BPD Ventilation Strategies

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NATIONWIDE CHILDREN'S
When your child needs a hospital, everything matters.

@mjkielt

Disclosures

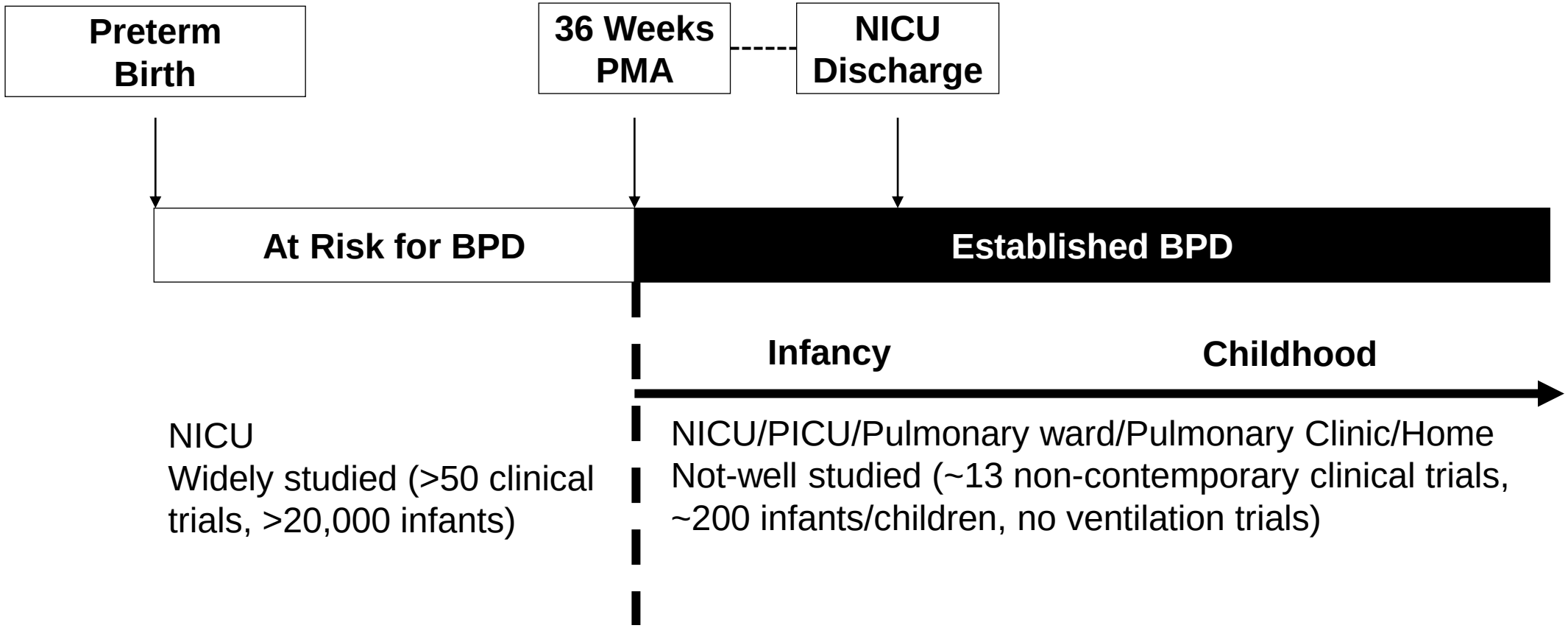
- None

- I won’t be discussing NAVA because (I think) it is the wrong mode to use BPD ☺

Objectives

- Review pulmonary mechanics of common neonatal respiratory diseases.
- Compare and contrast conceptual approaches to mechanical ventilation in infants with respiratory distress syndrome versus bronchopulmonary dysplasia.
- Appraise real-world evidence of approaches to mechanical ventilation in ventilator-dependent infants with established bronchopulmonary dysplasia.

Central Dichotomy of BPD



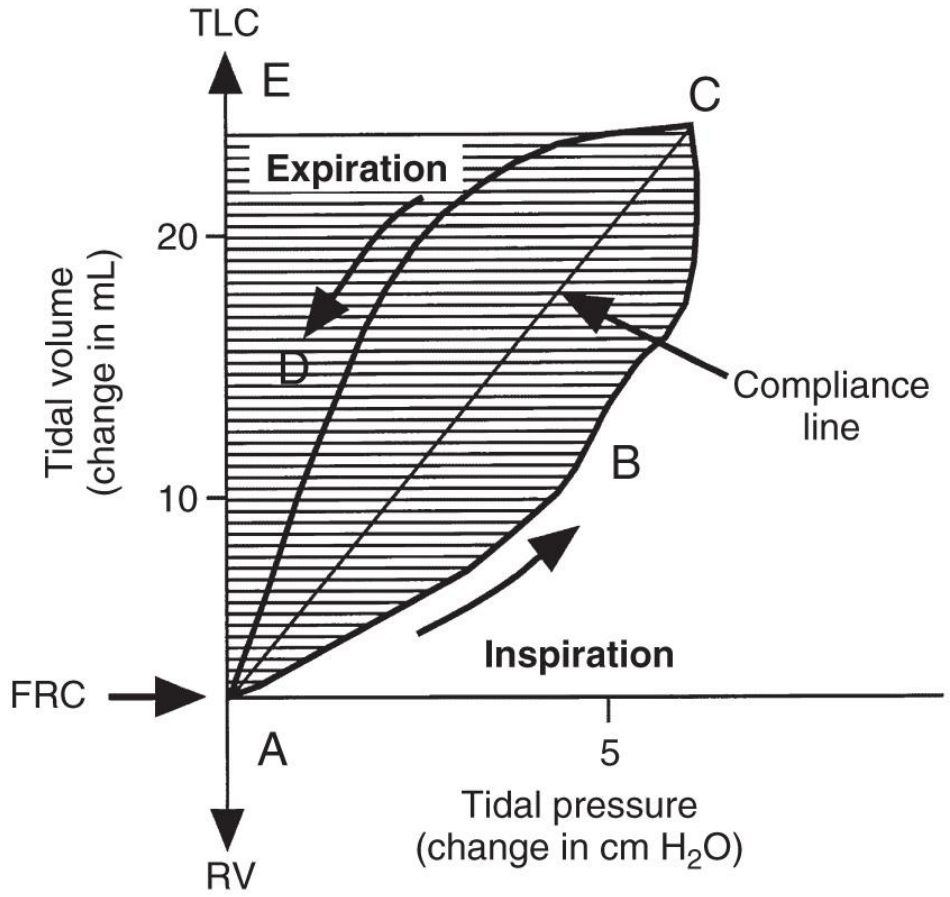
Beam *et al.*, JPerinatology 2014
Jensen, NeoReviews 2019
Cristea *et al.*, AJRCCM 2021

Review of Respiratory Mechanics

- Compliance
- Resistance
- Time Constant

Compliance

- Measure of change in volume for a given change in pressure
  - $C_L = \Delta V / \Delta P$
- Static Compliance
- Dynamic Compliance



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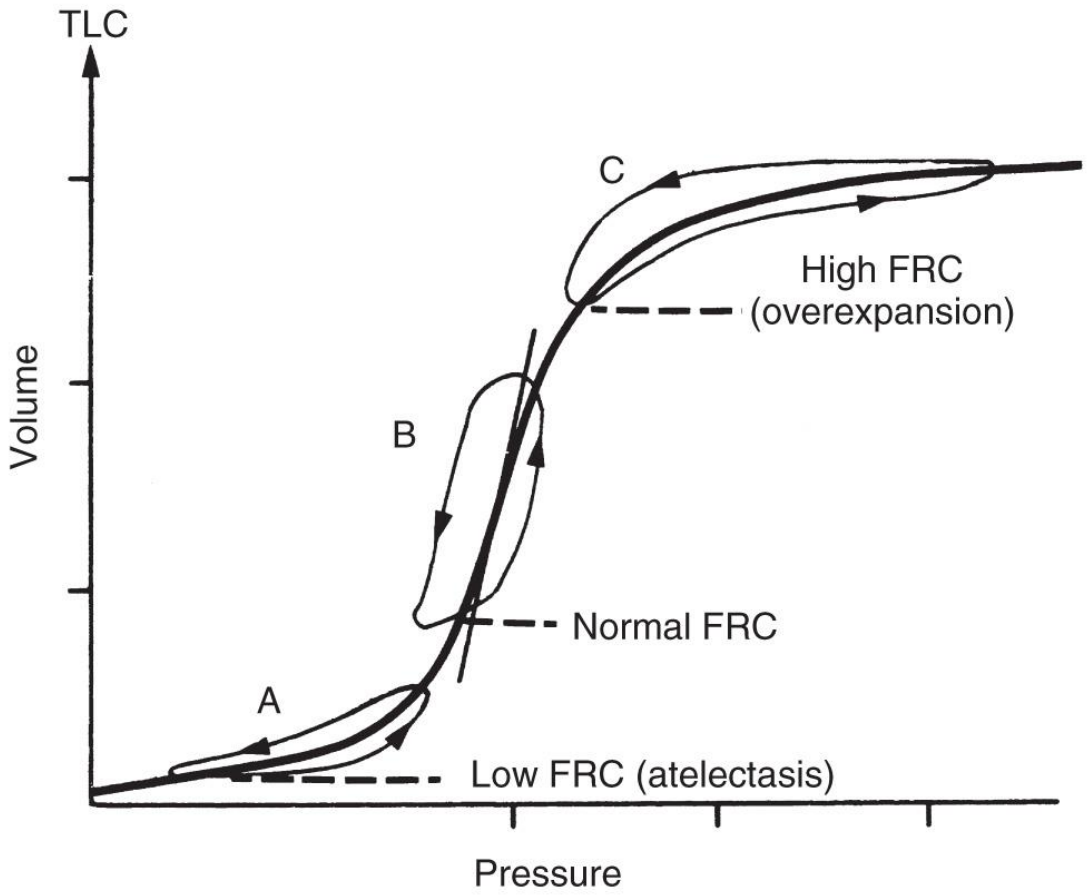
Compliance Depends on Functional Residual Capacity



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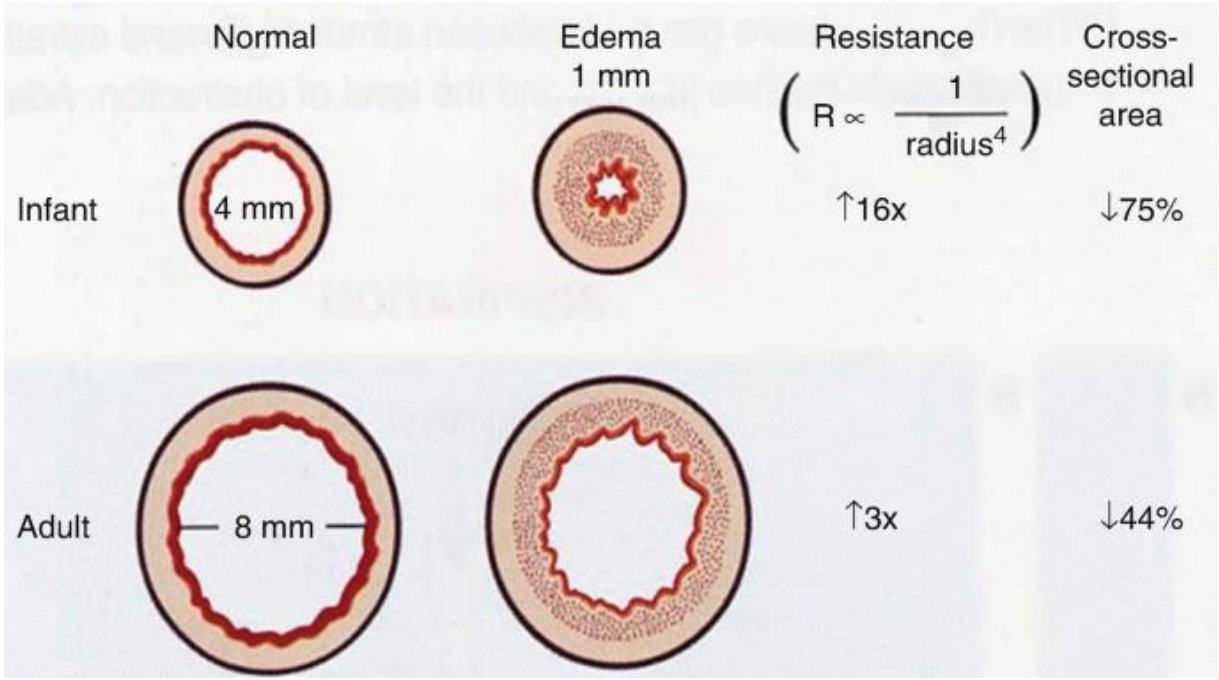
Resistance

- Airway resistance occurs between moving molecules in the gas stream and between these moving molecules and the wall of the respiratory system (e.g., trachea, bronchi, bronchioles).
- Poiseulle's Law –
  - $R \propto L \times \eta / r^4$
  - Mild airway narrowing results in substantial increase in resistance



Elhakeem et al. Textbook of Clinical Otolaryngology, 2022

Time Constant

- Measure of how quickly lungs can inflate or deflate
- **Product of compliance and resistance**
- Inspiratory time constants are roughly 50% of expiratory time constants
- By the end of x3 time constants, 95% of a breath is exhaled

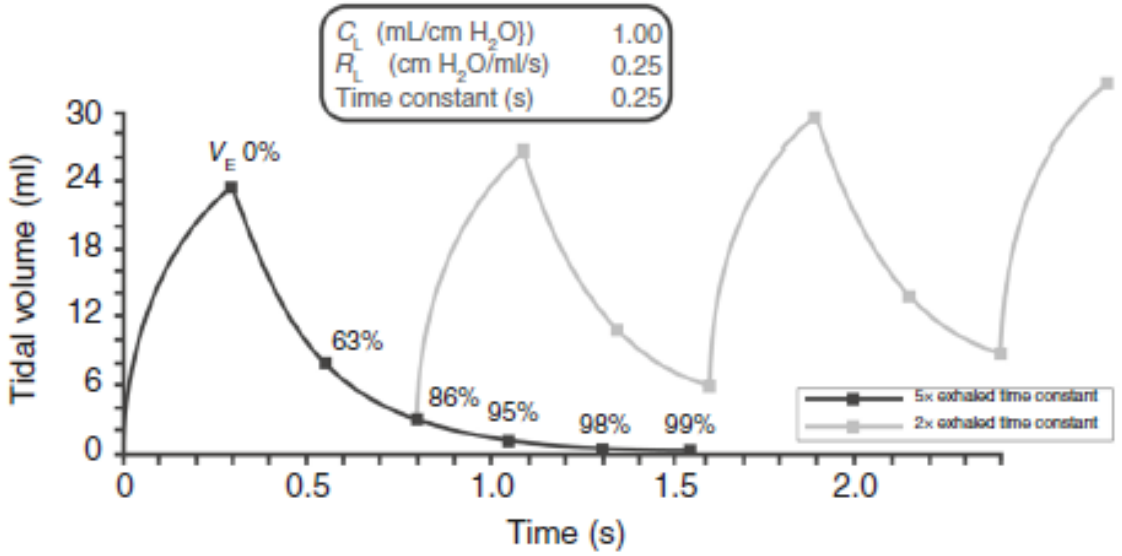


Fig. 3 Volume–time plot for one breath with tidal volume 24 ml. In this example, the time for complete exhalation is shown as the *black line* and is 5× the exhaled time constant ($\tau_E = 0.25$ s) or 1.25 s. If exhalation is stopped before 1.25 s by the next ventilator breath, then so-called "breath stacking" occurs and hyperinflation ensues as shown by the *gray line*.

Sindelar *et al.*, Pediatric Research 2021

How Do Compliance, Resistance, and Time Constants Relate?

$$C \times R = \tau$$

Compliance	Resistance	Time Constant
Normal	Normal	Normal

Keszler et al. Assisted Ventilation of the Neonate, 2022

How Do Compliance, Resistance, and Time Constants Relate?

$$C \times R = \tau$$

Compliance	Resistance	Time Constant
Normal	Normal	Normal
High	Normal	Long

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How Do Compliance, Resistance, and Time Constants Relate?

$$C \times R = \tau$$

Compliance	Resistance	Time Constant
Normal	Normal	Normal
High	Normal	Long
Normal	High	Long

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How Do Compliance, Resistance, and Time Constants Relate?

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Compliance	Resistance	Time Constant
Normal	Normal	Normal
High	Normal	Long
Normal	High	Long
High	High	Very long

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How Do Compliance, Resistance, and Time Constants Relate?

$$C \times R = \tau$$

Compliance	Resistance	Time Constant
Normal	Normal	Normal
High	Normal	Long
Normal	High	Long
High	High	Very long
Low	Normal	Short

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How Do Compliance, Resistance, and Time Constants Relate?

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Compliance	Resistance	Time Constant
Normal	Normal	Normal
High	Normal	Long
Normal	High	Long
High	High	Very long
Low	Normal	Short
Normal	Low	Short

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How Do Compliance, Resistance, and Time Constants Relate?

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Compliance	Resistance	Time Constant
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Normal	Low	Short
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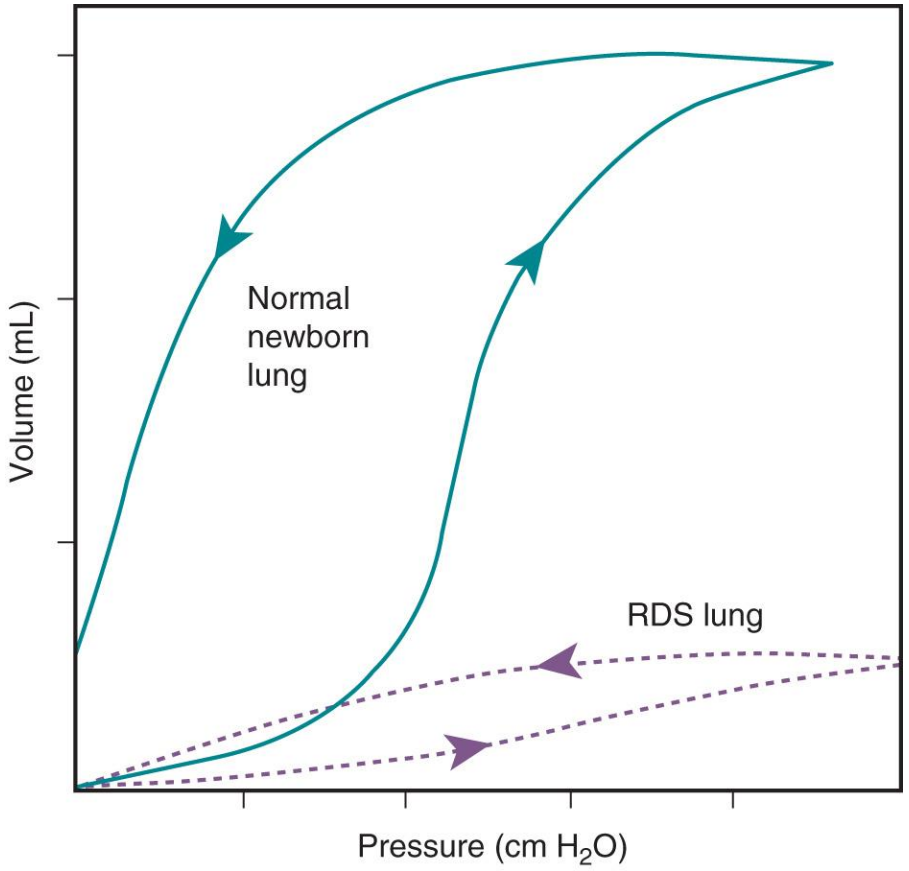
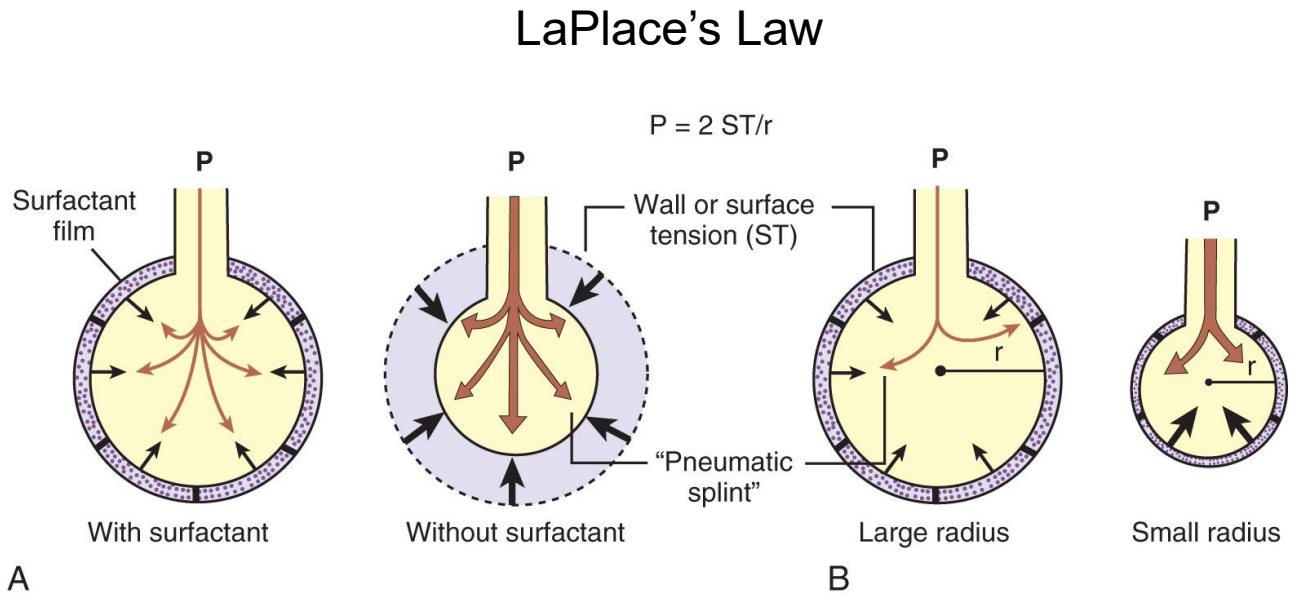
Respiratory Mechanics in Common Neonatal Respiratory Conditions: RDS

- Respiratory Distress Syndrome





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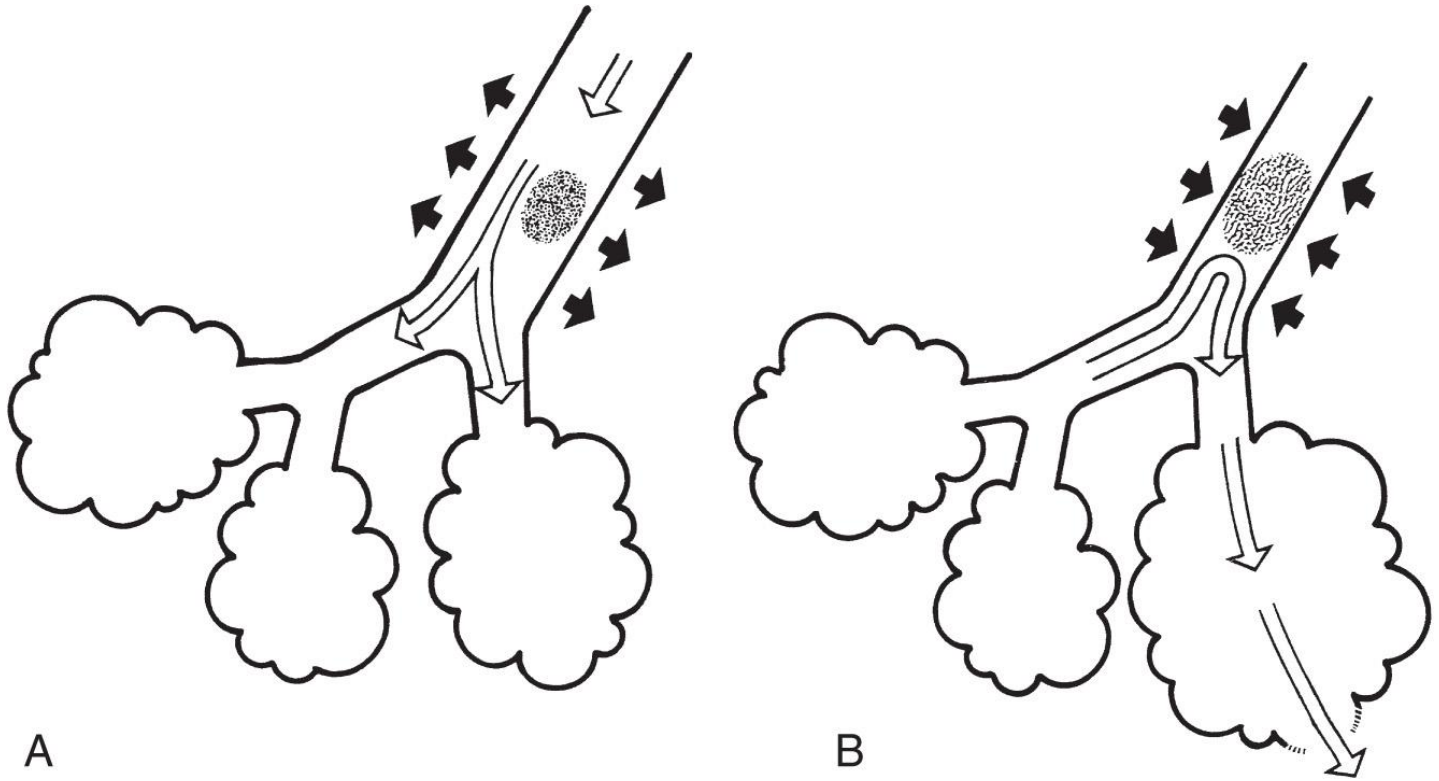
Respiratory Mechanics in Common Neonatal Respiratory Conditions: MAS

- Meconium Aspiration Syndrome



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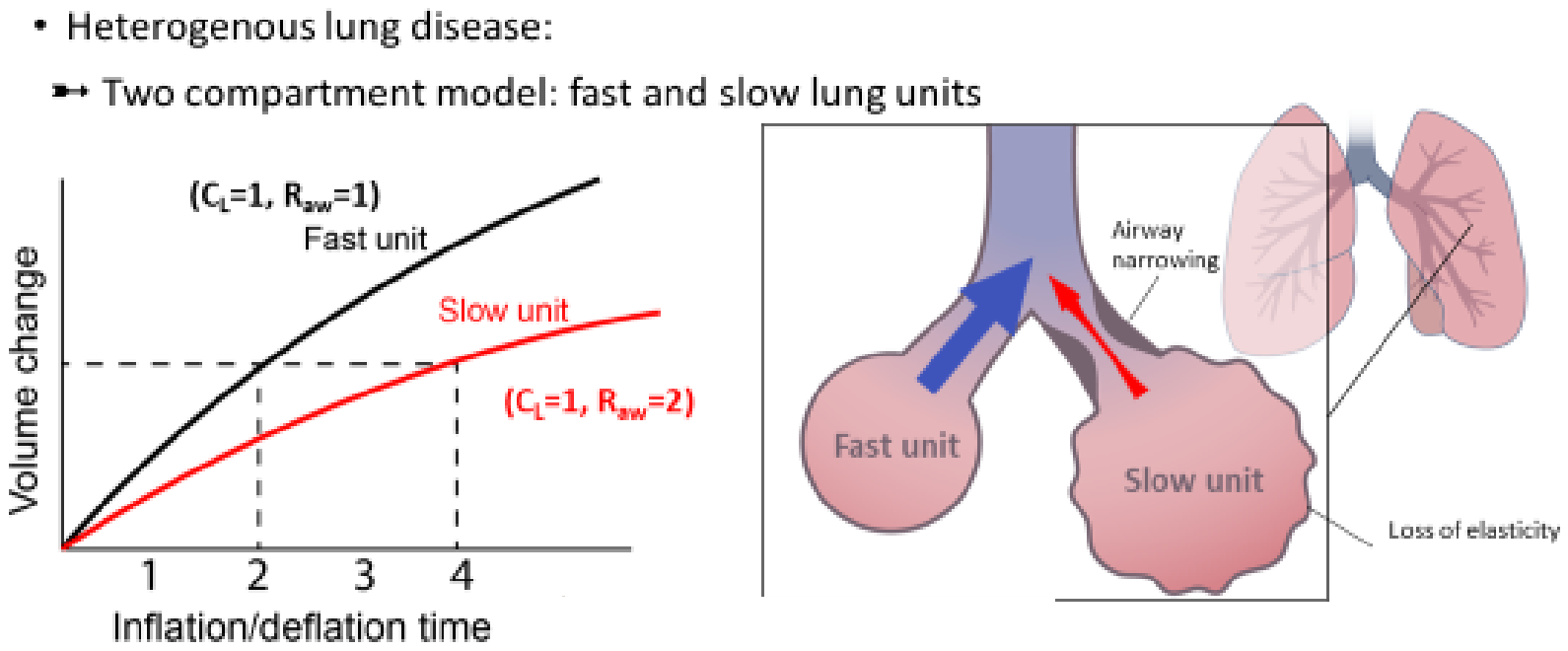
Respiratory Mechanics in Common Neonatal Respiratory Conditions: BPD

- Bronchopulmonary Dysplasia



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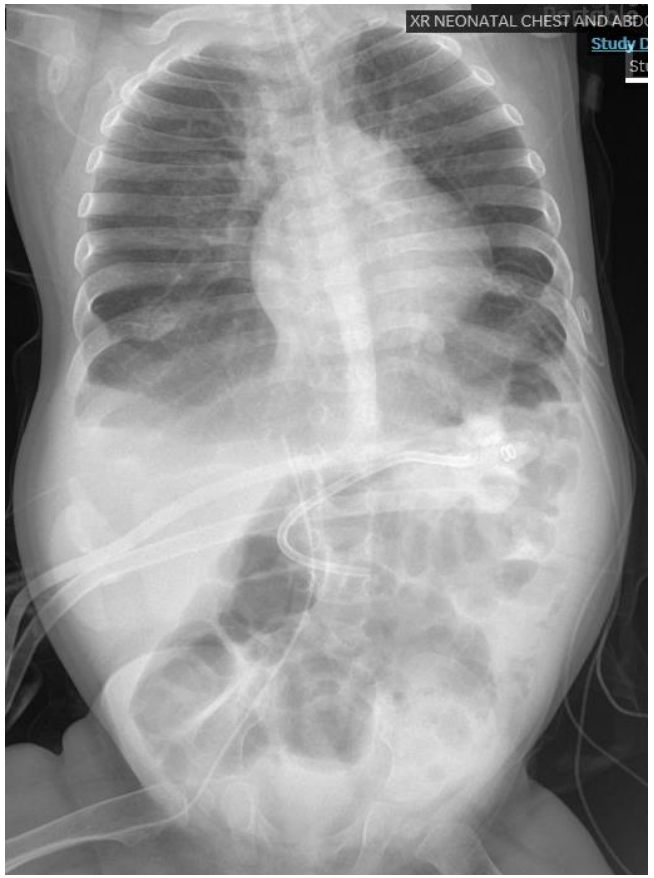
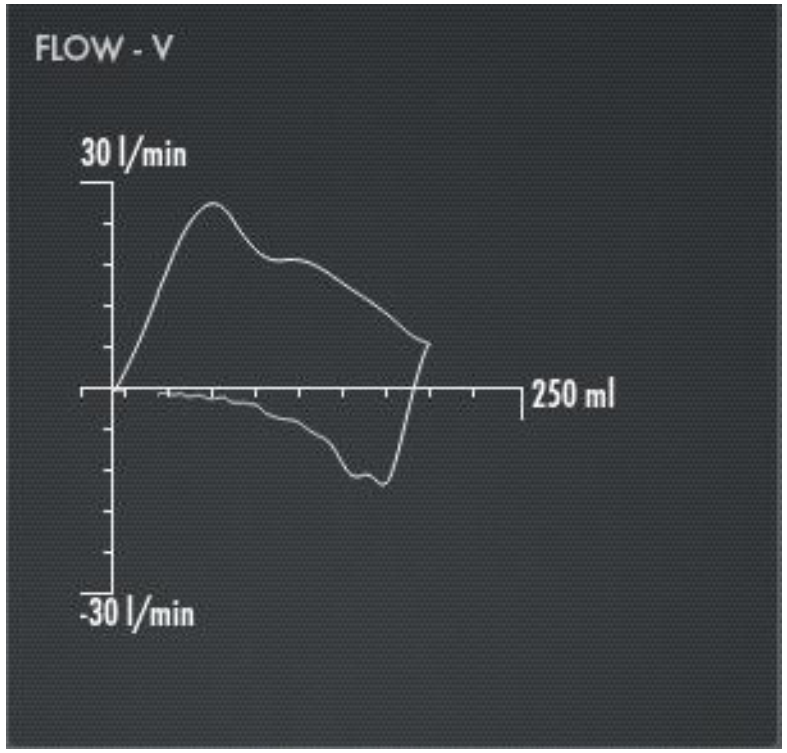
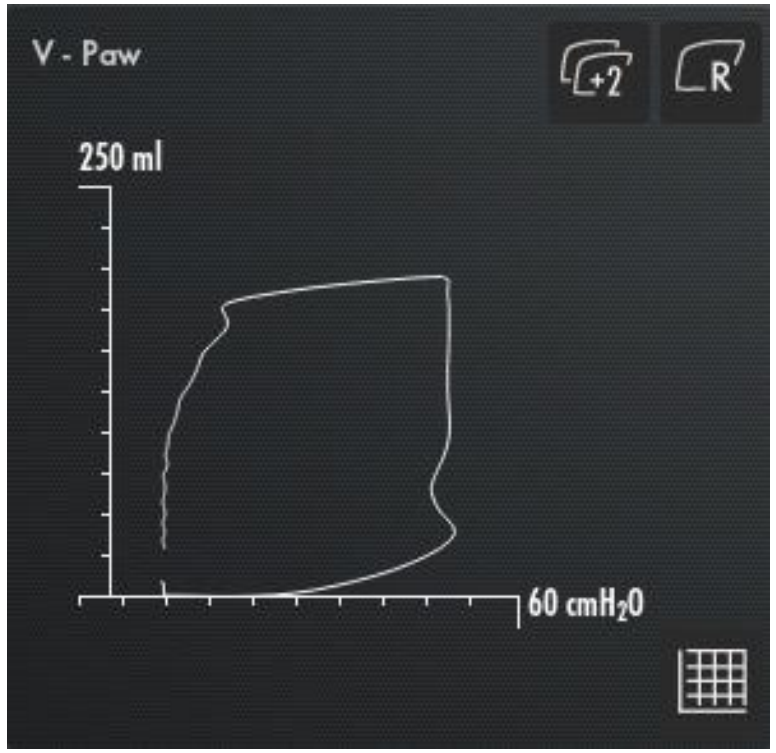
Respiratory Mechanics and Neonatal Lung Disease

Disease	Compliance	Resistance	Time Constant
RDS	Decreased	Normal	Short
MAS	Normal or decreased	Increased	Long
BPD	Normal or Increased	Increased	Long

Respiratory Mechanics in Common Neonatal Respiratory Conditions: BPD







Specific Considerations for Chronic Phase Ventilation in BPD

- Goals of mechanical ventilation in BPD are fundamentally different than the goals of mechanical ventilation in RDS

- RDS – “lung protective strategy”
  - Avoid injury
  - Minimize volutrauma
  - Rapid weaning
  - Extubation ASAP
- BPD – “lung supportive strategy”
  - Support the injured lung
  - Provide adequate ventilation for gas exchange and growth
  - Gradual weaning
  - Extubation when oxygenation and growth at goal

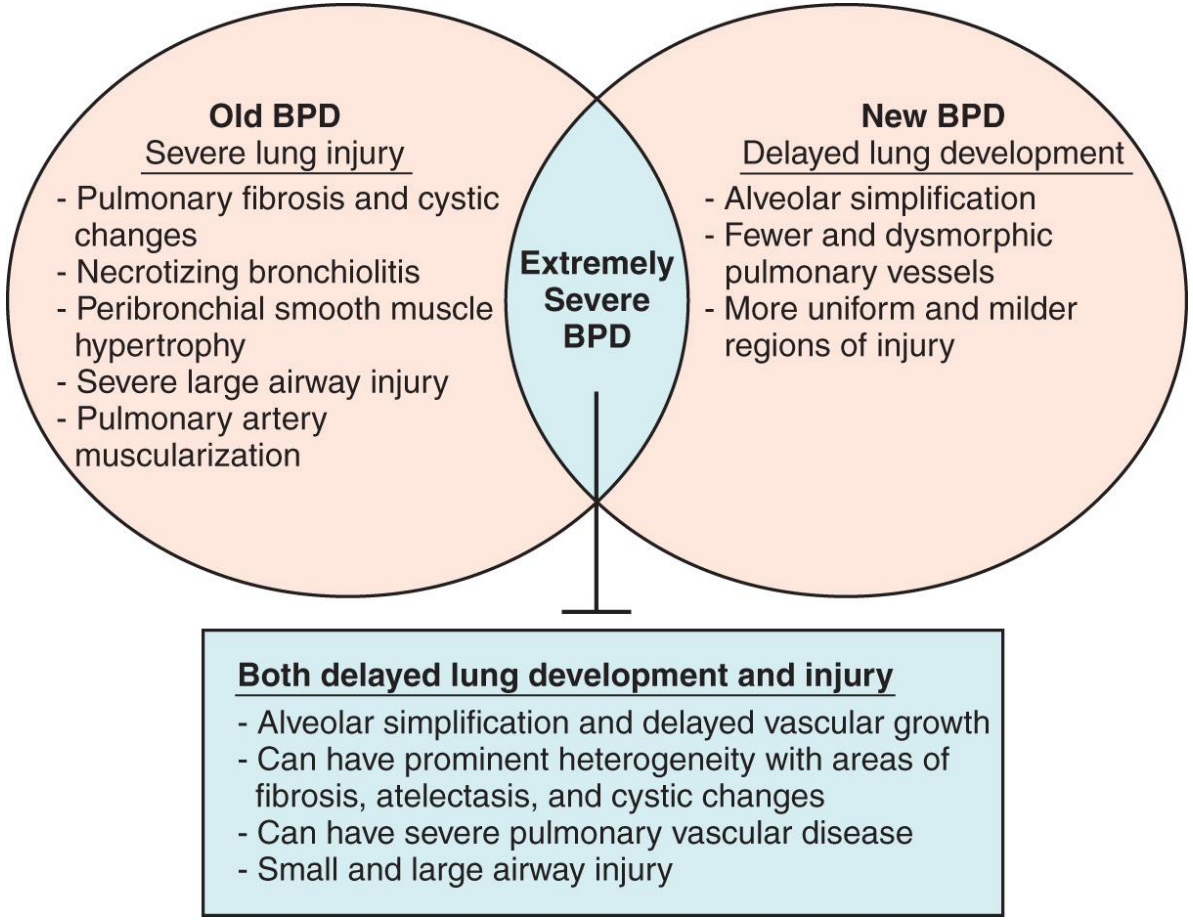
Nelin *et al.*, The Newborn Lung 2018

Comparison of Mechanical Ventilation Strategies

Setting	Lung Protective	Lung Supportive
Pathology	RDS	BPD
Vt	4-6 ml/kg	8-15 ml/kg
PEEP	5-6 cm H_2O	8-14 cm H_2O
Rate	40-60 breaths per minute	10-20 breaths per minute
Ti	0.25-0.35	0.6-1.0

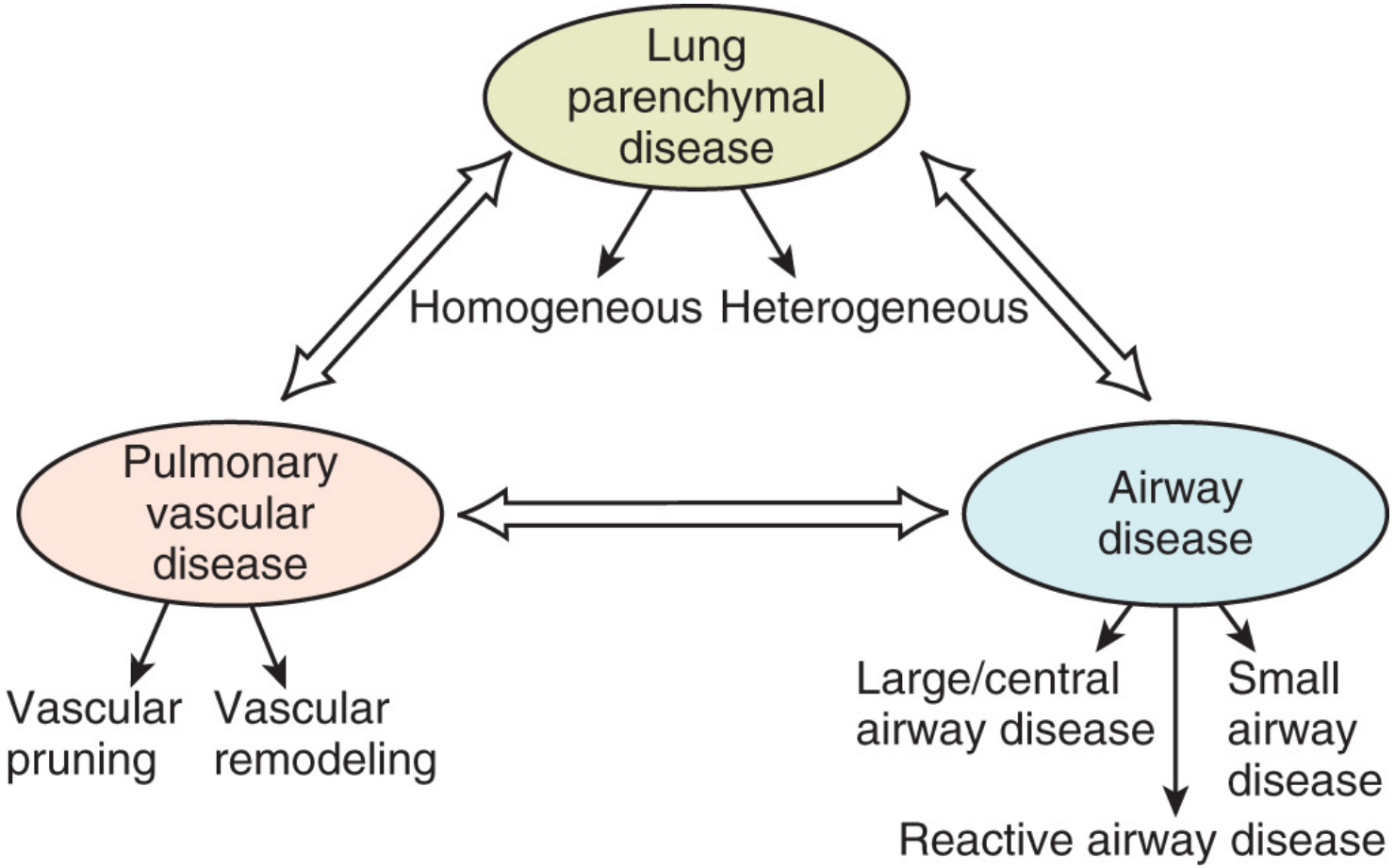
Keszler *et al.*, Assisted Ventilation of the Neonate, 2022

Mechanical Ventilation in Severe BPD



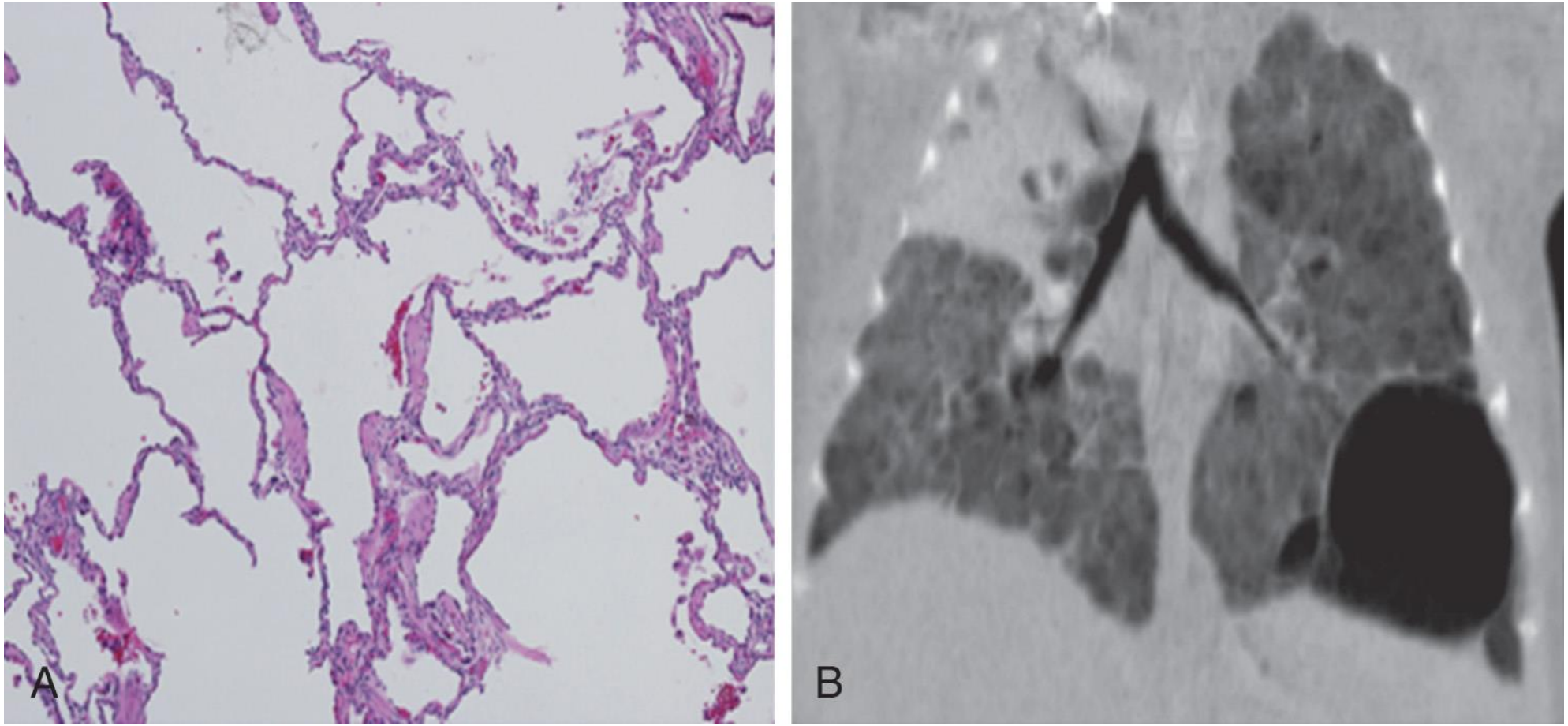
Zhang and Bamat, Assisted Ventilation of the Neonate, 2022

Clinical BPD Phenotypes



Zhang and Bamat, Assisted Ventilation of the Neonate, 2022

Heterogeneity in BPD



Zhang and Bamat, Assisted Ventilation of the Neonate, 2022

Mechanical Ventilation in Patients with BPD

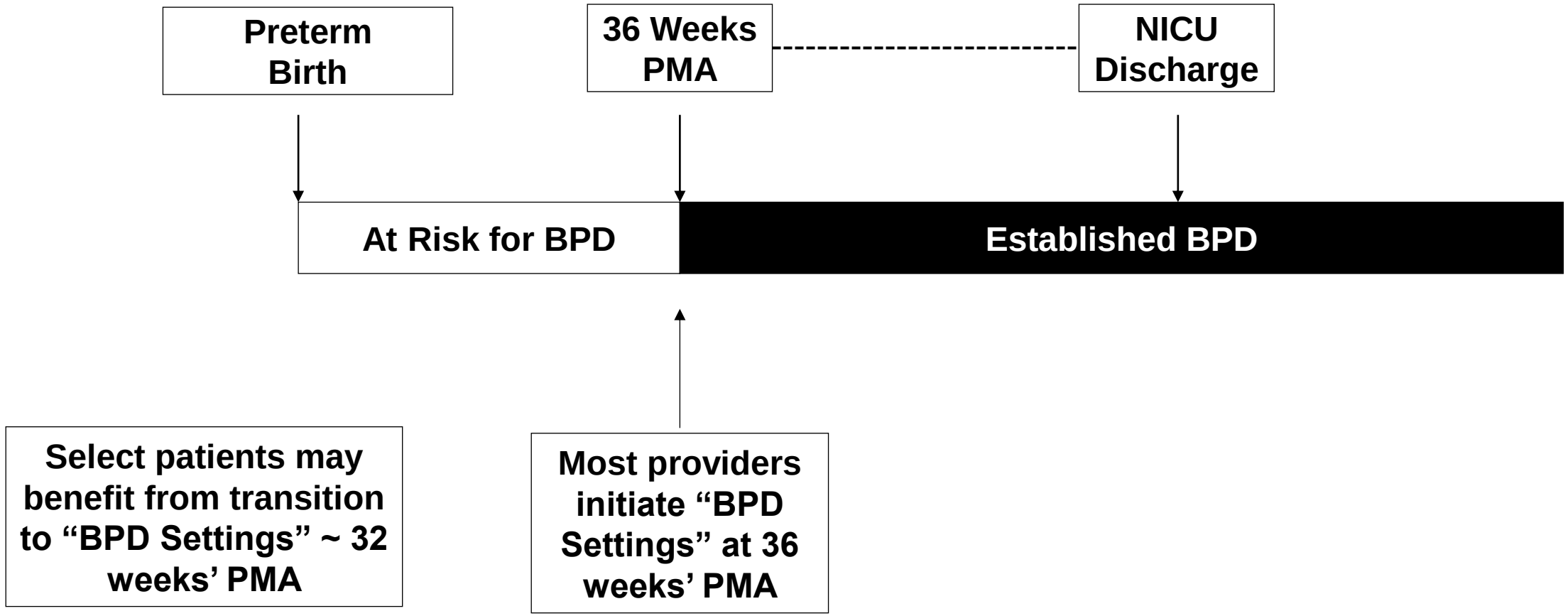
Table 22.1 VENTILATOR STRATEGIES IN BRONCHOPULMONARY DYSPLASIA

Late (established BPD)	Strategies for effective gas exchange: 1. Marked regional heterogeneity: • Larger tidal volumes (10–12 mL/kg) • Longer inspiratory time (≥0.6 s) 2. Airways obstruction: • Slower rates allow better emptying, especially with larger tidal volumes • Complex roles for PEEP with dynamic airway collapse 3. Interactive effects of vent strategies: • Changes in rate, tidal volume, inspiratory and expiratory times, pressure support are highly interdependent • Overdistention can increase agitation and paradoxically worsen ventilation 4. Permissive hypercapnia to facilitate weaning

BPD, Bronchopulmonary dysplasia; F_{IO_2}, fraction of inspired oxygen; *PEEP*, positive end-expiratory pressure.

Nelin *et al.*, The Newborn Lung 2018

When to Transition to “BPD Settings?”



Setting up the Ventilator in SIMV

- **Establish optimal lung volume**
  - May need higher VT of 8–12 mL/kg
  - Provide adequate PEEP (may need PEEP >10–15 cm H 2 O)
  - Adequate PS to support spontaneous breath (maybe as high as the PIP needed on the mandatory vent breath)
- **Promote even distribution of ventilation**
  - Long inspiratory time and expiratory time to adequately ventilate the slow compartments (i-time may be >0.5–0.8 seconds)
  - Low set vent rate (10-20/min) to ensure long enough e-time
  - Adequate PS to help maintain minute ventilation and achieve overall low respiratory rate
- **Maintain open airway**
  - Inspiration phase: enough pressure from both vent breath PIP and PS
  - Exhalation phase: adequate PEEP

Note: Ventilator Modes Were not Created Equal

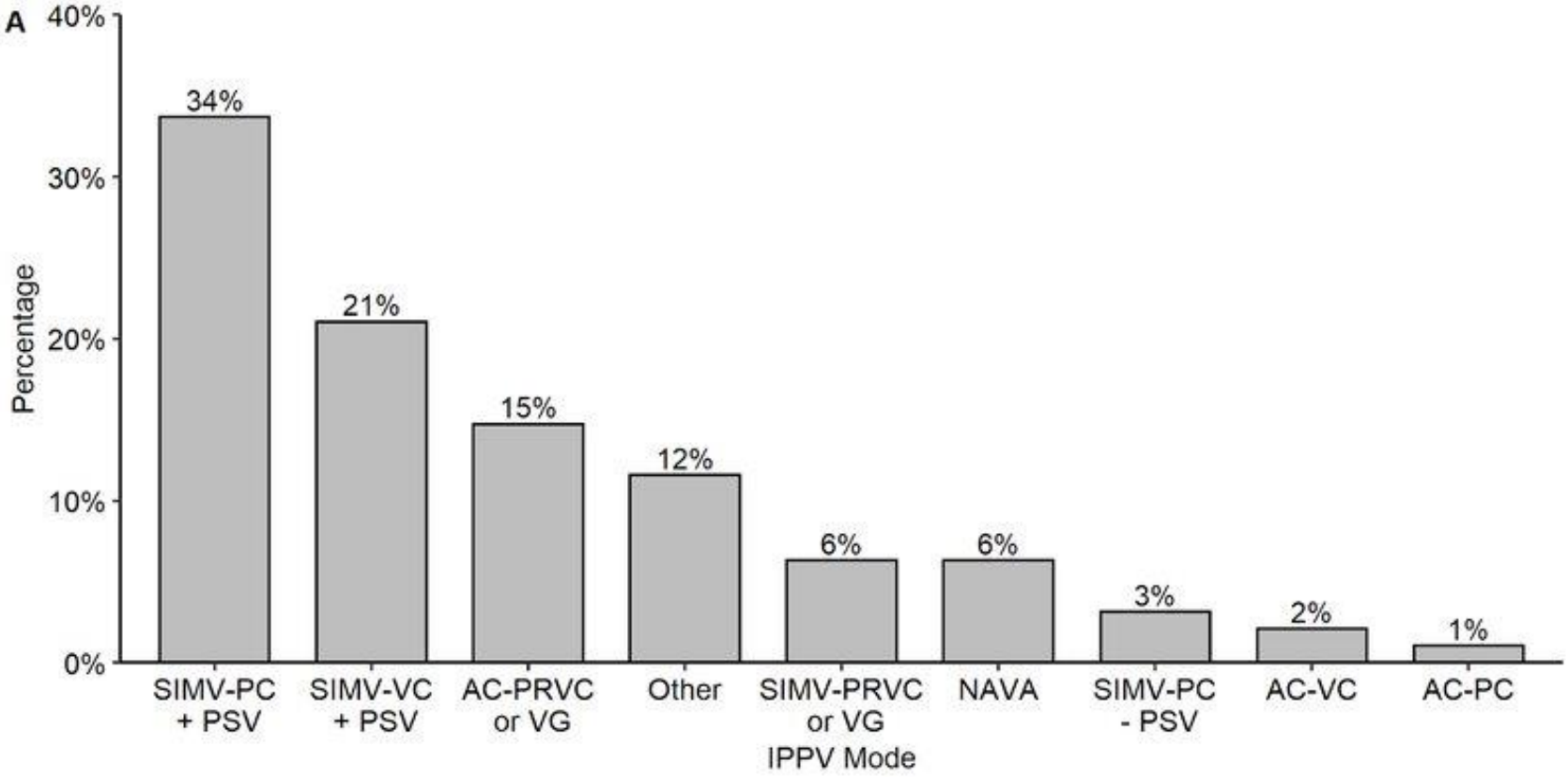
- Assist Control
  - All breaths fully supported
  - Consistent Ti breath-to-breath

- SIMV
  - SIMV breaths may differ from PS breaths
  - Ti varies between SIMV and PS breaths

- “Volume Guarantee”
  - Assist Control
  - Pressure Support

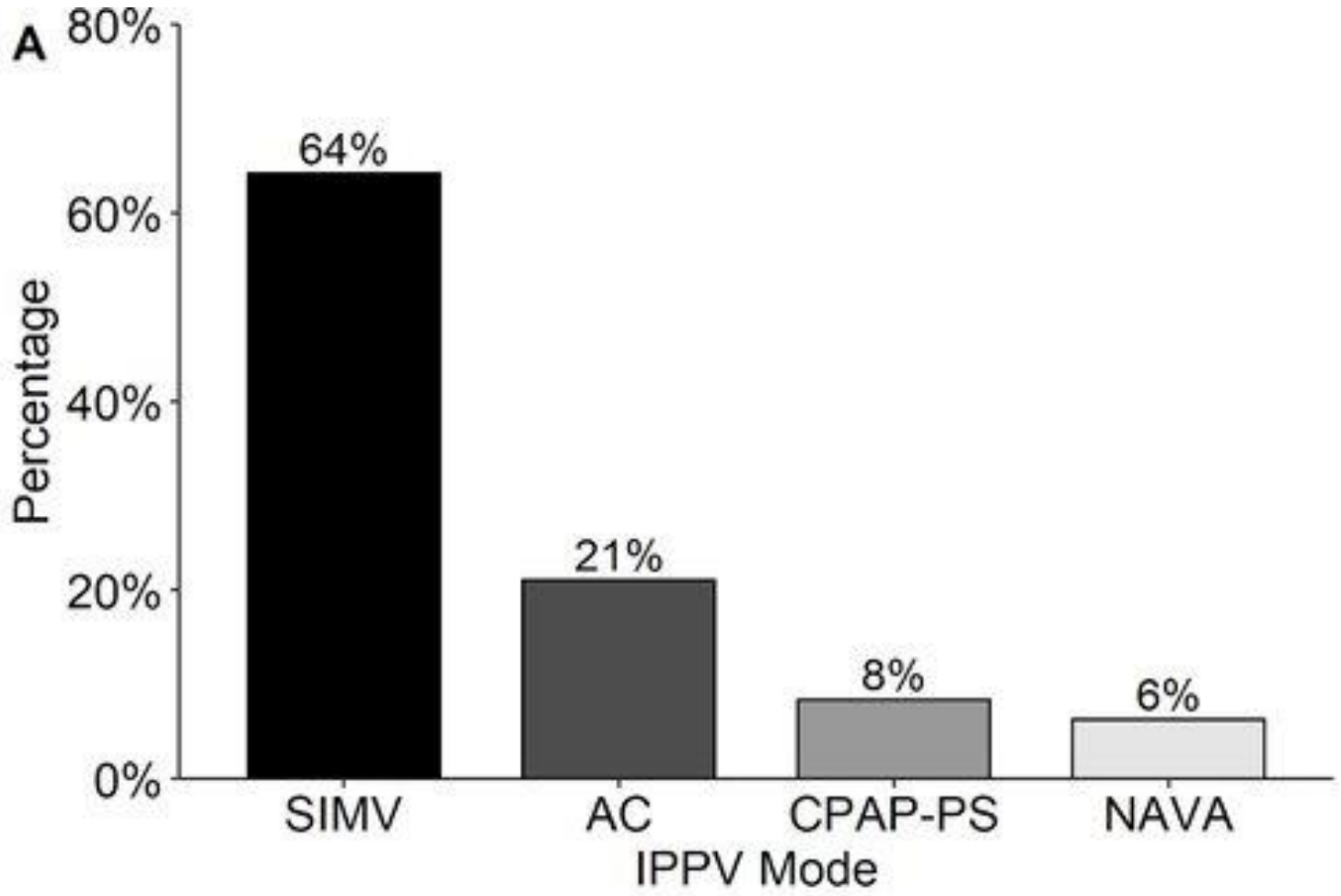
Keszler et al., Assisted Ventilation of the Neonate, 2022

Ventilation Mode Varies Significantly Across BPD Collaborative Centers



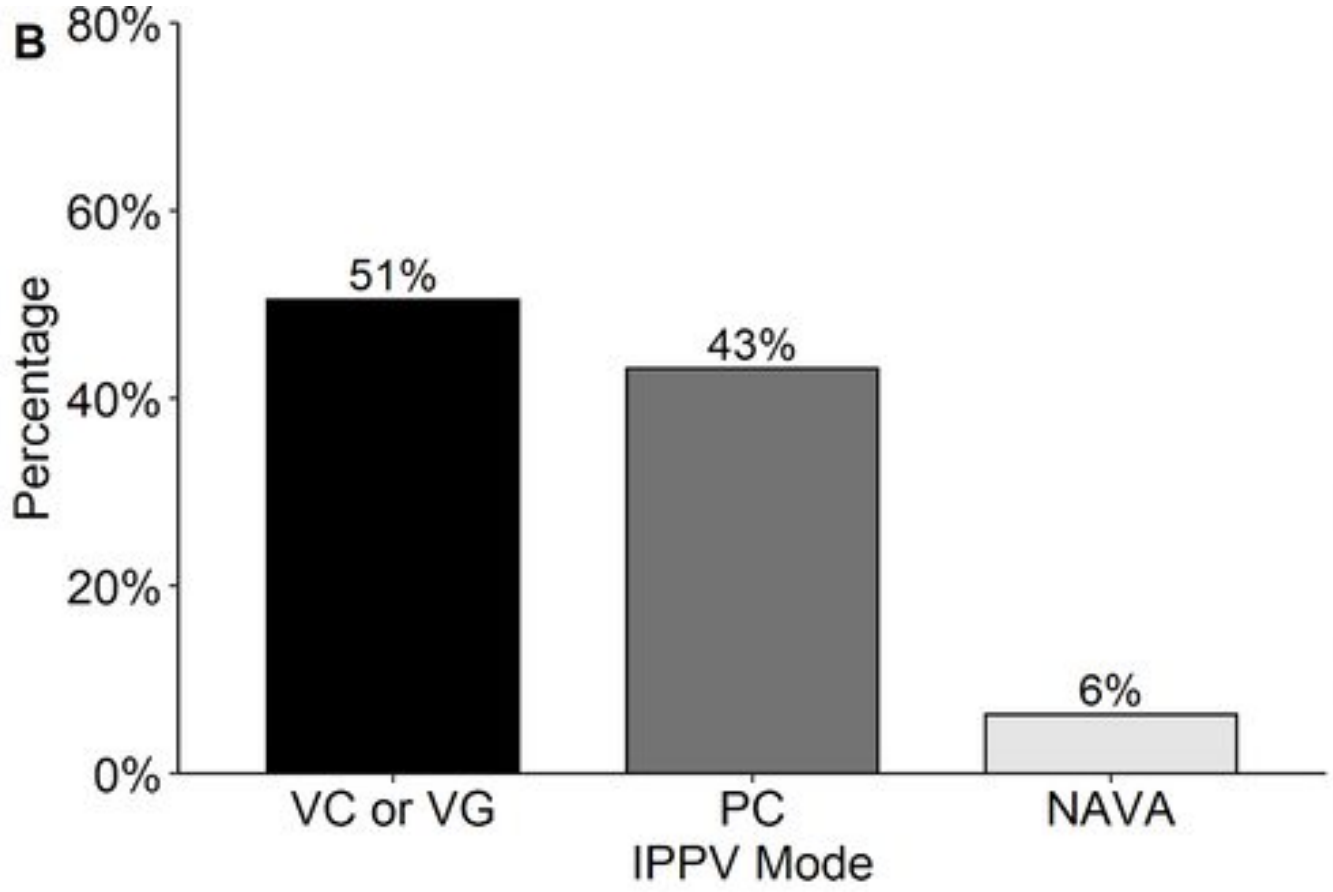
McKinney *et al.*, JPeds 2021

SIMV Is the Most Common Mode Used



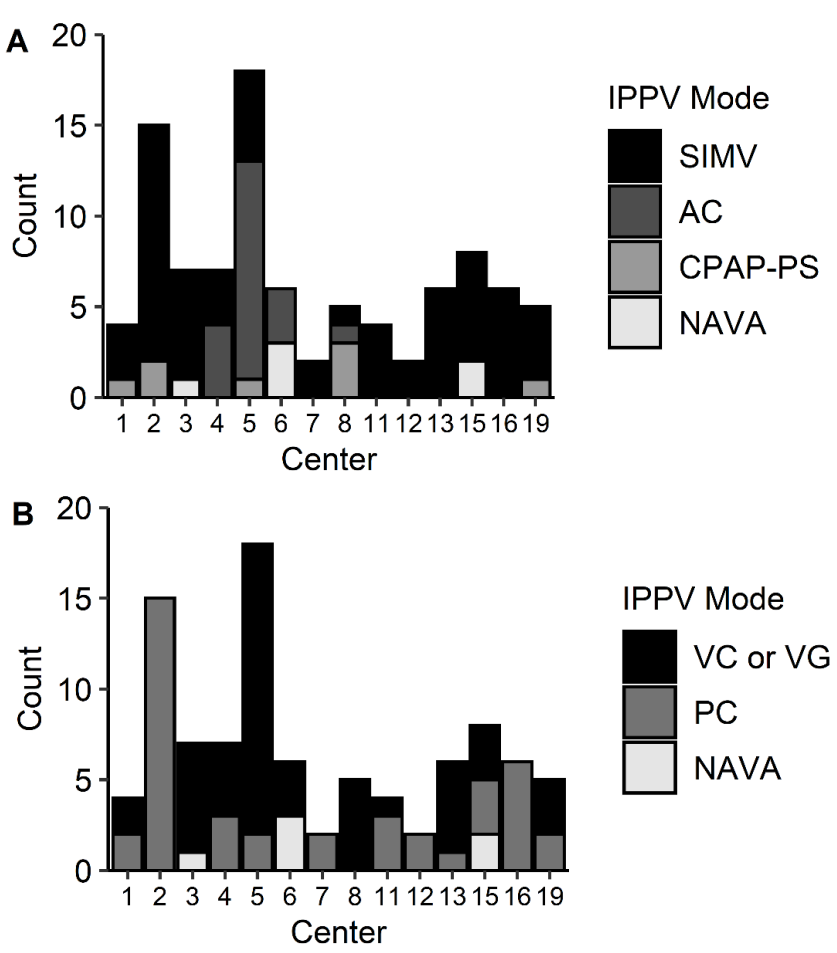
McKinney *et al.*, JPeds 2021

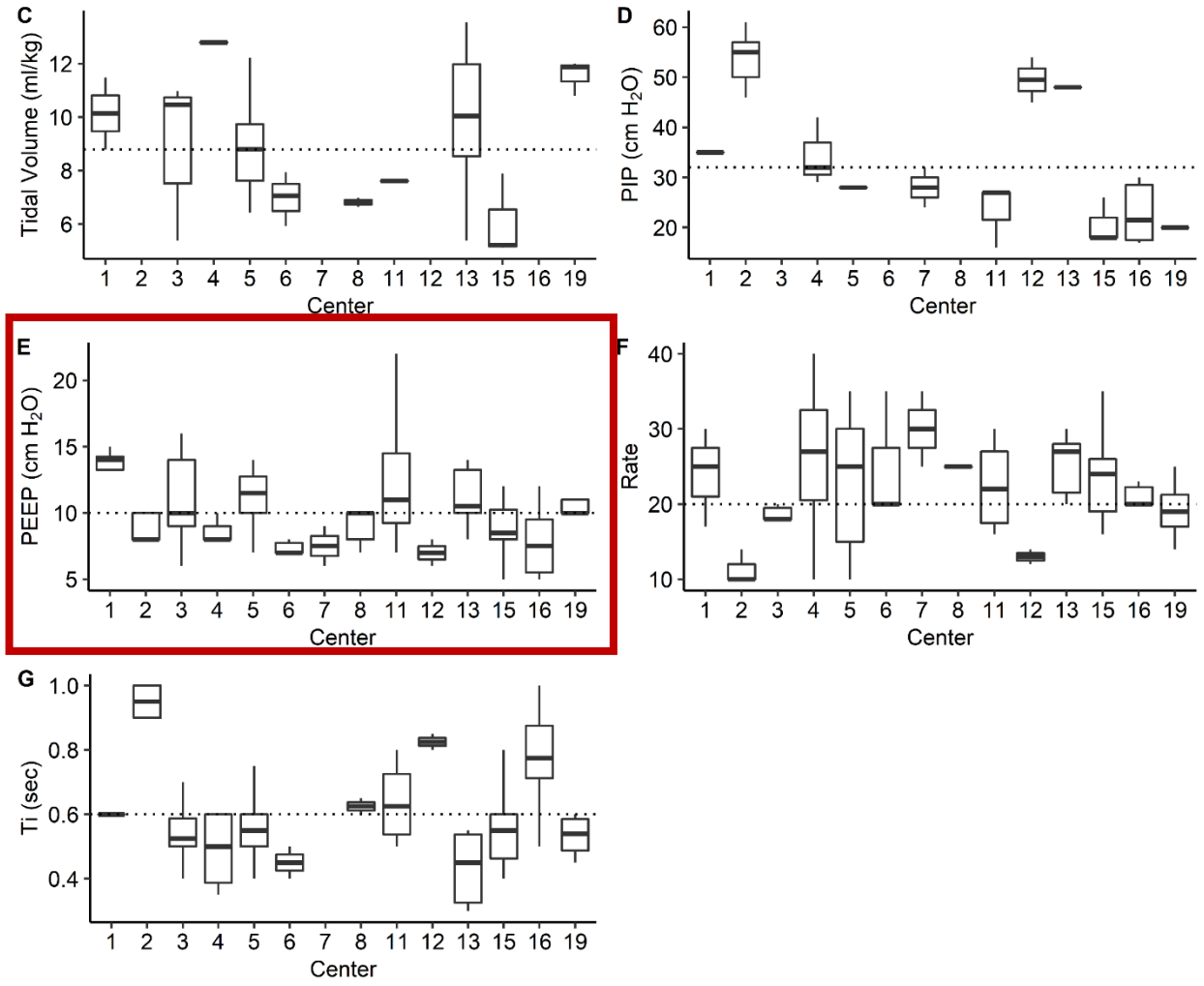
Most Patients Ventilated in Volume Control or Volume Guarantee



McKinney *et al.*, JPeds 2021

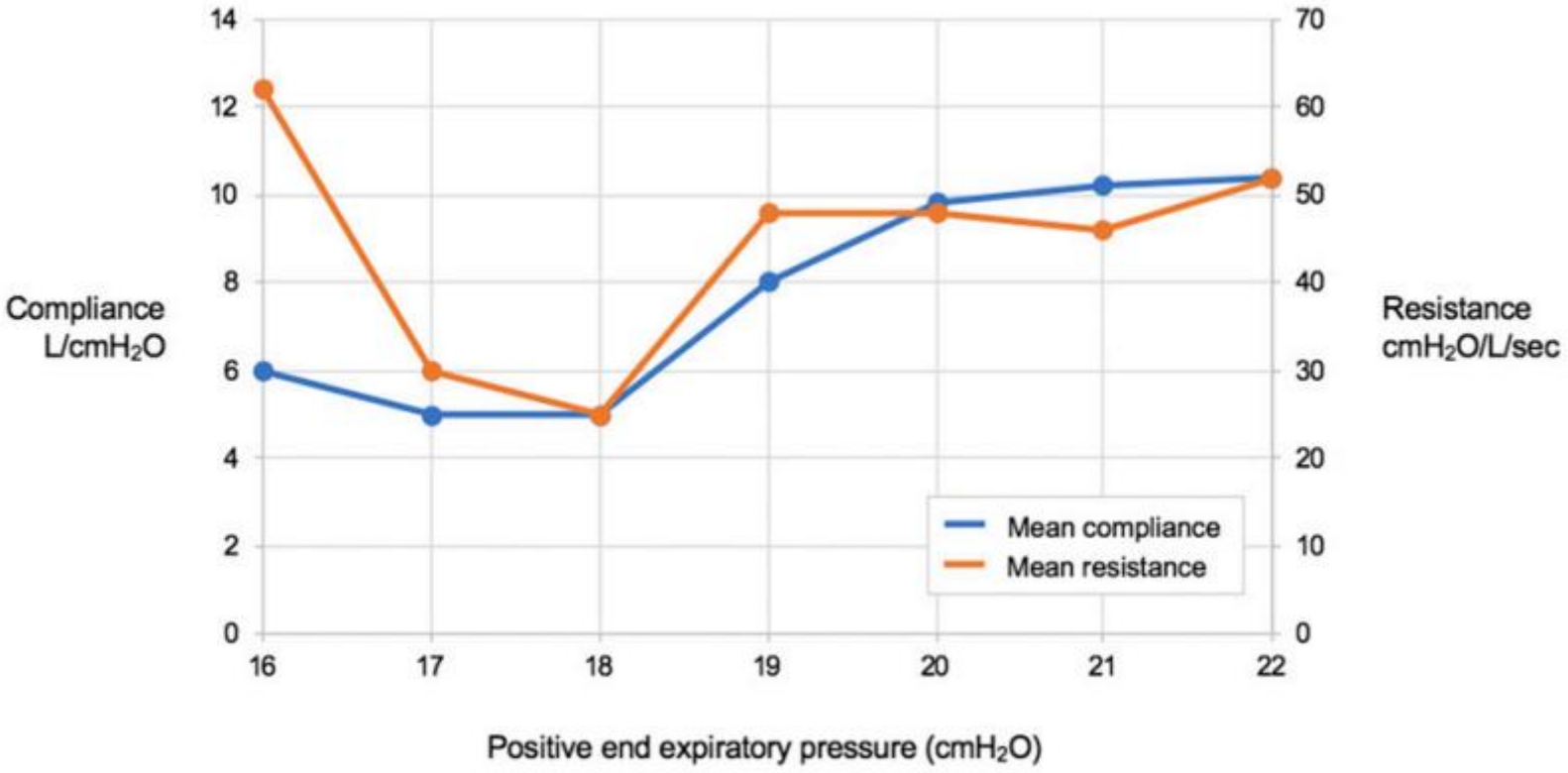
Mode and Settings Varied Significantly By Center





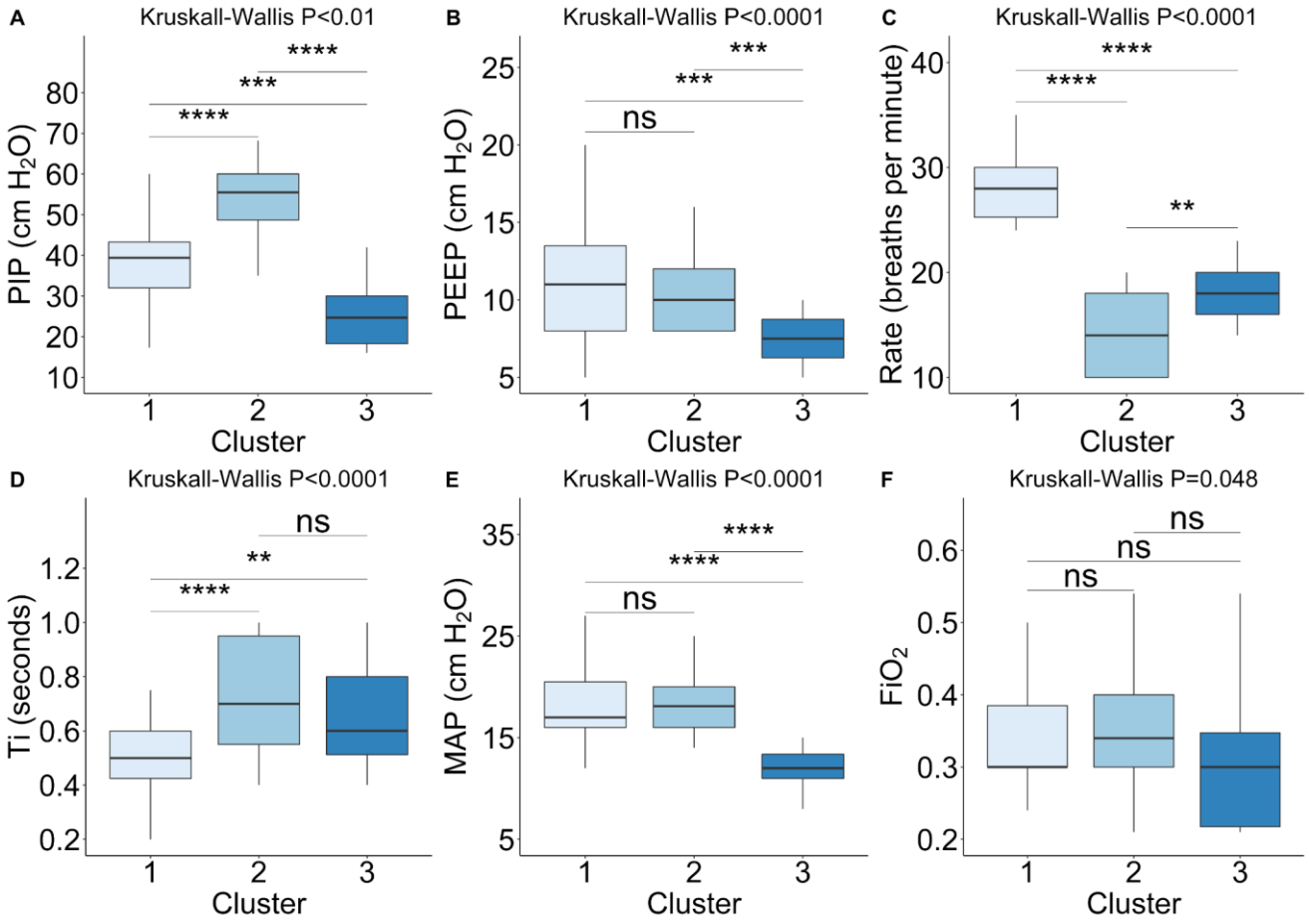
McKinney *et al.*, JPeds 2021

What is the Optimal PEEP?



Gibbs *et al.*, NeoReviews 2020

When Clustering Settings, Three Distinct Approaches Emerge

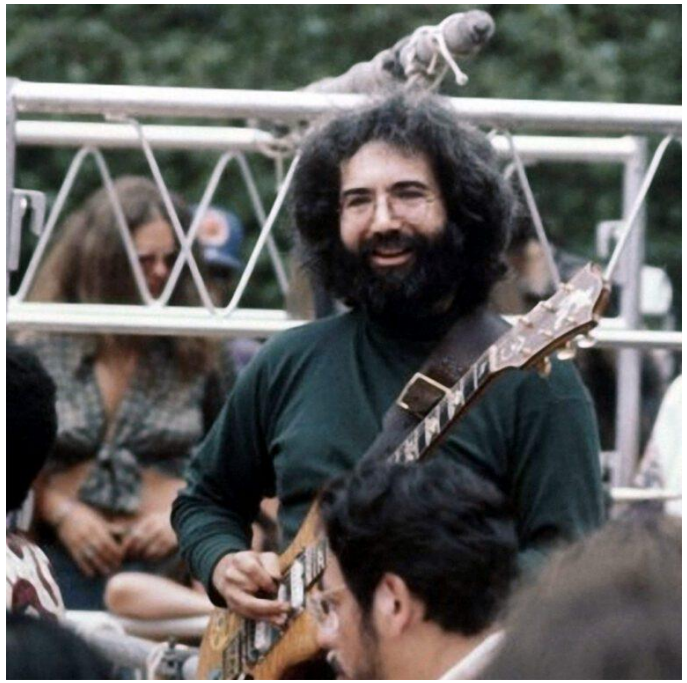


Kielt *et al.*, Pediatric Pulmonology 2020

Take Home Points

- Respiratory mechanics differ between common neonatal respiratory diseases.
- Respiratory mechanics in BPD are characterized by multi-compartment lung model with “slow” and “fast” compartments.
- A lung supportive mechanical ventilation strategy in BPD is characterized by relatively high tidal volumes, low rates, long inspiratory times, and high PEEPs.

Questions



“We're like licorice. Not everybody likes licorice, but the people who like licorice really like licorice.” - Jerry Garcia