Neonatal resuscitation with T-piece and the risk of inadvertent PEEP

Effects of device expiratory resistance investigated by simulations

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Introduction

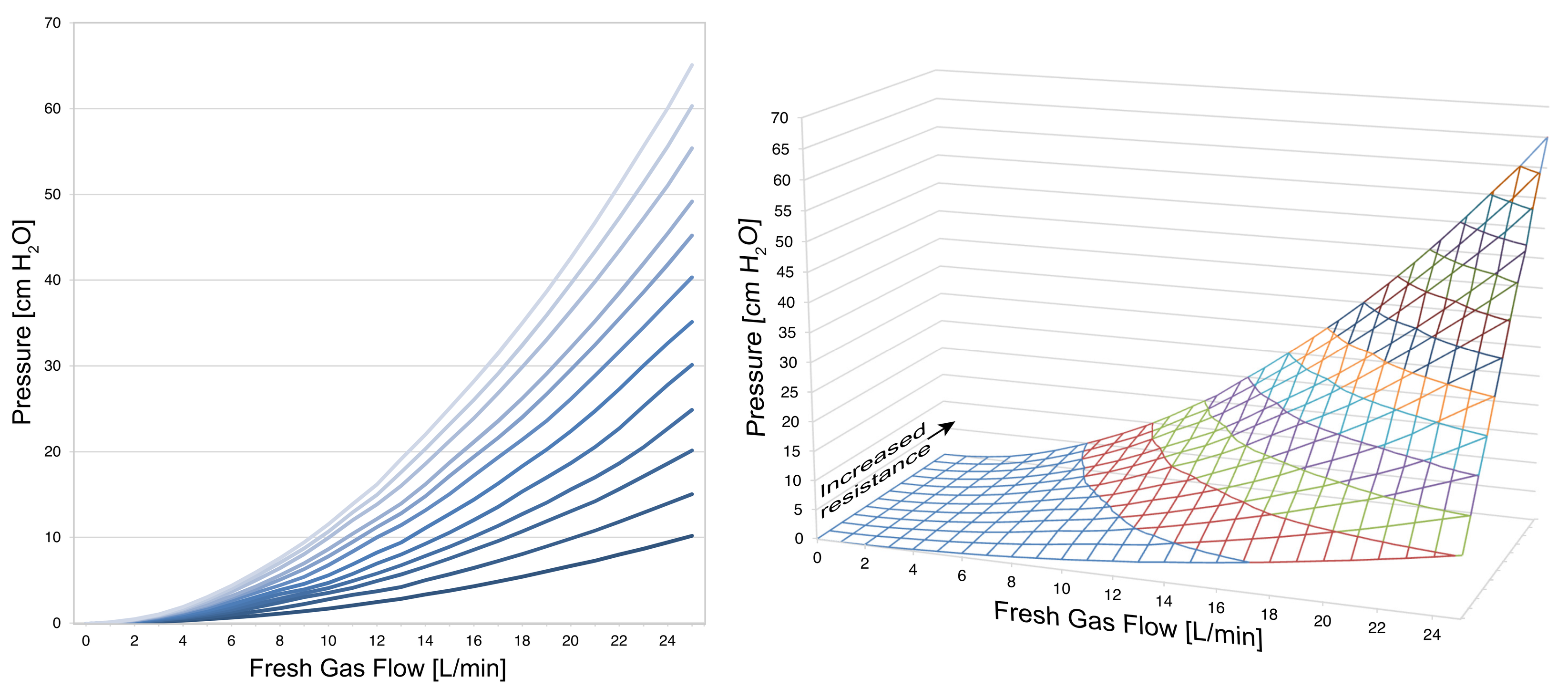
T-piece systems (TPR) allow positive pressure ventilation (PPV) with positive end expiratory pressure (PEEP) in infants. During expiration, the flow passes through an adjustable resistor valve. This generates PEEP but also adds a high resistance to expiration, explaining the risk of inadvertent PEEP seen in TPR systems. We hypothesized that passive expiration could be modelled from a start peak inspiratory pressure (PIP) to PEEP for resistance and compliance using their mathematical relationship.

The objective was to predict and explain the risk of inadvertent PEEP for TPRs. The main outcome was graphically displaying the pressure reduction during expiration.

Methods

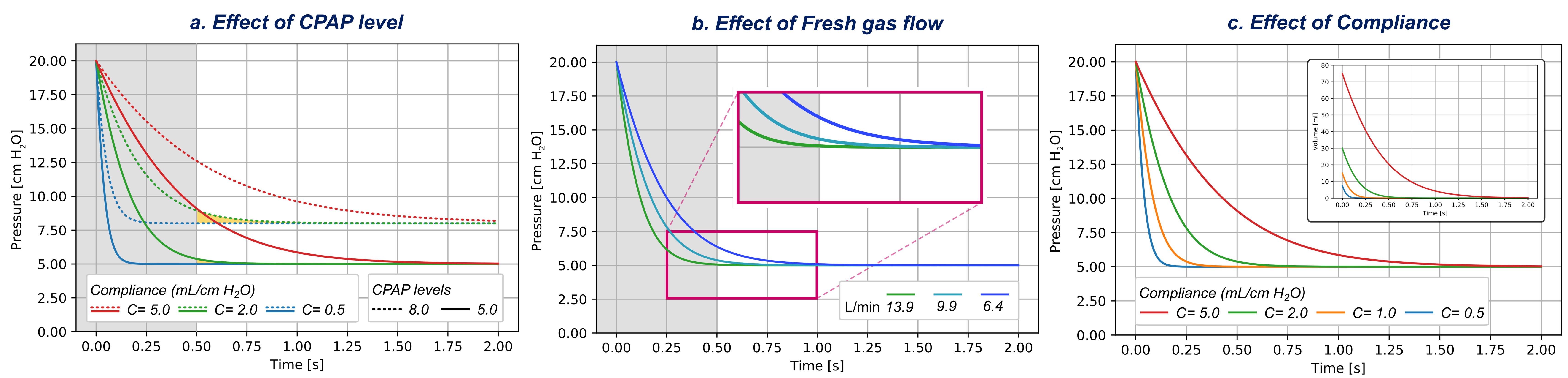
Expiratory resistance of TPRs (Neopuff and GE-resuscitator) was determined for flow and pressure ranges relevant to neonatal resuscitation. These non-linear resistance curves were used to determine the resistance (polynomial equation) at a given fresh gas flow and PEEP level. This equation was then used to calculate flow, volume and pressure during exhalation for different compliances, starting at PIP and finishing at PEEP. The script for calculating the simulated exhalation was developed by the research group. Pressure decrease over time (expiratory time constants) was displayed graphically at different levels of compliance and fresh gas flow. The following variables were examined: respiratory rate, CPAP level, fresh gas flow and compliance.

Fig 1. Resistance



Resistance of T-piece system (Neopuff): By tightening the valve the resistance increased (increased slope in left graph and inward shift in right graph). The valve has no discrete steps or grading and therefore no unit. Adjusting the valve is normally done by measuring PEEP at a given flow (ie 5 cm H_2O @ 10 L/min).

Fig 2. Pressure decrease during expiration



Pressure decrease during expiration for Neopuff: The effect of increased respiratory rate can be seen in all graphs. Gray areas represent an expiratory time of 0.5 seconds (respiratory rate 60 with I:E 1:1). The fresh gas flow in fig 2a and c was fixed at 9.9 L/min. At a higher CPAP, the increased time needed for expiration and the decreased fresh gas flow is related to the increased resistance (fig 2a). By increasing the compliance the time needed for expiration is increased due to larger tidal volumes.

Results and conclusions

Resistance of TPR

Expiratory resistance curves of the TPR displayed a non-linear increase with flow (fig 1). These were identical for GE and Neopuff (data not shown). The resistance graphs can be displayed as a contour graph (fig 1b). From this, the resistance for all possible combinations of PEEP and fresh gas flows can be derived.

Factors increasing the risk of inadvertent PEEP

Increasing the **respiratory rate** reduced the time available to complete expiration (fig 2a-c). Increasing the **compliance** required longer time to complete expiration due to a larger tidal volume (fig 2a and c). Increasing **PEEP** by tightening the valve increased the resistance (fig 1 and fig 2a). The tighter valve also explains the increased resistance seen with a fixed PEEP and **decreased fresh gas flows** (fig 2b).

Limitations

The internal resistance seen in real patients was not added in these measurements. Adding this resistance would further increase the risk of inadvertent PEEP. The model used a non-linear resistance but linear compliance as in most mechanical models.

The model allows testing of other levels of PEEP (only 5 and 8 cm tested) and PIP (only 20 cm tested). According to the manual, TPRs can be used at fresh gas flows of 5-15 L/min and our simulations did not cover the full range (Fig 2b). Compliance could be higher than the used maximum 5 ml/cm H_2O, for example in larger infants.

Plain language summary

Exhaling through the small hole in a T-piece resuscitator is difficult.

The risk of incomplete exhalation increases with

- high respiratory rate
- increased CPAP level
- low fresh gas flow
- high compliance and tidal volume

What's next

Tests of more systems and endotracheal tubes.
Confirm our findings in animals and humans.

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Conflict of interests: KI researchers are involved in a new system for neonatal resuscitation

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