Pediatric Respiratory System: Basic Anatomy & Physiology

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Outline

- Introduction
- Developmental Anatomy
- Developmental Mechanics of Breathing
- Developmental Anatomy and Physiology of the Pulmonary Circulation
- Other key points in Pediatrics
Introduction

- MV is the cornerstone of contemporary critical care and it is “lifesaving in certain conditions”

- MV is supportive only and can be associated with significant adverse effects and complications when applied improperly

- Only by understanding the normal function of the respiratory system we can formulate mechanisms for supporting a failing physiology.
Developmental Anatomy

The diagram illustrates the timeline of development, from fertilization to birth and beyond. It highlights the stages of development, including:

- Embryonic period
- Pseudoglandular stage
- Canalicular stage
- Saccular stage
- Alveolar stage
- Postnatal period

The timeline is marked in weeks, months, and years, highlighting key transitions and stages in the development of an organism.
Developmental Anatomy

- Lung and chest wall development (2-8 yrs)

- The process of alveolization continues beyond the infant age
  - 20-50 million alveoli at birth in a term infant
  - 300 million by the age of 8 years

- The increase in alveoli parallels the increase in alveolar surface area
  - 2.8 m² at birth
  - 32 m² at 8 years of age
  - 75 m² by adulthood
Key Function

Oxygenation & Ventilation
Children vs Adult

- Collateral ventilation through the pores of Kohn and Lambert’s canal are not well developed in the early years.

- Collateral pathways may help prevent atelectasis, which is more common in children than in adults.
Developmental Mechanics of Breathing
Normal Elastic Recoil

FUNCTIONAL RESIDUAL CAPACITY

END-INSPIRATION
Lung Elastic Recoil

- The lung matrix of a neonate contains only small amounts of collagen; the elastin-to collagen ratio changes during the first months and years of life and affects lung stiffness and potential for overdistension and recoil.

- Lung recoil increase with age in children over 6 years of age (more elastin)
Lung Elastic Recoil

- The presence of an air–liquid interface increases the elastic recoil of the lung because of surface tension forces.
- Surfactant, a phospholipid protein complex, has been shown to profoundly lower surface tension.

Classic model of the distal lung in which individual alveoli are controlled by Laplace’s law (P=2T/r). Small alveoli would empty into large alveoli.
Compliance of the Lung and Chest Wall

- During the first year of life, the compliance of the respiratory system increases by as much as 150% (mainly lung).
- The infant chest wall is remarkably compliant and compliance decreases with increasing age.
- The elastic recoil of an infant’s chest wall is close to zero and with age increases because of the progressive ossification of the rib cage and increased intercostal muscle tone.
Compliance in Newborn
Children vs Adult

- Considerable structural changes in the chest wall may change infant and childhood predisposition to respiratory failure, lung injury, and ventilation-associated lung injury.

- The orientation of the ribs is horizontal in the infant; by 10 years of age, the orientation is downward.
Inspiration & Expiration

Ossification of the rib cage, calcification of the costal cartilage, and development of muscular mass develops progressively until adulthood.
Clinical Implications

- Decreased recoil of the infant chest wall increases the possibility of lung collapse in the setting of lung disease.
- The excessive compliance of the infant chest wall requires the infant to perform more work than an adult chest to move a similar tidal volume.
- During respiratory distress, a significant portion of the energy generated from diaphragmatic contraction is wasted through the distortion of the highly compliant rib cage.
- Diaphragms could fatigue and infants could become apneic.
Resistance

- The main site of airway resistance in the adult is the upper airway; however, it has been shown that peripheral airway resistance in children younger than 5 years of age is four times higher than adults.
- The major site of resistance is the medium-sized bronchi.
Resistance: Kids vs Adults

<table>
<thead>
<tr>
<th></th>
<th>Normal</th>
<th>Edema 1 mm</th>
<th>Resistance</th>
<th>Cross-sectional area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infant</td>
<td>4 mm</td>
<td>1 mm</td>
<td>$R \propto \frac{1}{\text{radius}^4}$</td>
<td>↑16x</td>
</tr>
<tr>
<td>Adult</td>
<td>8 mm</td>
<td></td>
<td>↑3x</td>
<td>↓44%</td>
</tr>
</tbody>
</table>
Pulmonary Function Volumes

- Maximal inspiratory level
- Inspiratory reserve volume (IRV)
- Inspiratory capacity (IC)
- Vital capacity (VC)
- Total lung capacity (TLC)
- Resting end-expiratory level
- Tidal volume (VT)
- Expiratory reserve volume (ERV)
- Functional residual capacity (FRC)*
- Residual volume (RV)*

*Not determined by spirometry
Lung Volume

- Functional residual capacity (FRC) is determined by the static balance between the outward recoil of the chest wall and the inward recoil of the lung.

- In infants, the outward recoil is quite small, and the inward recoil is only slightly less than that in adults.

- Accordingly, the static balance of forces results in a low ratio of FRC to total lung capacity (TLC) of approximately 10%–15%, limiting gas exchange.
Closing Capacity

- Definition: The volume of gas that remains in the lung when small alveoli and airways in dependent regions of the lung are collapsed or considered closed.

- The closing capacity is composed of residual volume and closing volume.

- Children younger than 6 years of age have a closing capacity greater than FRC in the supine position (V/Q mismatch).
Developmental Anatomy and Physiology of the Pulmonary Circulation

- Development of the lungs and development of the pulmonary vasculature are closely related.
- The arterial tree undergoes complex remodeling in the peripheral portions of the pulmonary circulation following changes in wall stress.
- Muscularization of the pulmonary vasculature occurs throughout infancy and reaches adult levels by adolescence.
- Pulmonary vascular muscle thickness is a function of gestational age and blood flow.
Effects on pulmonary vascular resistance as lung volume changes.
Pulmonary Hypertension

The ability of the pulmonary vasculature to constrict is not age dependent, and even newborns with only a small amount of arterial muscularization are able to induce significant pulmonary vasoconstriction, as noted in neonates with persistent pulmonary hypertension (PPHN).
Other Issues

- Prominent occiput
- Tongue is disproportionately large in relation to mouth
- Larynx is higher in neck
- Narrowest portion at cricoid ring
Pediatric Airway

**Figure 13.** Cricoid pressure (the Sellick maneuver).
Uncuffed ET tube & Leak with MV
Why Kids Are More Difficult?
Conclusion

- Considerable structural changes in the airway, lung and chest wall may change infant and childhood predisposition to respiratory failure, lung injury, and ventilation-associated lung injury.
Predisposing Factors

- An ongoing lung and chest wall development
- Immature collateral ventilation (collapse)
- Lung very compliant prone to over-distension
- The infant chest wall is remarkably compliant
- Poor recoil of the infant chest wall
- High peripheral airway resistance in children younger than 5 years of age (airway diseases)
- Low ratio of FRC to TLC (low reserve)
THANK YOU