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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, can lead to 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 that are associated with ineffectiveness of mechanical ventilation for treating these conditions. The assessment of TAA in this fragile population is challenging, and to date 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. Results indicate that risk factors are additive such that maximal TAA occurs in a virtual preterm infant with multiple co-morbidities, and addressing an individual risk factor causes an incremental change in TAA. An abruptly obstructed upper airway caused immediate nearly paradoxical breathing and tidal volume reduction. In most simulations, increased TAA occurred together with decreased tidal volume. The simulated indices of TAA are consistent with 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 distortion, respiratory system, pulmonology, dynamic simulation, mathematical model