# The influence of an orifice plates as a flow sensors on the removal of carbon dioxide in high frequency oscillatory and jet ventilation

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*Abstract*— **Forthe comfortable and safe use of high-frequency ventilation (HFV) it is suitable to use a system for continual monitoring of inspiratory and expiratory gas flow especially for calculating tidal volumes. The orifice plate is one of the usable solutions for experimental practice. But the orifice plate causes an increase in flow resistance in the ventilation circuit, which may affect the elimination of $CO_2$ from the patient's lungs. Proper compensation for the pressure losses caused by the orifice plate is then necessary.**

*Keywords*— **High frequency ventilation, orifice plate, $CO_2$ elimination.**

## I. Introduction

High frequency ventilation (HFV) is a technique of mechanical ventilation, which uses a high respiratory rate and low tidal volumes that are comparable to or smaller than the anatomic dead space in the patient's airway. From this perspective, HFV seems to be a safe technique of mechanical ventilation with a minimal risk ofvolutrauma [1]. HFOV (High Frequency Oscillatory Ventilation) and HFJV (High Frequency Jet Ventilation) are techniques applied especially in therapy of pulmonary disease of extremely preterm infants with typical device representatives: 3100A(SensorMedics, CareFusion, CA) for HFOV and Life Pulse (Bunnell Inc., Salt Lake City, UT) for HFJV.

However, monitoration of tidal volumes or flow, is not a standard use (parameter) in these devices [2].Suitable sensors for the experimental measurement of flow during HFV are hot-wire anemometers or orifice plates. The commercially available respiratory monitor Florian (Acutronic, Switzerland) which usesa hot-wire for measuring flow and $V_T$ during HFOV is sometimes used in clinical practice but the themonitor is not produced anymore. However, these sensors, especially the orifice plate,can have a negative effect on the course of mechanical ventilation because the measuring elements increase resistance in the ventilation circuit [3].

The aim of this study is to investigate whether the flow sensor (particularly the orifice plate) affect the ability of $CO_2$ avoided and whether it is possible to compensate the negative effects.

## II. Methods

The arrangement of the experiment is presented in figure 1 and figure 2. The experiment was realized in several variations in order to compare HFOV and HFJV with and without the orifice plate and during different frequencies as it is shown in table 1.

Table 1 Variations of the $CO_2$ elimination experiment.

| Type of HFV | | Orifice plate | Respiratory Rate [breath/min] |
|---|---|---|---|
| High frequency oscillatory ventilation **(HFOV)** | High frequency jet ventilation **(HFJV)** | Without OP | 300 |
| | | | 420 |
| | | | 540 |
| | | | 660 |
| | | With OP | 300 |
| | | | 420 |
| | | | 540 |
| | | | 660 |
| | | With OP, compensated | 300 |
| | | | 420 |
| | | | 540 |
| | | | 660 |

A sealed rigid bottle was used as the model of the respiratory system of a newborn patient with a volume 1000 mL,compliance2.87 mL/cm$H_2O$, fitted with an endotracheal tube with a diameter of 3 mm.It included ports for monitoring pressure inside the model, for filling the modelled patient's respiratory system by $CO_2$ and a closed loop for analysing the concentration of $CO_2$ (an exhaustion gas sample for analysis and return samples of $CO_2$ gas back to model). Patient monitor S/5 (DatexOhmeda,Finland) was used as a $CO_2$analyzer.

The newborn respiratory system model was continuously infused by 110 mL/min (±1 mL/min) of $CO_2$ in each configuration. A VT Mobile (FlukeBiomedical, Ohio)electronic flow meter was used to control the dosige rate of $CO_2$.

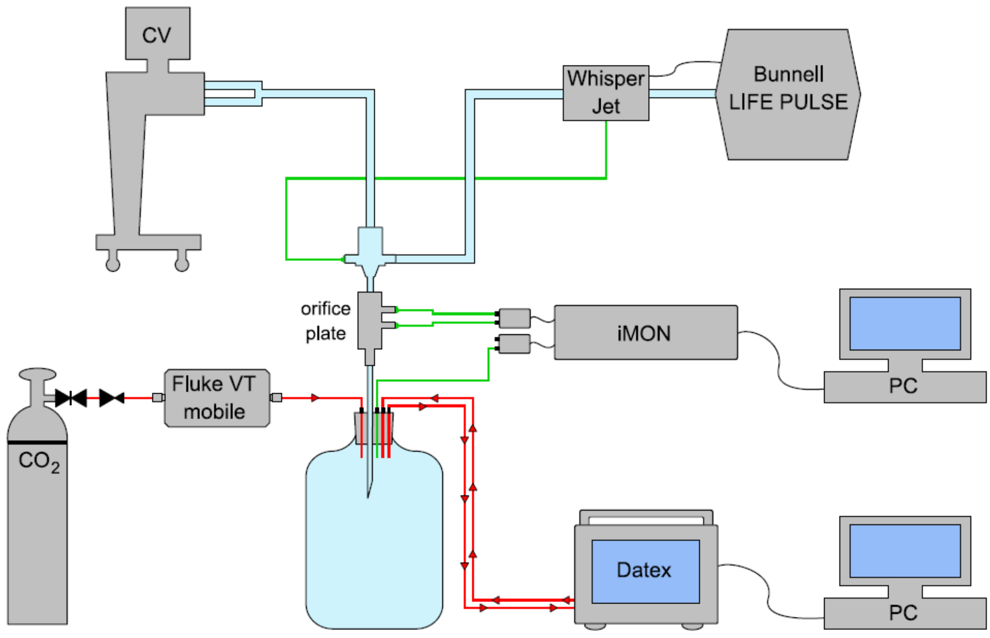


Fig. 1 Setup of the $CO_2$elimination experiment using HFJV. We continuously infused 110 ml/min (±10 ml/min) of $CO_2$ into a rigid bottle using the Fluke VT mobile and in the same time we tried to eliminate it out of the bottle using theBunnel LIFE PULSE high frequency jet ventilator (PIP = 20 cm$H_2O$ – without compensation). A conventional ventilator was used to produce PEEP (5 cm$H_2O$) in the system. We measured the concentration of $CO_2$ in the bottle using the DatexOhmeda patient monitor and we observed the pressure inside the bottle using the experimental system iMON.

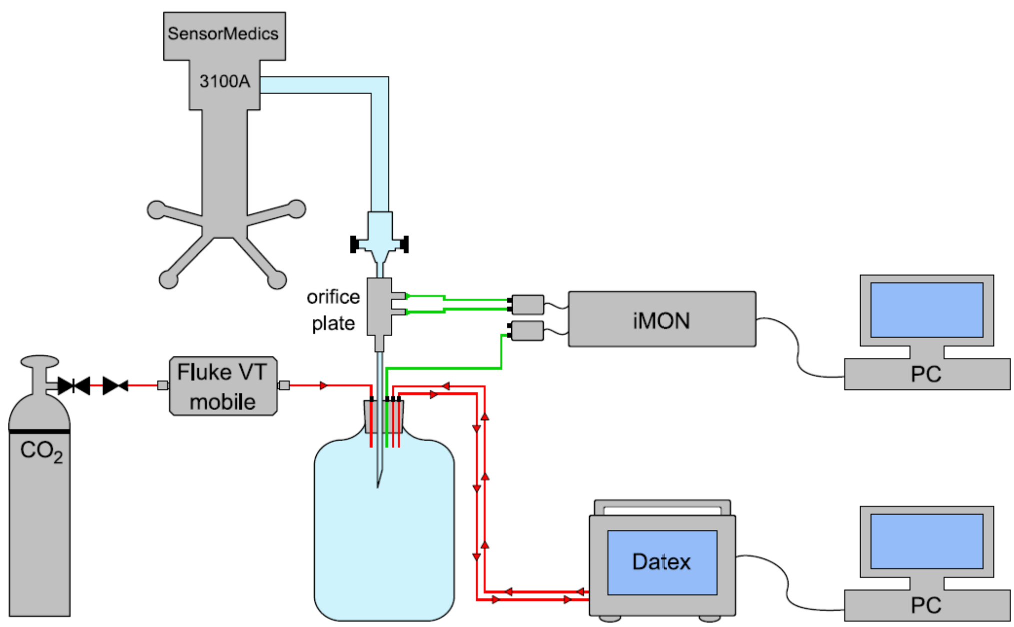


Fig. 2 Setup of the $CO_2$ elimination experiment using high frequency oscillatory ventilation. We used the SensorMedics 3100A ventilator (Paw = 12,5 cm$H_2O$, maximal intensity of oscillations).

At the same time we were tried to eliminated $CO_2$ from the rigid bottle by HF (high-frequency) ventilators according to the Table 1.

The pressure inside of the bottle was measured in order to observe decrease of pressure caused by the orifice plate. Specialized equipment (iMON monitor) with pressure sensors 26PC01(Honeywell, United States) with a pressure range of 1 psi was developed for the simultaneous measurement of up to three pressures at the same time. Signals from the sensors were amplified through instrumental amplifiers INA 128 (Texas Instruments, Dallas, Texas, United States) and recorded by a multifunctional measuring card NIDAQ 6009 (National Instruments, Austin, Texas, United States). The sampling frequency was 1 kHz. LabVIEW Signal Express (National Instruments, Austin, Texas, United States) was used for signal analysis. Pressure losses were compensated by adjusting a higher peak inspiratory pressure on the ventilators (HFJV) or changing the CDP (continual distending pressure) during HFOV.

The actual concentration of $CO_2$ was recorded by SW and the data were processed using Matlab Curve fitting tool (MathWorks, Natick, Massachusetts, U.S.A.).

### *A. Sensor – orifice plate*

The experimental orifice plate was designed and made of stainless steel. The orifice plate is placed in the ventilation circuit between the jet-adapter and the endotracheal tube. Dimensions of the aperture are shown in Figure3 and its flow-pressure characteristics are shown in Figure4.Both connectors located on the orifice plate were attached to the differential pressure sensor but this signal was not further processed.

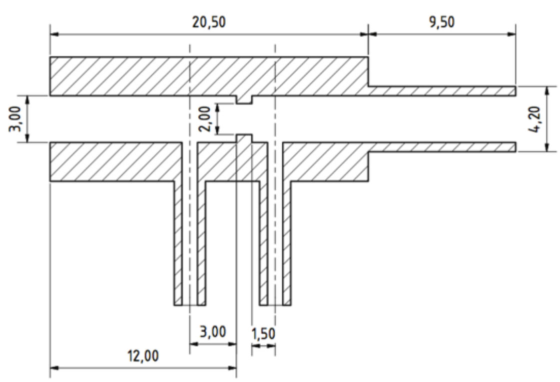


Fig. 3 Orifice plate - cut

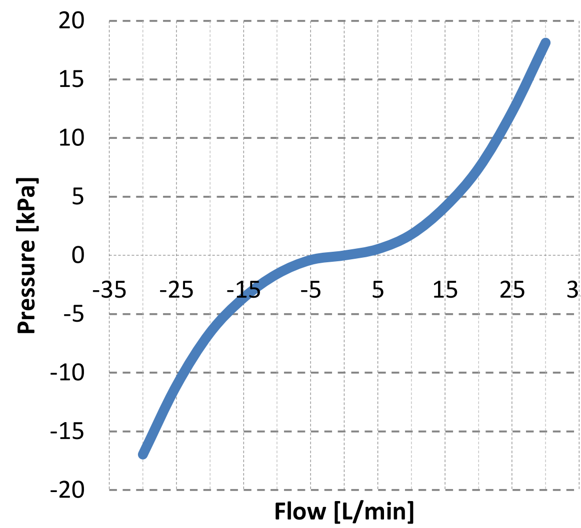


Fig. 4 Pressure-flow characteristics of the experimental flow sensor

## III. Results

The increase of $CO_2$ concentration in the bottle can be described by the following equation:

$$c(CO_2) = c_f \cdot \left(1 - e^{-\frac{t}{\tau}}\right)$$

Values of the final concentration of $CO_2$dependent on frequency (Respiratory Rate)and the time constant $\tau$ are shown in figure 5.

## IV. Discussion

This experiment establishes the effect of an orifice plate on the elimination of carbon dioxide in high frequency ventilation. The orifice plate was used as a flow meter for measuring inspiratory and expiratory flow, respectively volumes, during HFOV and HFJV. Time constants during HFJV were increased when using the orifice plate without compensation. The result of this phenomena was that the final concentration of carbon dioxide in the lung model increased.After the compensation for the pressure loss, deterioration of carbon dioxidewas not detected and the system acted as it would without the orifice plate. For clinical use of the orifice plate (as a flow sensor) is compensation of losses inevitable, but difficult for forecast. This plays an important role during practical application in clinics.

The effect of the orifice plate during high frequency ventilation was not as evident as in the previous case with jet ventilation. The embedded sensor caused only small changes in the time constants and did not affect the final concentration of $CO_2$ in the lung model.

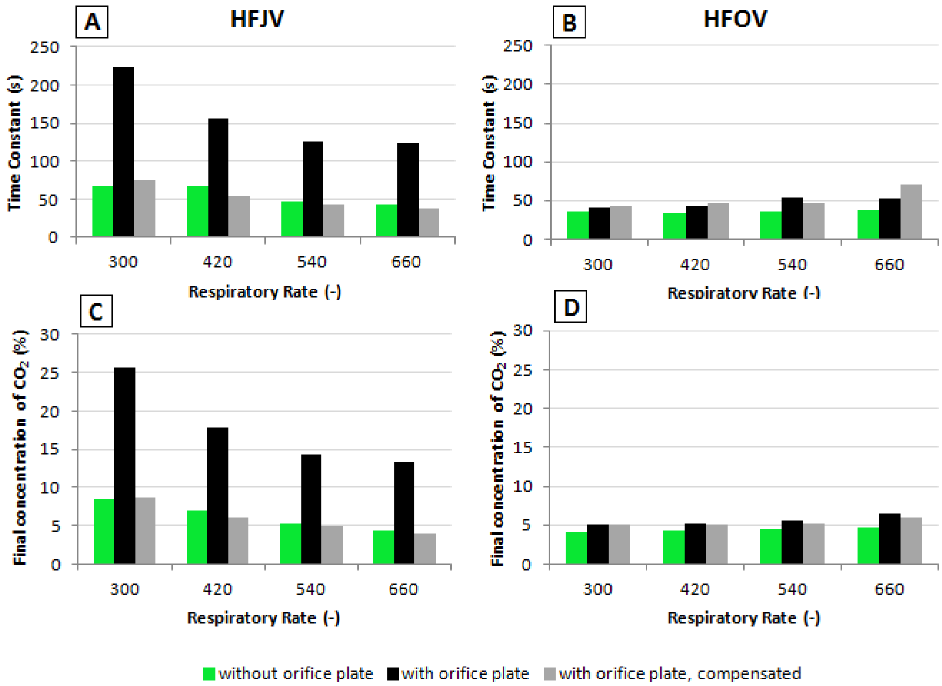


Fig. 5 Values of the time constant (τ) (A, B) and the final concentration of $CO_2$ ($c_f$) (C, D) for different variations of the carbon dioxide elimination experiment. These values were found in the Matlab Curve Fitting tool. We smoothed the data using the function (1) $c(CO_2) = c_f \cdot (1-e^{\frac{t}{\tau}})$. Goodness of fit ($R^2$) intervene between 0,9865 and 0,9994 for different variations of the experiment.

## V. Conclusion

We came to the conclusion that ventilation parameters such as flow, resp. tidal volumes, can be monitored by an orifice plate in HFOV, because the orifice plate doesn't affect $CO_2$ elimination significantly. In HFJV there is a considerable increase in the final concentration of $CO_2$ when the orifice plate is used. Compensation for the loss in pressure was effective but recognizing how to set up for it in clinical practice could be difficult.

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## Conflict of Interest

The authors declare that they have no conflict of interest.

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