Proceedings of the 28th IEEE
EMBS Annual International Conference
New York City, USA, Aug 30-Sept 3, 2006

Direct measurement of airway pressure in ventilated very low birth weight infants

Ants R. Silberberg* and Kenneth Sandberg**

Abstract— **A new method for direct measurement of airway pressure using a fiber optic pressure sensor (FOPS) has been tested in very low birth weight infants during mechanical ventilation. Airway pressure and ventilatory flow was recorded in an initial investigation in three newborn infants with a birth weight less than 1000 g. The method for direct measurement of airway pressure was found to be feasible in ventilated infants and can form a basis for reliable measurements which can be used to derive information on lung function and to guide in finding an effective ventilator management.**

I. INTRODUCTION

Assessment of lung function in very low birth weight infants with respiratory disorders is difficult. This group of patients often require respiratory support by means of mechanical ventilation and to find an effective ventilator treatment is a major clinical challenge. It is also important to prevent problems with ventilator induced injuries and to minimize barotrauma [1] [2]. A positive prognosis is dependent upon early treatment and diagnosis based on reliable measurements related to the ventilated patient. Monitoring of pressure and volume loops together with knowledge of respiratory mechanics and FRC (Functional Residual Capacity) are valuable tools in finding an effective ventilator treatment [3] [4].

The diagnosis of respiratory disorders are based on several parameters summarized in the term lung function [5]. Some of these parameters can be derived from measurements of ventilatory flow and pressure applied by the ventilator to the patient.

An infant who is mechanically ventilated is intubated and the pressure applied to the patient is often measured at the proximal end of the endothracheal tube (ETT). This means that the ETT and its properties are included in the system we want to study. The pressure drop along the ETT adds a resistive component when the resistance of the respiratory system is derived [6]. Flow measurements and leakage around the ETT also causes problems when it comes to recording signals of high quality reflecting the true conditions during ventilation. If the pressure could be measured at the distal end of the ETT at least one of these measurement problems could be eliminated. A fiber optic pressure sensor (FOPS) was used to measure airway pressure at the distal end of the ETT. This method has previously been used in children [7].

This work was supported by the Wilhelm and Martina Lundgren Science Foundation and the Karl G. Eliasson Science Foundation.

* Department of Signals and Systems, Biomedical Engineering Division, Chalmers University of Technology, SE-412 96 Göteborg, Sweden ants.silberberg@chalmers.se

** Department of Paediatrics, Göteborg University, SE-416 85 Göteborg, Sweden kenneth.sandberg@vgregion.se

II. PURPOSE

The purpose of this work was to investigate if direct measurement of airway pressure using a fiber optic pressure sensor was feasible in ventilated newborn infants during mechanical ventilation in a neonatal intensive care environment. Together with measurements of airway flow the recorded pressure should be used to derive information on lung function. The FOPS technique was used together with a traditional method of measuring airway pressure. The two different pressure recordings were compared as well as the derived lung function parameters.

III. METHOD AND SUBJECTS

1) Test of pressure recording devices: Pressure recordings from the FOPS device was compared to pressure recordings using a device with another type of pressure sensor. In a laboratory setup, the two devices simultaneously recorded the pressure at approximately the same point. A ventilator was used together with a silicon bellows lung model.

2) Measurements in newborn infants: Ventilatory flow and airway pressure, both at the proximal and distal end of the ETT, was recorded in three newborn infants during mechanical ventilation (birth weight 755-885 g, gest.age 25-28 weeks). Several sequences of data was sampled at a rate of 200 Hz. Ventilator pressure settings were slightly altered; peak inspiratory pressure (PIP) and positive end-expiratory pressure (PEEP).

A. Airway pressure

Airway pressure was measured at the distal end of the ETT using a miniaturized pressure transducer with a silicon sensor element, 0.42 mm in diameter, connected to an optical fibre, 0.25 mm in diameter (Samba Sensors), and a control unit (Samba 3000). The fiber was led inside the ETT and entered the tubing system from the ventilator in a Y-piece close to the ETT-connector. Even when an ETT with an inner diameter of 2.5 mm was used the added flow resistance in the ETT due to the transducer fiber was considered to be negligible.

B. Reference pressure

The airway pressure at the proximal end of the ETT was measured by a pressure recording device with a 10 kPa on-chip temperature compensated and calibrated silicon pressure sensor (Motorola MPX2010). The signal from this recording device was used as a reference pressure.

C. Ventilatory Flow

The flow signal was taken at the analog output port of the ventilator. The ventilator, Dräger Babylog 8000, has a heated wire flow meter and was placed at the proximal end of the ETT.

D. Pressure - Volume loops

Two different pressure and volume (PV) loops was presented. One using the FOPS pressure and the other using the reference pressure at the proximal end of the ETT. The volume signal was derived from numerical integration of the flow signal. The PV-loops can be used to study the mechanical properties and visualizes the dynamic response as the change in lung volume caused by transpulmonary pressure variations.

E. Respiratory Mechanics

A single compartment lung model, according to equation 1, was used to derive the resistance, R, and compliance, C, of the respiratory system,

$$P(t) = \frac{1}{C}\int \dot{V}(t)dt + R\dot{V}(t) + P_o. \qquad (1)$$

Linear regression was used to calculate resistance, compliance and a static pressure, P_o, from sampled values of pressure, P, and flow, $\dot{V}$, for single breaths [8].

IV. Result

A. Pressure recordings

There was a good correspondence between the signals from the two pressure recording devices. Figure 1 show the FOPS pressure signal plotted against the reference pressure signal (uncalibrated in Volt). The correlation factor was > 0.99. The pressure used in figure 1 was generated by a ventilator with the following settings, PIP/PEEP=20/3 cmH_2O and 80 breaths/min. The whole sequence was 9.2 s long and figure 2 show the pressure signal profile in a subsequence of 2 s.

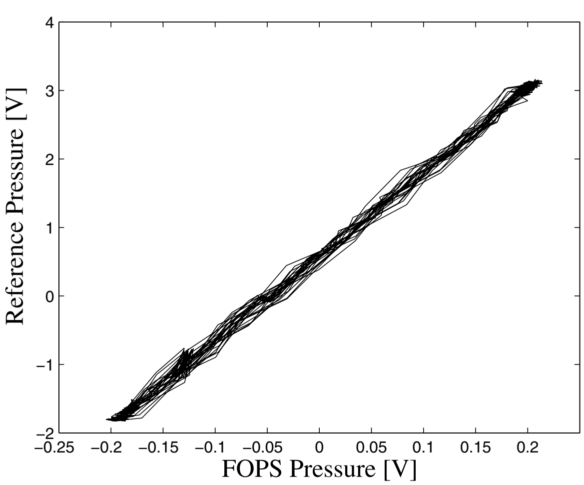

Fig. 1. Relation between pressure recordings

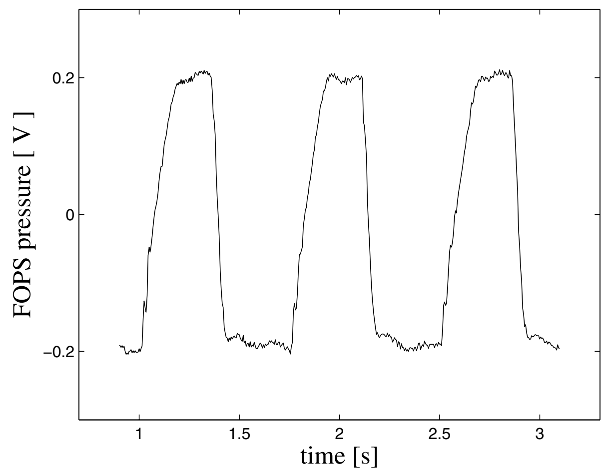

Fig. 2. Pressure signal profile

B. PV-loops

Figure 3 show two loops from a single breath. The ventilator setting was: PIP/PEEP = 21/3 cmH_2O and 40 breaths/min. In the outer loop has the reference pressure been used and the FOPS pressure was used for the inner loop.

The difference in the shape of the two loops is mainly due to the resistance of the ETT which is included in the system when the reference pressure at the proximal end of the ETT is used. A wide loop indicates a system with a higher resistance compared to a system with a more narrow loop. The FOPS pressure and the reference pressure for the two PV-loops in figure 3 is shown in figure 4.

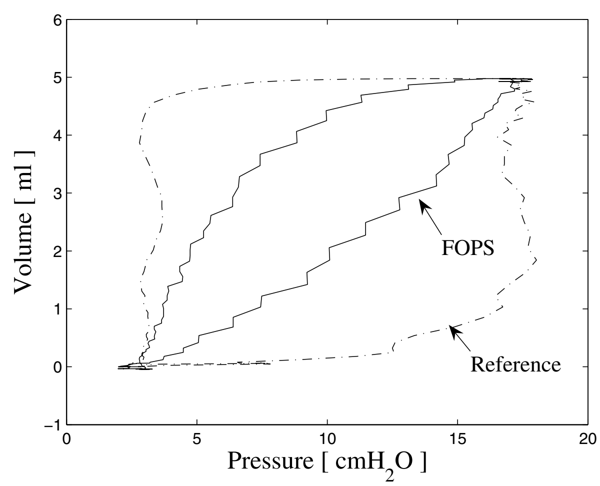

Fig. 3. Pressure - Volume loops

C. Respiratory mechanics

The resistance value derived from flow and the pressure at the proximal end of the ETT, R_p, was considerably higher than the resistance derived using the FOPS pressure, measured at the distal end of the ETT, R_d. In a newborn

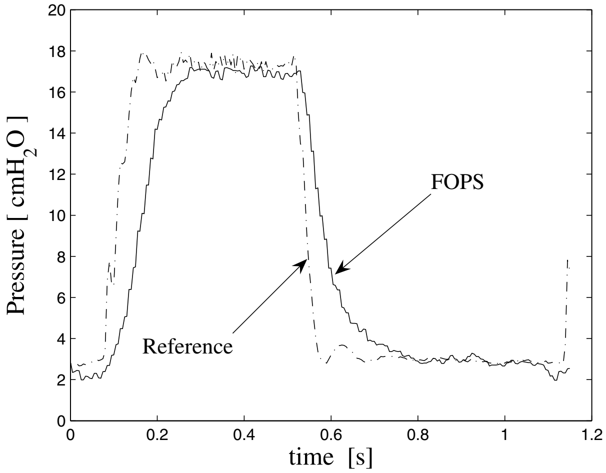

Fig. 4. FOPS and reference pressure

infant with a birth weight of 755 g the R_d values were between 76 and 107 cmH_2O/l/s and the R_p values between 230 and 300 cmH_2O/l/s. These values were derived when the PEEP value was varied between 3 and 5 cmH_2O but the PIP setting was fixed at 21 cmH_2O. The patient was intubated with an ETT, inner diameter: 2.5 mm, length: 11.5 cm.

The compliance value derived using the pressure at the proximal end of the ETT, C_p, was slightly higher than the compliance derived using the FOPS pressure, measured at the distal end of the ETT, C_d. The C_d values were between 0.30 and 0.36 ml/cmH_2O and the C_p values between 0.32 and 0.40 ml/cmH_2O. These results, describing the compliance and resistance values, are derived from the same pressure and flow recordings.

V. CONCLUSIONS AND FUTURE WORKS

A. Conclusions

The method for direct measurement of airway pressure using the FOPS device was found to be feasible in ventilated infants. An initial practical problem was to place the sensor at the very end of, or slightly inside, the ETT but not outside the tube. Pressure disturbances which could be related to cardiac activity has been seen but disappeared when the fiber length in the ETT was decreased.

A difference in the calculated resistance values caused by the difference in the two pressure signals was expected. The resistance value of the ETT was much higher than the flow related pressure component of the respiratory system when the smallest ETT with an inner diameter of 2.5 mm was used. A decrease in tube diameter leads to a large increase in the flow resistance [6].

The difference in the compliance values was much smaller than the corresponding resistance values. This was also expected since the ETT is likely to be much less elastic than the lung. A major advantage using the FOPS pressure is that the influence of the ETT can be eliminated when it comes to derive the mechanical properties of the respiratory system.

B. Future Works

A reliable method for measurement of the airway pressure together with airway flow gives important information about the conditions during mechanical ventilation. The dynamic pressure and volume changes, which can be monitored, are even more valuable if it could be related to the actual FRC level. To make pressure and flow measurements in combination with a method for measuring FRC would be of great importance. Even if the FRC value is not available it would be interesting to study the mechanical response of the respiratory system due to different ventilator pressure settings. Maybe it would be possible to find an effective operating point (pressure and volume) on the S-shaped curve describing the overall static relationship between volume and pressure for the lung. This is of considerable importance in newborn infants where high pressures can cause barotrauma. On the other hand, if the ventilator pressure is too low the oxygenation may be poor. A positive end-expiratory pressure causes the lung to stay open and the peak pressure can recruit collapsed lung units which improves the gas exchange in the lung.

REFERENCES

[1] A.S. Slutsky, "Lung injury caused by mechanical ventilation," *Chest*, vol. 116, pp. 9S-15S, 1999

[2] D. Dreyfuss and G. Saumon, "Ventilator-induced lung injury. Lessons from experimental studies," *Am J Respir Crit Care Med*, vol. 157, pp. 294-323, 1998

[3] B.A. Sjöqvist, K. Sandberg, O. Hjalmarson and T. Olsson, "Calculation of lung volume in newborn infants by means of a computer-assisted nitrogen washout method," *Pediatric Research*, vol. 18(11), pp. 1160-1164, 1984

[4] J. Hammer, A. Numa and C.J.L. Newth, "Total lung capacity by N_2 washout from high and low lung volumes in ventilated infants and children," *Am J Respir Crit Care Med*, vol. 158. pp. 526-531, 1998

[5] J. Stocks, "Lung function testing in infants," *Pediatric Pulmonology*, Suppl. 18, pp. 14-20, 1999

[6] M.D. Wall, "Infant endotracheal tube resistance: effects of changing length, diameter, and gas density," *Critical Care Medicine*, vol. 8(1), pp. 38-40, 1980

[7] S. Søndergaard, S. Karason, A. Hanson, K. Nilsson, S. Höjer, S. Lundin and O. Stenqvist, "Direct Measurement of Intratracheal Pressure in Pediatric Respiratory Monitoring," *Pediatric Research*, Vol. 51, No. 3, pp 339-345, 2002

[8] V.K. Bhutani, E.M. Sivieri, S. Abbasi and T.H. Shaffer, "Evaluation of pulmonary mechanics and energetics: A two factor least mean square analysis," *Pediatric Pulmonology*, vol. 4, pp. 150-158, 1988