CFD Simulations of the CPAP Devices Neopuff and Inspire rPap in Neonatology

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OBJECTIVE

Previous research showed that the Neopuff T-piece resuscitator exhibits stronger pressure fluctuations during spontaneous breathing, while the Inspire rPAP maintains pressure stable [1,2].
Pressure stability is paramount to minimize the imposed work of breathing (iWOB) and facilitate quick recovery. The objective of this study is therefore to identify the root cause of pressure fluctuation using CFD and to help improve neonatal CPAP devices in the future.

Fig. 1: Usage of Inspire rPAP neonatal CPAP ventilator with nasal prongs [3].

Fig. 2: Demonstration of Neopuff T-piece resuscitator with face mask [4].

METHODS

CAD software was used to create digital models of the ventilation components (mask, Inspire rPAP, Neopuff). Additionally, two neonatal airway geometries were segmented from MRI data and combined with the mask, ensuring consistent device interfaces for comparability (Figure 4 and Figure 5).
Steady-state 3D CFD simulations, employing the k-ω-SST turbulence model, were conducted for three respiratory scenarios: resting, inhalation, and exhalation.
Both devices were simulated under identical boundary conditions to allow for direct comparison. The volume flow rate at the device inlets was set to $1.02e^{-4}\,\frac{kg}{s}$ $(5\,\frac{l}{min})$, whereas the breathing inlet and outlet at the airway were set to $8.166e^{-6}\,\frac{kg}{s}$.

Fig. 3: Inspire rPAP fluid domain model with Airway 1.

Fig. 4: Neopuff fluid domain model with Airway 1.

RESULTS

Without simulated breathing, both systems showed stable mask and airway pressures. During breathing, however, the Neopuff exhibited strong pressure fluctuations (up to 46.12%), while the Inspire rPAP remained more pressure stable (max. 6.28%) (Table 1).

Tab. 1: Area-weighted static pressure values in Pa in Inspiration and Expiration simulation averaged over Airway 1 and Airway 2 and standard deviation.

Device	Simulation	Device Inlet in Pa	Airway Inlet in Pa	Mask plane in Pa
Inspire	Inspiration	4823.47 ± 32.36	314.77 ± 3.72	320.5 ± 0.65
	Expiration	4815.76 ± 10.29	335.19 ± 1.84	333.74 ± 0.55
Neopuff	Inspiration	160.36 ± 4.02	140.03 ± 13.05	159.81 ± 4.05
	Expiration	222.35 ± 5.89	223.61 ± 4.975	221.82 ± 5.92

Direct comparison reveals higher flow velocities in the Inspire rPAP due to its narrower geometry. The turbulent, high-energy inflow primarily exits through the outlet valve, while only residual flow collides head-on with the weaker expiratory stream (Figure 5). The residual flow directed toward the patient supports inhalation, resulting in lower resistance and reduced effort. In contrast, the Neopuff inflow enters the device at a 90° angle without attenuation, inducing turbulence, resistance, and pressure fluctuations within the system (Figure 5).

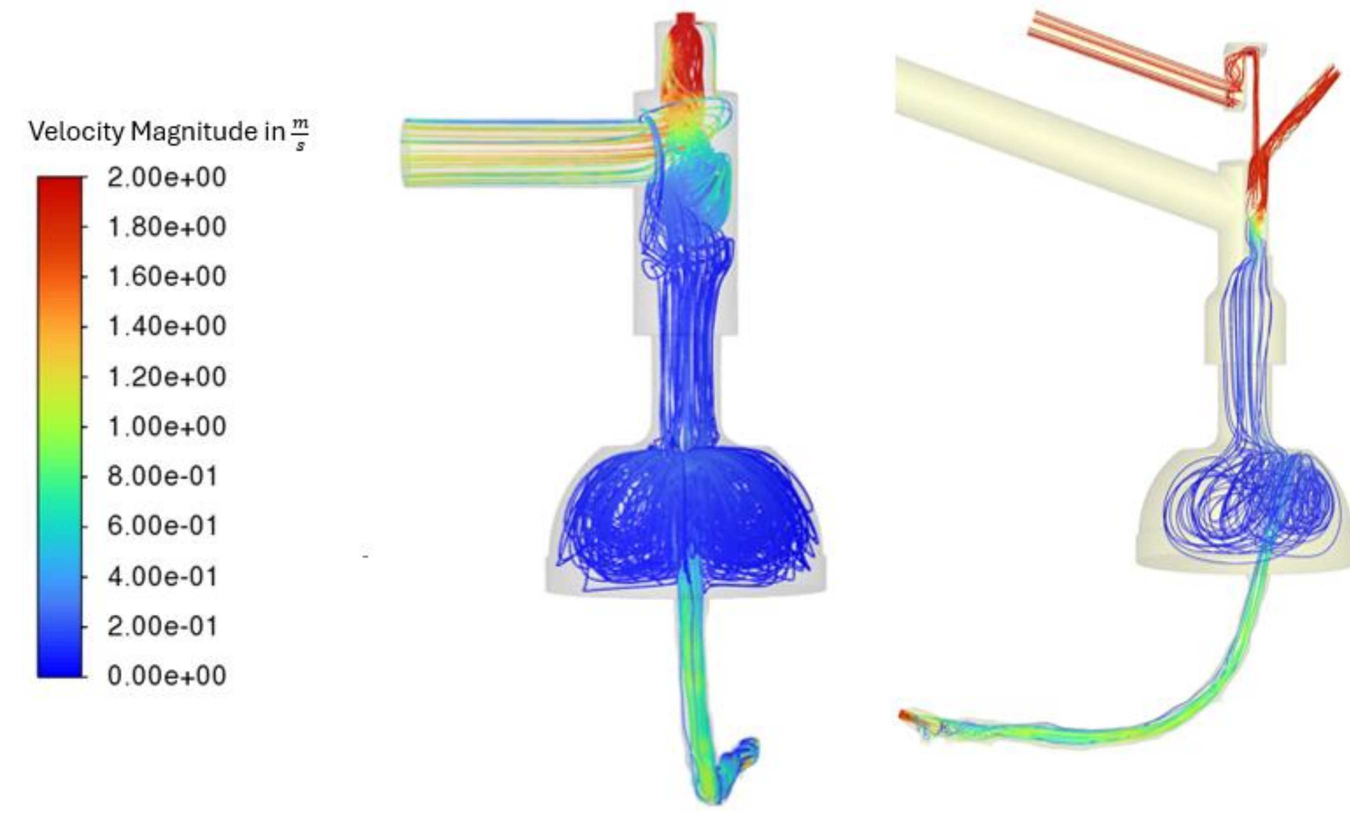

Fig. 5: Velocity magnitudes visualized through pathline plots in Neopuff (left) and Inspire rPAP (right) during expiration scenario.

CONCLUSION

The Inspire rPAP maintained superior pressure stability despite higher velocities and turbulence, highlighting the role of internal flow-guiding geometry. Its multi-tube design channels high-energy flow through the outlet, shielding the patient interface. In contrast, the Neopuff's T-piece creates vortices and resistance, which increases iWOB. Thus, internal flow control should receive greater emphasis during the engineering process.

References: [1] Gruber et al. What cpap to use in the delivery room? bench comparison of two methods to provide continuous positiveairways pressure in neonates. BMJ Paediatrics Open, 8(1):29-48, Nov 2024. [2] Donaldsson et al. Initial stabilisation of preterm infants: a new resuscitation system with low imposed work of breathing for use with face mask or nasal prongs. Archives of Disease in Childhood - Fetal and Neonatal Edition, 102(3):203–207,2017. [3] Connect Medizintechnik GmbH. rpap™ generator für erstversorgung. https://www.connect-medizintechnik.at/produkte-neonatologie--paediatrie/erstversorgung-und-reanimation/rpap-generator-fuer-erstversorgung.html [4] Fisher & Paykel Healthcare. T-piece resuscitator. https://www.linkedin.com/posts/fisher-%26-paykel-healthcare_nicu-resuscitation-neopuff-activity-6811217101408276480-W2fU/, 2021.