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Pressure oscillation delivery to the lung: Computer simulation of neonatal breathing parameters

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ABSTRACT

Preterm newborn infants may develop respiratory distress syndrome (RDS) due to functional and structural immaturity. A lack of surfactant promotes collapse of alveolar regions and airways such that newborns with RDS are subject to increased inspiratory effort and non-homogeneous ventilation. Pressure oscillation has been incorporated into one form of RDS treatment; however, how far it reaches various parts of the lung is still questionable. Since *in-vivo* measurement is very difficult if not impossible, mathematical modeling may be used as one way of assessment. Whereas many models of the respiratory system have been developed for adults, the neonatal lung remains essentially ill-described in mathematical models. A mathematical model is developed, which represents the first few generations of the tracheo-bronchial tree and the 5 lobes that make up the premature ovine lung. The elements of the model are derived using the lumped parameter approach and formulated in Simulink™ within the Matlab™ environment. The respiratory parameters at the airway opening compare well with those measured from experiments. The model demonstrates the ability to predict pressures, flows and volumes in the alveolar regions of a premature ovine lung.

1. Introduction

The design of respiratory support devices for neonates requires assessment of their interaction with subjects at various stages of the design process. Clinical trials are time consuming and not economically feasible for small evaluation studies. Computer simulations, as an adjunct to laboratory testing, may provide valuable insight into the effect that certain design parameters have on neonatal respiratory variables.

Previous models have either concentrated on whole lung (Barbini et al., 2001; Nucci et al., 2002; Tomlinson et al., 1994) or left/right lung (Crooke et al., 1996) ventilation in adults. Neonatal models developed (Costantino and Fiore, 1997; Costantino and Fiore, 2001; DeJongh, 1995; Schmidt et al., 1998) either utilize symmetric branching geometry or are at most two-compartment models. However, the neonatal lung has different mechanical and physical characteristics across the different lobes.

Other single (Athanasiades et al., 2000; Liu et al., 1998; Mead, 1961; Woo et al., 2004) and two (Crooke and Head, 1996; Schmidt et al., 1998) compartment models in the literature cannot predict inhomogeneous ventilation and do not consider flow dependent resistance, which is important in describing the upper airways (Bates and Milic-Emili, 1993). An asymmetric bronchial tree model leading to several independent alveolar compartments was developed previously (Polak and Lutchen, 2003). However lobe viscoelasticity is neglected and the model was developed for a normal adult lung and as such cannot be directly used for studies on premature neonates whose airway structure is incomplete, with alveolarisation only starting at 34 weeks gestation.

The aim of the present study is to investigate the transmission of pressure oscillations, delivered at the mouth, to various parts of the lung. A validated mathematical model suitable for neonatal respiratory studies is developed.

2. Method

This model accounts for the asymmetric structure of the airways from the trachea to the lobes including the chest wall, their different viscoelastic and inertial properties, neonatal morphology and empirical data. Due to larger thoracic forces, lung compliance and surfactant levels, pressure, flow rate and tidal volume fluctuations are greater in the adult lung (Barbini et al., 2001; Nucci et al., 2002; Tomlinson et al., 1994) when compared to the neonatal lung (DeJongh, 1995) and so these relationships need to be specifically described for neonates to determine proper assessments of their interaction with devices intended for use on infants.

Realistic data including pressure, flow and volume measurements are collected from premature ovine lungs to better quantify neonatal respiratory parameters.

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