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A new device to remove obstruction from endotracheal tubes during mechanical ventilation in critically ill patients

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Abstract. *Objective:* To evaluate the efficiency of a new device developed to remove obstructions from endotracheal tubes (ETT) in mechanically ventilated patients.
Design: Open study in mechanically ventilated sedated and paralyzed ICU patients.
Setting: General ICU and Laboratory of Respiratory Mechanics of the University of Rome "La Sapienza".
Patients: 8 consecutive unselected mechanically ventilated, critically ill patients in which a partial obstruction of ETT was suspected on the basis of an increase of the peak inspiratory pressure (>20%) plus the difficult introduction of a standard suction catheter.
Interventions: Obstructions to ETT were removed with an experimental "obstruction remover" (OR)
Measurements: "In vivo" ETT airflow resistance (0.25; 0.5; 0.75; 1 l/s) was evaluated before and after use of the OR; the work of breathing necessary to overcome ETT resistance (WOB_{ett}) was also evaluated before and after OR use.
Results: The use of OR significantly reduced in all patients the ETT "in vivo" resistance (From 5.5±2.3 to 2.9±0.5 $cmH_2O/l/s$ at 0.25 l/s, $p<0.05$; from 9±2.4 to 3.8±0.8 $cmH_2O/l/s$ at 0.5 l/s; from 12.2±3.5 to 5.7±1.2 $cmH_2O/l/s$ at 0.75 l/s; from 16.9±6 to 9.3±3.8 $cmH_2O/l/s$ at 1 l/s, $p<0.01$ respectively). Also the WOB_{ett} was significantly reduced after use of the OR (from 0.66±0.19 to 0.34±0.08 J/l; $p<0.05$)
Conclusion: this experimental device can be safely and successfully used to remove obstructions from the ETT lumen, without suspending mechanical ventilation, reducing the need for rapid ETT substitution in emergency and life-threatening situations.

Key words: Mechanical ventilation – Endotracheal tubes – Obstruction – Acute respiratory failure

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The acute obstruction of endotracheal tubes (ETT) is a common complication in mechanically ventilated patients, above all in the presence of bronchorrea, large minute volumes or poorly warmed and humidified gases [1, 2, 3]. These situations produce the progressive drying of airway secretions that tend to adhere to the ETT causing the progressive occlusion.

This complication can be life-threatening, and often requires rapid ETT substitution, sometimes in a catastrophic condition [3]; therefore a device able to remove the obstructions from ETT, without needing substitution should be of clinical interest.

The aim of this study was to evaluate a new device, called "obstruction remover" (OR), designed to safely and rapidly remove obstructions produced by inspisated airway secretions from the ETT, without discontinuation of mechanical ventilation. We used this device in a group of sedated and paralyzed patients, mechanically ventilated for acute respiratory failure, in which an ETT obstruction was suspected.

The ETT flow resistance was evaluated before and after treatment with the OR; accordingly, we also analyzed the modifications of the amount of work of breathing necessary to overcome ETT resistance (WOB_{ett}).

Patients and methods

Eight patients (mean age 52±18 years) admitted to our general ICU for treatment of acute respiratory failure of various etiologies were studied. Main patient data are detailed in Table 1.

The protocol was approved by our institutional Ethics Committee and informed consent was obtained from patients or families. All patients were nasotracheally intubated with a Portex 8 mm ID ETT, cut to 32 cm length.

All patients were mechanically ventilated with a Puritan Bennett 7200 Ventilator (USA) for a period ranging between 1–13 days preceeding the study and were in stable clinical conditions. In 6 patients the inspired gas humidification was obtained with a heat and moisture exchanger (DAR, Italy) and in two with a Fisher- Pykel hot water humidifier.

All were sedated with flunitrazepam continuous infusion and paralyzed with pancuronium bromide.

Table 1. Main patients data

Patient	Sex	Age (years)	ETT (ID mm)	Diagnosis
1	F	20	8	Encephalitis
2	F	60	8	Postop. ARF
3	M	63	8	Trauma
4	M	70	8	COPD
5	M	28	8	Trauma
6	M	56	8	Postop. ARF
7	M	62	8	Postop. ARF
8	M	64	8	Cong. heart failure

ETT, Endotracheal tube; ARF, acute respiratory failure

In all patients ETT partial obstruction was suspected on the basis of a sudden increase of peak inspiratory pressure (>20% from baseline) and confirmed by difficult passage of a standard suction catheter (3 mm ID) through the ETT.

Ventilator setting was as follows: respiratory rate 12–14 cycles/min; FIO_2 0.4–0.5; VT 10 ml/kg; I:E 1:2; ZEEP; square flow.

The patients were studied in semi-recumbent position, with the head in the midline position; during the whole procedure a physician not involved in the study was present to take care of the patient. Airflow was measured with a pneumotachograph (Fleish n° 2) connected to the ETT via a cone, and to a Valydine MP 45 differential pressure transducer; volume was obtained by airflow signal electrical integration (Gould Integrator).

Airways pressure was simultaneously recorded at the distal end and proximal end of the ETT (Spectramed pressure transducers); the tracheal pressure was recorded at a distance of 2 cm from the ETT tip, with an air filled uncompliant catheter provided with multiple side holes and an occluded hole [4]. No appreciable shift or alteration in amplitude up to 20 Hz was observed with the described pressure measureing system.

All variables were recorded on a 4 channel pen recorder (Roche 3000).

After careful tracheal suction, basal measurements of "in vivo" ETT resistance were obtained by dividing peak inspiratory pressure values simultaneously measured at the proximal and distal ends of ETT by 4 different inspired flow (0.25, 0.5, 0.75, 1 l/s) keeping constant tidal volume (10 ml/kg) FIO_2 and respiratory rate.

The OR was then slowly introduced in the endotracheal tube through a 4 cm length fibronchoscopy adapter (DAR Italy) in the closed position (see Fig. 3). Basically, the device is similar to a fiberoptic bronchoscopy forcep and must be introduced, through an adapter, in the ETT till the distal extremity; once introduced, a sort of "umbrella" is opened and pulled back throughout the ETT removing the secretion plug. The device has a length of 41 cm, with 4 notches indicating distances from the tip at 32, 34, 36, 38 cm respectively. A stopper had been placed at 36 cm length in order to exactly open the "umbrella" just at the ETT tracheal end, thus avoiding any risk of an airway lesion. The "umbrella" of the OR was then opened by pushing the handle (Fig. 3) and the device gently removed without jerking from ETT, always in an open position.

In the case of presence of dry secretion fragments mobilized but not removed from the upper part of the ETT, a new manoeuvre of OR introduction was performed.

At this point, after a 3 min pause, all the measurements of ETT resistance at 4 levels of inspired flow were repeated.

Moreover, the amount of work of breathing (WOB_{ett}) necessary to overcome the ETT resistance before and after obstruction removal was evaluated in 6 patients; this was done applying the simplified method for WOB measurement proposed and validated by Marini et al. in apnoic patients during complete ventilatory support with constant flow [5, 6]. In this condition inspiratory time represents an analog of delivered volume and therefore inspiratory WOB can be derived from pressure/time plots; in details, mid-cycle airways pressure expressed in cmH_2O divided by 10 gives WOB/l of ventilation. We subtracted the amount of WOB/l, calculated by plotting airways pressure/time, measured at the carinal end of the ETT (thus excluding ETT), from the total amount of WOB/l obtained by plotting airway pressure signal/time, measured at the distal ETT end (thus including also the ETT). This difference represents the part of WOB just necessary to overcome the ETT resistance for the applied flow (WOB_{ett}). The measurements of WOB_{ett} were obtained with a 0.75 l/s constant airflow.

In order to define the resistive behaviour of the ETT before and after use of the OR we evaluated the coefficients K1 and K2 of the Rohrer's equation ($R = K1 + K2\,\dot{V}$) The values of ETT resistance at different flows and WOB_{ett} obtained before and after obstruction removal were compared with the *t* test for paired measures and Wilcoxon signed rank test. *P* values <0.05 were considered statistically significant.

Results

The results of our study are expressed in Figs. 1 and 2. In detail Fig. 1 shows the modifications of endotracheal tube resistance before and after the use of the obstruction remover in a large range of flows (from 0.25 to 1 l/s; $p<0.05$ at 0.25, $p<0.01$ at 0.5, 0.75, 1 l/s).

Accordingly, also the values of peak inspiratory pressure were significantly reduced at 0.5, 0.75 and 1 l/s (Table 2).

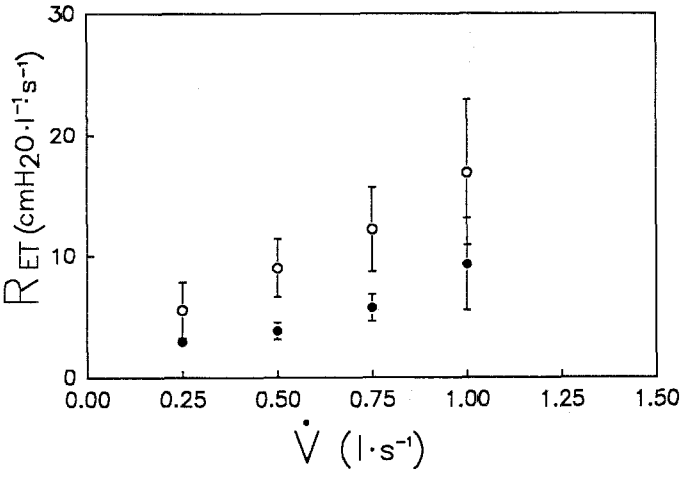

Fig. 1. Modifications of endotracheal tube resistance before (○) and after (●) desobstruction

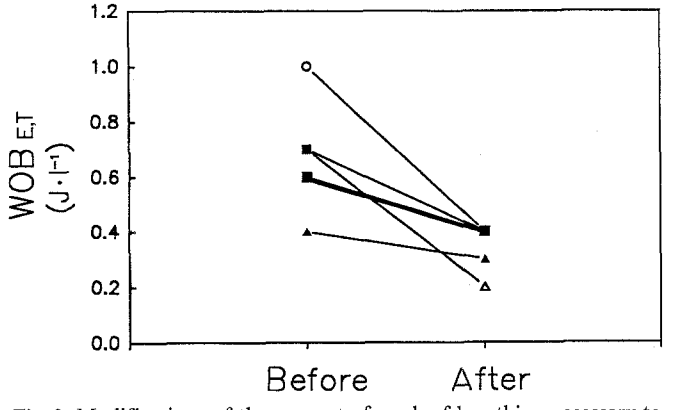

Fig. 2. Modifications of the amount of work of breathing necessary to overcome the endotracheal tube (*ETT*) resistance ($\dot{V} = 0.75$ l/s). (WOB_{ett}) before and after obstruction removal in mechanically ventilated patients

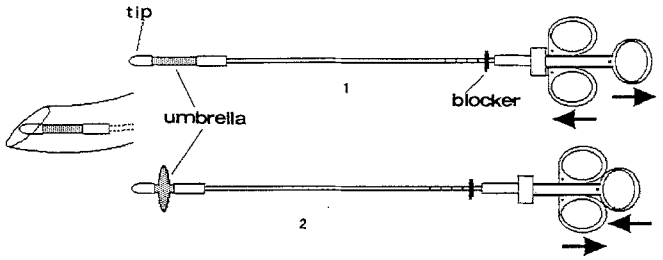

Fig. 3. Schematic representation of the device used in this study. *1*, basal condition; *2*, opened position. *Inset:* the device tip at the endotracheal tube carinal end

Table 2. Individual values of peak inspiratory pressure measured at the airway (PIP aw) and at the trachea (PIP trach) in basal conditions and after the use of the obstruction remover (values in cmH_2O; airflow = 1 l/s)

Patient	Basal PIPaw	Basal PIP trach	After OR PIP aw	After OR PIP trach
1	43	20	36.5	19.5
2	46	29	34.5	28
3	32.8	20	27	20
4	33.2	27	34	28
5	36.5	18	27	18
6	40	16	28	17
7	37	21	30.5	21
8	48.5	30	41.5	31
$\bar{X}+SD$	39.6 ± 5.7	22.6 ± 5	32.3 ± 5	22.8 ± 5.3

In 6 patients the amount of work of breathing made by the ventilator to overcome the ETT resistance was also evaluated (WOB_{ett}) at a flow 0.75 l/s, similar to the value of inspired flow generally used in our ICU on mechanically ventilated patients. Also in this case we observed a statistically significant reduction of WOB_{ett} after the use of the obstruction remover ($p<0.01$) (Fig. 2).

The coefficients K1 and K2 of Rohrer's equation ($R = K1 + K2\ \dot{V}$) for the measurements of the ETT flow/pressure relationship in basal conditions and after the OR use resulted to be: basal K1 = 4.07 and K2 = 1.46 ($r = 0.99$); after OR, K1 = 1.88 and K2 1.55 ($r = 0.99$).

It is interesting to note that in 5 out of 6 patients the WOB_{ett}/l accounted for more than a third of the total amount of WOB per liter of ventilation, thus underlining the importance of the ETT patency for the correct management of critically ill ventilated patients.

No mechanical or clinical problem was observed during the study.

Discussion

The acute obstruction of the ETT is not a rare complication during mechanical ventilation in ICU [3]; when detected early it requires specific manoeuvres (instillation of saline and aspiration, fibrobronchoscopy) and/or the rapid substitution of the ETT.

In this condition the substitution of the ETT can be complicated, above all if the obstruction is important and the patient is hypoxic or hypercapnic, by haemodynamic instability or life-threatening arrhythmias.

Whatever the technique of inspired gas humidification, an important percentage of mechanically ventilated patients suffer from ETT partial or complete occlusion, above all if mechanical support longer than 5 days is required [7]. We therefore developed with the technical assistance of DAR Laboratories (Mirandola, Italy) a device to remove obstruction from the ETT without needing the discontinuation of the mechanical ventilatory support.

This study has demonstrated the efficacy of the OR in a group of mechanically ventilated patients affected by different diseases in which a partial obstruction of the ETT lumen due to airway secretions had developed. In all patients the use of the OR produced the removal of variable amounts of secretions, significantly reducing the resistance of the ETT and the amount of WOB necessary to overcome ETT airflow resistance (WOB_{ett}).

It is important to note that this device can be used also in subjects with complete occlusion of the ETT, in view of the shape of the tip, the rigidity and the thin diameter (2 mm), that allow an easy passage through the obstruction.

These data are interesting not only for the possible use in an emergency situation, but also for routine use in patients starting the phase of weaning; in this phase the ETT is a sort of functional interface between the ventilator and the patient. As recently reported by Banner [8] the ETT during triggered ventilation acts as a resistor over which a pressure decrease must be developed by the patients to start a breath and can represent (as also showed in this study) a large source of WOB waste. Our device can therefore allow a better patient-machine interaction when the patient is on a triggered assisted mode of ventilation (Assist Control, SIMV, Pressure Support Ventilation), reducing the narrowing of the ETT normally observed in patients intubated for long periods [9].

A possible problem with all the devices requiring an ETT manipulation could be an increased risk of pulmonary infection; we never observed pulmonary infective complications after the use of the OR in this group of patients or in more than 40 other patients in which the OR has been clinically used in our ICU in the last year, probably also because the device is sterile and for single use.

In conclusion, this device can be successfully used to rapidly remove major obstruction from the ETT of critically ill patients undergoing mechanical ventilation, reducing the need of emergency ETT substitution; moreover it can be routinely used in patients ventilated in assisted modes to clean up the ETT, eliminating an important source of additional WOB.

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