author. E-mail: gilles.dhonneur@jvr.aphp.fr

Background. Because recovery of an efficient swallowing reflex is a determining factor for the recovery of airway protective reflexes, we have studied the influence of the tracheostomy tube cuff pressure (CP) on the swallowing reflex in tracheostomized patients.

Methods. Twelve conscious adult intensive care unit (ICU) patients who had been weaned from mechanical ventilation were studied. Simultaneous EMG of the submental muscles with measurement of peak activity (EMGp) and amplitude of laryngeal acceleration (ALA) were performed during reflex swallows elicited by pharyngeal injection of distilled water boluses during end expiration. After cuff deflation, characteristics of the swallowing reflex (latency time: LaT, EMGp, and ALA) were measured at CPs of 5, 10, 15, 20, 25, 30, 40, 50, and 60 cm H2O.

Results. LaT and CP were linearly related (P<0.01). CP was inversely correlated (P<0.01) to both ALA and EMGp.

Conclusions. We demonstrated that LaT, EMGp, and ALA of the swallowing reflex were influenced by tracheostomy tube CP. The swallowing reflex was progressively more difficult to elicit with increasing CP and when activated, the resulting motor swallowing activity and efficiency at elevating the larynx were depressed.

Keywords: acceleromyography; airway protection; cuff pressure; electromyography; swallowing reflex; tracheostomy

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cuff deflation with a stable respiratory rate, arterial oxygen saturation, and expired carbon dioxide expiratory partial pressure. In order to be included, the patients had to demonstrate they were co-operative and able to respond on command simple orders such as ‘swallow your saliva’ and ‘raise your right hand’.

Once recruited, the stomach content of the patient was suctioned and the nasogastric feeding tube was removed. The patients were then requested to fast for a minimum of 6 h. The studies were conducted with the patient sat up at 45°. Before measurement of the swallowing reflex characteristics, oropharyngeal secretions were suctioned. After tracheostomy tube cuff deflation (TRACOE VARIO™, high-volume and low-pressure cuff, POURÉT Medical, Clichy, France), suction was performed through the tracheostomy tube to remove secretions that had been sitting on the top of the cuff. Figure 1 shows details of the electrophysiological measurements. A 0.8 mm ID, polyvinyl catheter was placed through the nostril into the oropharynx using water lubricant gel without local anaesthetic. The tip of the catheter was positioned at the inferior limit of the oropharynx. This was checked visually and the catheter secured. Surface electrodes, used to measure EMG activity of the submental swallowing muscles, were placed 2 cm away from the mid-line and 1.5 cm above the hyoid arch. The EMG was amplified and band-pass filtered from 30 to 300 Hz, and then rectified and integrated (100 ms time constant), and the peak electromyographic activity was measured (EMGp).

The quality of laryngeal elevation was measured by accelerometry with the use of a piezoelectric probe measuring 2 × 2 × 4 mm (Entran; Garston, Watford, UK), which was fixed in the mid-line with an adhesive tape 0.5 cm above the tip of the thyroid cartilage. This probe measured acceleration values ranging from 5 to −5 G. The probe was oriented to measure the amplitude of laryngeal acceleration (ALA) generated by the contraction of the submental swallowing muscles.

In order to synchronize pharyngeal stimuli with respiration, ventilatory flows were monitored at the T-piece of the tracheostomy tube with a pneumotachograph (Fleish 2) and a differential pressure transducer (Validyne MP 45, Northridge, CA, USA). Reflex swallows were systematically elicited with boluses of distilled cold water (3°C) injected through the pharyngeal catheter at the end of expiration. The latency time of the swallowing reflex (LaT) was defined as the time elapsing between the moment of bolus injection of distilled water in the hypopharynx (a double-piston syringe allowed simultaneous injection of distilled cold water into the pharynx and 1 ml of air into the ventilatory circuit) and the beginning of the evoked EMG signal (Fig. 2).

Patients were included in the study, if reflex swallows could be elicited and if the characteristics of the swallowing reflex could be measured accurately. In order to evaluate pharyngeal sensory perception, we first determined in each tracheostomized patient the pharyngeal sensory threshold (PST). After cuff deflation (CP = 0 cmH2O), patients received in a random order 0.3, 0.5, 0.8, 1, 3, 5, or 10 ml boluses of cold (3°C) distilled water through the pharyngeal catheter. PST was arbitrary defined as the lowest (stimulation) volume of distilled water systematically triggering three successive end-expiratory reflexively activated swallows with an LaT of below 10 s. The following variables, LaT, EMGp, and ALA elicited with PST, were considered as the control values for the swallowing reflex in that patient.

If a 10 ml cold water bolus did not systematically elicit a reflex swallow or a PST of >5 ml was associated with frank tracheal aspiration signs, or if only poor-quality recordings of LaT, EMGp, or ALA could be obtained during elicited reflex swallows, the patient was excluded from the study. All signals were recorded simultaneously and stored on a personal computer.

The control values of the swallowing reflex were compared with those obtained with the tracheostomy cuff inflated with air to different pressures: 5, 10, 15, 20, 25, 30, 40, 50, and 60 cm H2O (Endotest manometer, Pressure Cuffs, Rusch, Betschdorf, France), applied in a random order determined by a computer-generated randomization list. At each CP and for each variable (LaT, EMGp, and ALA), a mean value of a set of three consecutive measures performed over 1 min was normalized to the control value. An interval of at least 1 min was allowed between each

Fig 1: Schematic illustration of the method used to evaluate the influence of CP increase on the swallowing reflex in tracheostomized patients. EMG and laryngeal acceleration (LA) were measured during reflexively elicited swallows at different values of CP measured using a CP controller (CPC). A pneumotachograph and a differential pressure transducer (PnT) were used to synchronize hypopharyngeal stimulations with the end-expiratory phase. A double-piston syringe (DPS) was used to simultaneously inject the pharyngeal stimulus (predefined: 0.3–5 ml volume, cold 3°C, distilled water bolus), and flush 1 ml of air within the ventilatory circuit.
measurement and return to the basal respiratory rate was required before the next measurement was performed. After each set of three tests, CP was reset to 0 cm H2O.

When all the measurements were completed, patients were asked to swallow 10 ml of water gel coloured with a white dye given orally with the cuff deflated. A flexible bronchoscope was passed through the tracheostomy to identify pulmonary aspiration manifest as coloured liquid seen on the tracheal wall.

The overall impact of CP increase upon the swallowing reflex variables was evaluated using a Friedman test. Then, a Wilcoxon non-parametric test for repeated measures was performed to evaluate the impact of a specific level of CP upon each variable.

Regression lines obtained by the method of least squares and the Spearman correlation coefficients were calculated to assess the relationship between CP and the three variables LaT, EMGp, and ALA. Values are mean [standard deviation (SD)] unless specified. A P-value of <0.05 was considered statistically significant.

Results
Eighteen patients were recruited and 12 completed the trial. Among the recruited patients, four lacked capacity to give consent at the time of the trial. For these patients, consent to enter the study was given by family members. Retrospectively, we obtained signed consent from all the patients.

Six patients were excluded. Reasons for exclusion were a low amplitude of ALA measures (n=2), poor pharyngeal sensation as confirmed by the impossibility to trigger reflex swallows (n=2), and because of frank tracheal aspiration signs (n=2) during PST determination.

The mean age of patients studied was 37 (range: 19–54) yr. Most of the patients were admitted in the ICU because of severe thoracic and abdominal trauma. Percutaneous tracheostomy was performed 10 days after ICU admission (range; 7–18). All the patients were fully conscious at the time of swallowing reflex evaluation performed 14 (range: 5–20) days after cuffed tracheostomy tube placement.

The mean (sd) PST volume and control LaT were 1.5 (1.3) ml and 1.5 (0.8) s, respectively. A significant linear relationship (P<0.05) was observed between PST and control LaT [LaT=0.4 (PST)+0.8; r2=0.726, P<0.05].

We observed that CP and LaT were significantly correlated (Fig. 3). An inverse correlation was identified between CP and both ALA and EMGp (Figs 4 and 5, respectively). The characteristics of the swallowing reflex deteriorated with increasing CP. ALA and LaT were the most sensitive variables to CP increase. ALA and LaT significantly deteriorated with a CP of
25 and 30 cm H₂O, respectively. When compared with the control value, the mean LaT was increased by 2.3-fold when CP was 60 cm H₂O.

The mean changes in respiratory rate and SaO₂ over the time period elapsing between the first and last CP tests were 1.5 (3.0) bpm and −1.9 (0.6)%, respectively. Four patients experienced pulmonary aspiration when attempting to swallow 10 ml of coloured thin liquid.

Discussion

In this study, the sensory component of the swallowing reflex was evaluated by LaT and the motor component was reflected by submental EMGp and resulting ALA. We demonstrated that increasing tracheostomy tube CP influenced both sensory and motor components of the swallowing reflex. The swallowing reflex was progressively more difficult to elicit with increasing CP and when activated, the resulting motor swallowing activity was depressed. These findings suggest that peripheral mechanical constraints and centrally controlled inhibition may be involved in CP increase-induced deterioration of instrumental characteristics of the swallowing reflex.

We have used the method described by Nishino and colleagues using submental EMG to study the swallowing reflex. The method is easy to perform and to repeat in the same patient and allows for evaluation of the pharyngeal reflex components of swallowing. We have improved the accuracy of latency time calculation. Instead of visual observation of laryngeal movements, we identified precisely on signal recordings both the time of pharyngeal stimulus and the beginning of evoked EMG response. Moreover, we recorded the average values generated by repeated stimuli over 1 min. These methodological improvements prevented non-stimulated swallows interfering with our results. Although superficial submental EMG recording was shown to be a valuable means of identifying swallowing activity, this method does not allow precise quantification of pharyngeal muscular activity.

In order to better quantify the motor component of the swallowing reflex, we performed simultaneous measurements of submental EMG in combination with the resulting acceleration of laryngeal elevation. It has been demonstrated that the pattern of laryngeal elevation acceleration characterizes pharyngeal subhyoid muscle function and the resulting acceleration signal peak amplitude correlates with the amount of laryngeal elevation.

When compared with healthy volunteers placed in the same experimental conditions (personal unpublished data), reflex swallows in tracheostomized conscious young patients required a more intense afferent input to be elicited and demonstrated a longer activation time. A number of factors may explain this fact. Although we did not examine directly the mucosal lesions caused by prolonged contact of upper airway tubes (nasogatric and orotracheal), the alteration of chemoreceptors or mechanoreceptors located in pharyngeal mucosa may have impaired sensation, resulting in an
increased PST. It has been demonstrated that residual effects of sedation influence the swallowing reflex and such cannot be excluded as a cause for the prolonged swallowing reflex latency time. The influence of other factors such as hypoxaemia and hypercapnia that have been demonstrated to impair the swallowing reflex appear unlikely in the present study. All of our patients were weaned from mechanical ventilation assistance before entering the protocol and SpO2 did not vary during the tests. Since respiratory rate we have measured remained stable during CP increase challenge, it is unlikely that large arterial CO2 changes may have occurred.

Although tracheal cuff-induced dysphagia in tracheostomized patients has been discussed in many publications, only few have investigated the influence of CP on airway protective mechanisms. No study has evaluated the impact of tracheostomy CP upon swallowing physiology. The frequency of reduced laryngeal elevation and silent aspiration has been shown to be greater when the cuff is inflated. Deflation of the tracheostomy cuff was shown to reduce the aspiration risk for liquid boluses and improve the laryngeal excursion during swallows.

We did not study the efficiency of airway protective mechanisms, but rather analysed the impact of tracheostomy CP on physiological mechanisms controlling the swallowing reflex. Our observations suggest that central inhibition of the swallowing centre is probably involved in CP increase-induced deterioration of the characteristics of the swallowing reflex. The swallowing reflex was progressively more difficult to elicit with increasing CP. This observation agrees with physiological studies demonstrating that sensory inputs from peripheral receptors affect the control of swallowing. EMG data and recordings of vagal motor fibres show reversible inhibition of swallowing during distension of the cervical oesophagus.

Using an intra-oesophageal balloon, Jean demonstrated that the neuronal swallowing activity was delayed and weakened by slight distension of cervical oesophagus and suppressed when the distension was increased. The authors also demonstrated that after balloon deflation, neuronal swallowing activity returned to normal. Increasing the tracheostomy tube CP was shown to increase intraluminal proximal oesophageal pressure. These observations mimic our data in tracheostomized patients. Inflation of the cuff induced-oesophageal anterior mucous membrane distension may have stimulated oesophageal mecano/stretch receptors, resulting in an inhibition of the central control of swallowing causing both a delayed swallowing reflex and impaired muscular activity of submental muscles.

The most marked effect of CP increase was lengthening of the swallowing reflex latency time by 2.3-fold when compared with the control. The magnitude of the decrease in laryngeal acceleration was less marked with a maximum reduction to 42% of control values at 60 cm H2O CP. Our results do not contradict a recent pharyngeal swallow biomechanics trial which concluded that tracheostomy tubes do not affect laryngeal movement. The authors did not measure tracheostomy CP, but rather inflated the cuff with a standard volume for all patients. It is possible that the patients we studied had normal hyoid bone displacement, but this displacement was performed with reduced acceleration when tracheostomy CP increased.

The results we report on the effect of CP on the swallowing reflex have clinical implications for intensive care daily practice. Although all patients we have included in the present trial were capable of swallowing on command, most of them had abnormal airway protective mechanisms. The present results emphasize for strict monitoring of CP in ICU tracheostomized patients. Inflation of tracheostomy cuff is mandatory but potentially a harmful procedure. Excessive CP may not only seriously damage tracheal wall with the risk of tracheal ulceration, dilatation, and perforation, but also impair spontaneous rehabilitation and efficiency of protective reflexes such as the swallowing reflex. We demonstrated that when CP exceeds 20–25 cm H2O, reflex swallows were elicited with difficulty and the efficiency of submental muscles was depressed. Impeded laryngeal elevation during swallowing was associated with imperfect closure of the larynx, resulting in possible aspiration of pharyngeal content. With a CP-induced reduction in spontaneous swallows and an open larynx, pharyngeal secretions may flow into the trachea and accumulate above the cuff with the risk of pulmonary aspiration. Moreover, maintaining an efficient swallowing reflex may favour high spontaneous swallowing rates, which probably contribute to swallowing effectiveness. In the case of dysphagia, swallowing function should be evaluated and re-educated with a CP controlled at 20–25 cm H2O.

Our study has limitations. First, we tested the effect of CPs exceeding 30 cm H2O, that is, higher than the commonly recommended CP. Moreover, we showed that the greatest impact of CP upon swallowing reflex occurred at the highest CPs. However, we demonstrated that LaT and ALA, both important determining factors for airway protective swallowing reflex efficiency, were significantly altered for CP situated in the upper limit of the normal range. Secondly, we have excluded from the present study patients showing poor pharyngeal perception and aspiration signs suggesting severe dysphagia. Then, it is questionable whether our findings could be applicable to patients with severe swallowing difficulties. We believe that the more the airway protective reflexes are altered, the more the impact of strict CP control during ICU stay is crucial for patient’s recovery of efficient swallowing reflex. Finally, we demonstrated significant correlations between CP and instrumental characteristics of the swallowing reflex, but it does not mean that these relations are strictly linear. Indeed, a non-linear relationship between CP and the measured parameters we have studied may better explain our results. Moreover, non-linear relationship analysis may permit identification of a critical pressure range for each variable, resulting at the point of deviation from linearity. Careful observation of Figures 3–5 suggests such a critical CP in the range of 25–40 cm H2O, above which the impact of CP increase upon the swallowing reflex seems to be marked. Above this critical CP range, the swallowing reflex is more difficult to elicit, the activity of
swallowing muscles is depressed, resulting in severe impairment of their efficiency at elevating the larynx as illustrated by intense reduction of laryngeal elevation acceleration. Interestingly, this critical CP range is situated within the clinical range of pressure commonly measured in ICU tracheostomized patients. Thus, although our results are statistically relevant, possible non-linear relationship analysis between tracheostomy tube CP and electrophysiological parameters of the swallowing reflex may be more clinically pertinent.

In conclusion, CP in the tracheostomy tube influences the characteristics of the swallowing reflex in conscious tracheostomized patients. Excessive CP alters electrophysiological characteristics of the swallowing reflex.

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Declaration of interest
None declared.

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