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Thoracoabdominal asynchrony in a virtual preterm infant: computational modeling and analysis

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Abstract

Thoracoabdominal asynchrony (TAA), the asynchronous volume changes between the rib cage and abdomen during breathing, are associated with respiratory distress, progressive lung volume loss, and chronic lung disease in the newborn infant. Preterm infants are especially prone to risk factors such as weak intercostal muscles, surfactant deficiency, and a flaccid chest wall also associated with ineffectiveness of mechanical ventilation for treating these conditions. The causes of TAA in this fragile population are not fully understood, and to date, the assessment of TAA has not included a mechanistic modeling framework to explore the role these risk factors play in breathing dynamics. We present a compartmental model of pulmonary mechanics that simulates TAA in the preterm infant under various adverse clinical conditions, including high chest wall compliance, applied inspiratory resistive loads, bronchopulmonary dysplasia, anesthesia-induced intercostal muscle deactivation, weakened costal diaphragm, impaired lung compliance, and upper airway obstruction. The key model feature is a partitioned chest wall with parameterized nonlinear rib cage and abdominal compliances. Model outputs relating to TAA and respiratory volumes were analyzed for physiological relevance using sensitivity analysis through the implementation of the Morris screening method in combination with a local, derivative-based method. Results indicate that risk factors are additive such that maximal TAA occurs in a virtual preterm infant with multiple adverse conditions, and addressing risk factors individually causes incremental changes in TAA. An abruptly obstructed upper airway caused immediate nearly paradoxical breathing and tidal volume reduction despite greater effort. In most simulations, increased TAA occurred together with decreased tidal volume. Simulated indices of TAA are consistent with published experimental studies and clinical outcomes, motivating further investigation into the use of computational modeling for assessing TAA in the preterm infant and additional populations.

Keywords: Chest wall compliance, respiratory system, pediatric pulmonology, dynamic simulation, mathematical model, sensitivity analysis