Mechanisms of Respiratory Failure

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I. Respiratory failure is present when there is a major abnormality of gas exchange.
   A. In an adult, the limits of normality are a PaO_2 of >60 mm Hg (8 kPa).
   B. In the newborn, the oxygen tension needed to maintain the arterial saturation above 90% varies between 40 and 60 mm Hg (5.3–8 kPa) depending upon the proportion of hemoglobin that is fetal and the arterial pH (a drop in pH of 0.2 eliminates the left shift produced by 70% of the hemoglobin being fetal). Thus, in the newborn period, respiratory failure is best defined in terms of oxygen saturation. There are, however, no agreed criteria (see below).
   C. Hypoxia may be associated with hypercarbia ($PaCO_2$ >6.7 kPa or >55 mm Hg).

$$PaCO_2 \oplus \frac{CO_2 \text{ production}}{\text{Alveolar ventilation}}$$

   Alveolar ventilation = (tidal volume − dead space × frequency)
   D. Respiratory failure associated with hypercarbia will occur, therefore, in situations associated with reduction in tidal volume and/or frequency.
   E. Respiratory failure in the neonatal period may be defined as:
      - PaO_2 <50 mm Hg (6.7 kPa) in an inspired oxygen of at least 50% with/without $PaCO_2$ >55 mm Hg (6.7 kPa)

II. Hypoxemia and hypercapnia in the neonatal period can result from multiple causes.
   A. Ventilation/perfusion (V/Q) mismatch
      1. Distinguished by a good response to supplementary oxygen (intrapulmonary shunting)
      2. Can be assessed using volumetric capnography
      3. Increased physiologic dead space, which can be assessed by capnography
      4. Found in the following conditions:
         (a) Respiratory distress syndrome
         (b) Pneumonia
         (c) Meconium aspiration syndrome

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S. M. Donn et al. (eds.), *Manual of Neonatal Respiratory Care*,
https://doi.org/10.1007/978-3-030-93997-7_65

(d) Bronchopulmonary dysplasia

B. Extrapulmonary (right-to-left) shunts are distinguished by relatively little improvement with supplementary oxygen and are found in:
   1. Pulmonary hypertension*
   2. Cyanotic congenital heart disease*

C. Methemoglobinemia*

D. Inadequate inspired oxygen*

*Note: Although these situations produce cyanosis, this is not from respiratory failure. Cyanosis appears when the reduced hemoglobin concentration of the blood in the capillaries is >5 g/dL. Cyanosis, therefore, does not occur in severe anemic hypoxia (hypoxia is oxygen deficiency at the tissue level).

III. Hypoventilation (reduced alveolar ventilation, reduction in tidal volume and/or frequency) distinguished by a high $PaCO_2$ in association with hypoxemia
   A. Reduced respiratory compliance found in the following conditions:
      1. RDS
      2. Pneumonia
   B. Reduced lung volume found in the following conditions
      1. RDS
      2. Pulmonary hypoplasia
   C. Compressed lung, found in the following conditions
      1. Pneumothorax
      2. Congenital diaphragmatic hernia
      3. Pleural effusion
      4. Lobar emphysema
      5. Congenital pulmonary airway malformation (Cystic adenomatoid malformation)
      6. Asphyxiating thoracic dystrophy

IV. Ventilatory pump failure
   A. Reduced central drive found in
      1. Maternal opiate treatment (high levels of sedation)
      2. Cerebral ischemia
      3. Intracerebral hemorrhage
      4. Apnea of prematurity
      5. Systemic disease such as sepsis
      6. Congenital central alveolar hypoventilation syndrome
   B. Impaired ventilatory muscle function found in
      1. Drugs (corticosteroids, neuromuscular blocking agents—synergism with aminoglycosides)
      2. Disuse atrophy (first signs occur after 1–2 days of mechanical ventilation)
      3. Protein calorie malnutrition
      4. Disadvantageous tension–length relationship (e.g., hyperinflation—diaphragm must contract with a much higher than normal tension. When completely flat, contraction of the diaphragm draws in the lower rib cage, producing an expiratory rather than inspiratory action).
      5. Neuromuscular disorders (Werdnig–Hoffman Disease, myotonic dystrophy, etc.)
      6. Diaphragmatic problems (e.g., hernia, eventration, anterior abdominal wall defects, diaphragmatic dysfunction)
      7. Phrenic nerve palsy (traumatic birth, Erb's palsy)
   C. Increased respiratory muscle workload, found in

1. Chest wall edema (hydrops)
2. Upper airway obstruction
3. Intubated infants with insufficient compensatory ventilatory support
4. Pulmonary edema, pneumonia
5. Intrinsic (inadvertent) PEEP

V. Disorders affecting the alveolar–capillary interface, distinguished, if incomplete, by a good response to increased supplementary oxygen
   A. Diffusion abnormalities (interstitial lung disease), e.g., pulmonary lymphangiectasia (Noonan syndrome)
   B. Anemia
   C. Alveolar–capillary dysplasia

Suggested Reading

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