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SHORT COMMUNICATION

Condensation of humidified air in the inflation line of a polyurethane cuff precludes correct continuous pressure monitoring during mechanical ventilation

Herbert Spapen · Walter Moeyersons · Wim Stiers · Geert Desmet · Emiel Suys

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Abstract Within continuously controlled limits of cuff pressure, an endotracheal tube cuff made of polyurethane (PU) prevents secretion inflow better than a conventional polyvinylchloride cuff. However, the temperature difference between ventilator gas and the air inside a PU cuff produces condensation droplets that accumulate in the cuff inflation canal. We investigated whether condensation influenced continuous cuff pressure monitoring. A PU-cuffed tube was placed into an artificial trachea and connected to a ventilator and test lung. An additional line was inserted at the distal cuff end to directly measure pressure inside the cuff. Methylene blue instillation via the inflation line mimicked condensation. Inspiratory (Pinsp) and expiratory (Pexp) pressures were continuously recorded. Six consecutive experiments were performed comparing pressures at baseline (T0) and at 24 h (T24). Shortly after dye instillation, pressures recorded at the inflation canal became permanently fixed at 25 cmH_2O. In contrast, pressures measured directly in the cuff progressively decreased (mean Pinsp 30 ± 3 vs. 20 ± 2 cmH_2O and mean Pexp 25 ± 0 vs. 12 ± 2 cmH_2O, T0 vs. T24, both $P < 0.05$). Thus, condensation in the inflation line of a PU-cuffed tube renders continuous cuff pressure monitoring unreliable, thereby increasing the risk for microaspiration.

Keywords Tracheal cuff · Cuff pressure · Polyurethane · Microaspiration

H. Spapen (✉) · W. Moeyersons · W. Stiers · G. Desmet · E. Suys
Intensive Care Department, University Hospital, Vrije Universiteit Brussels, Laarbeeklaan, 101, 1090 Brussels, Belgium
e-mail: h.spapen@skynet.be

Microaspiration of bacteria-colonized secretions from the subglottic space into the lower airways represents one of the leading pathogenic pathways of tracheobronchitis and subsequent pneumonia in mechanically ventilated patients [1]. The cuff of the endotracheal tube (ETT) forms a crucial obstacle for blocking secretion inflow. Cuff inflation pressure and cuff material are main determinants of this barrier function. Cuff pressures must be maintained within a tight range. A cuff inflated below 20 cmH_2O may facilitate leakage of secretions whereas cuff pressures exceeding 30 cmH_2O may cause mucosal injury [2]. Even when correctly applied, intermittent manual control fails to keep cuff pressures within these limits [3]. Devices that allow continuous cuff pressure monitoring may be more effective.

Recently, polyurethane (PU)-cuffed ETTs have been introduced. PU cuffs have better tracheal sealing properties because they form fewer folds and narrower alongside channels than conventional polyvinylchloride (PVC) cuffs. In vitro experiments repeatedly confirmed a superior effect of PU-cuffed tubes in preventing leakage of secretions compared with ETTs equipped with a PVC balloon [4–7]. However, its ultrathin (7 μm) design makes the PU cuff wall much more permeable for water molecules than the thicker (50 μm) PVC cuffs. Over time, temperature differences between the air inside the cuff and the air passing through the ETT cause condensation of humidified air inside the PU cuff. In patients intubated with a PU-cuffed ETT, we systematically observed that condensation did not remain limited to the pilot balloon but progressively migrated to the cuff inflation line. Because fluid accumulation in the inflation canal became substantial with ongoing ventilation (up to 0.5 ml daily in some patients), we developed an in vitro model to investigate its possible impact on continuous cuff pressure control and adjustment.

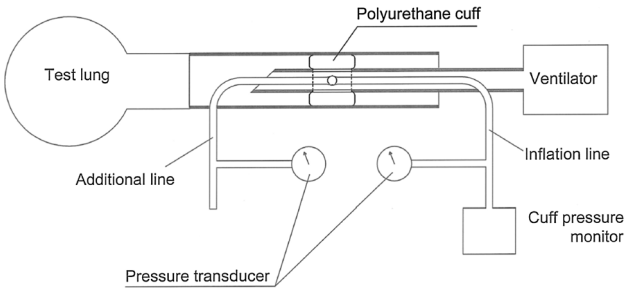

Fig. 1 Schematic presentation of artificial trachea model and pressure monitoring system

The experimental setup is depicted in Fig. 1. A PU-cuffed ETT (Microcuff; Kimberly-Clark, Roswell, GA, USA) was inserted in an artificial Plexiglas trachea and connected to a ventilator and test lung. The cuff inflation line was connected to an electronic device that continuously measured and automatically adjusted cuff pressure (VBM; Medizintechnik, Sulz am Neckar, Germany). The distal portion of the inflation line was sectioned just before its blind ending in the wall of the ETT. The newly created distal lumen was carefully dilated with a needle. Subsequently, an additional line was inserted through the lumen and advanced into the cuff. Finally, the construction was glued tight and checked for leakage by immersion in water at a cuff pressure of 100 cmH_2O. The inflation and additional lumen were both connected to a pressure transducer for direct independent pressure registration. Cuff pressure was set at 25 cmH_2O and positive pressure ventilation initiated. Ventilator settings were tidal volume = 500 ml; respiratory frequency = 15/min; *I/E* ratio = 1/2; PEEP = 5 cmH_2O. Aspiration of 5 ml air from the additional line (i.e., mimicking cuff deflation) resulted in immediate automatic correction of intracuff pressure to 25 cmH_2O. Subsequently, 0.1 ml methylene blue solution was instilled via the inflation line to mimic condensation (T0). Inspiratory (Pinsp) and expiratory (Pexp) cuff pressures were continuously recorded and compared with baseline values after 24 h (T24). Six consecutive experiments were performed. The Wilcoxon signed-rank test was used to compare pressures at T0 and T24.

From onset of dye instillation, inspiratory and expiratory cuff pressures recorded at the inflation canal became permanently fixed at 25 cmH_2O. In contrast, pressures measured directly in the cuff progressively decreased over time (mean Pinsp 30 ± 3 vs. 20 ± 2 cmH_2O and mean Pexp 25 ± 0 vs. 12 ± 2 cmH_2O, T0 vs. T24, both $P < 0.05$). An example of cuff pressure evolution over 24 h in one experiment is represented in Fig. 2. When the experiment was repeated without methylene blue administration, in-cuff pressure remained stable during the entire investigation period (results not shown).

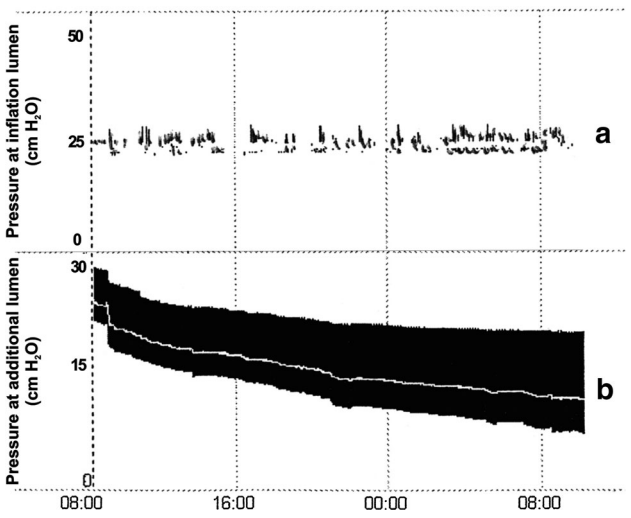

Fig. 2 Representative example of an experiment. Mean pressure measured at the inflation lumen (=actually recorded pressure) remains stable and constant around 25 cmH_2O (**a**). Mean pressure measured at the additional lumen (=real pressure in cuff) is gradually decreasing from 25 to 13.5 cmH_2O (**b**)

Underinflation of an ETT cuff is a major independent risk factor for aspiration. Ideally, cuff pressures should be maintained between 20 and 30 cmH_2O. Continuous cuff pressure control devices, either pneumatic or electronic, have shown effectiveness in keeping cuff pressures within recommended ranges [8]. In critically ill patients intubated with PU-cuffed ETTs, Jaillette et al. [9] showed that the amount of time spent with cuff under- or overinflation was significantly lower and cuff pressure swings less apparent during continuous pressure control compared with manual care. However, these authors also observed important condensation formation in the pilot balloon of all patients who exhibited significant longstanding cuff underinflation during continuous cuff pressure monitoring. The present study underpins this clinically relevant, yet insufficiently recognized, drawback of PU-cuffed tracheal tubes in a setting of continuous cuff pressure recording. Condensation of humidified air creates increasing resistance inside the inflation line of a PU cuff. When resistive pressure exceeds cuff pressure during inspiration, the continuously measured "external" pressure will become fixed within normal range whereas the "real" cuff pressure progressively and significantly decreases, reaching unsafe values after 24 h of ventilation. To our knowledge, the impact of condensation in the inflation line of a PU cuff on continuous cuff pressure recording has not been reported in the literature. Data on file from the manufacturer confirm that the degree of condensation correlates well with an increasing temperature gradient between ventilator gas passing through the ETT and air inside the PU cuff [10].

Interference with mechanical ventilation has not been described. However, accumulation of liquid droplets in the cuff inflation line lumen causes artificially low cuff pressure readings. Before obtaining pressure measurements, the manufacturer recommends clearing condensation from the inflation line by gentle manipulation of the pilot balloon to redirect the water back into the PU cuff [10]; however, such measures are highly impractical and difficult to apply in the case of continuous pressure monitoring. Comparable line condensation is never observed in PVC-cuffed tubes.

In conclusion, mimicking condensation in the inflation line of a PU-cuffed ETT caused significant overestimation of real intracuff pressures and impeded automatic cuff pressure adjustment. Unsuspected cuff deflation exposes ICU patients intubated with a PU-cuffed ETT to microaspiration, increases the risk of developing ventilator-associated pneumonia and may promote accidental extubation. Our findings argue against the routine use of PU-cuffed ETTs in an ICU setting, especially when continuous cuff pressure monitoring is applied.

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