Decoding Ventilator Waveforms

Patterns, Problems, and Solutions

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Objectives

Identify normal pressure, volume, and flow waveforms across common modes

Recognize patterns of dyssynchrony and common abnormalities

Interpret waveforms for bedside assessment

Apply troubleshooting strategies in real clinical scenarios

Why Waveforms Matter

- Real-time window into patient–ventilator interaction
- Early detection of complications
- Optimize comfort and lung protection
- Improve outcomes & reduce time on ventilator

Cause and Effect

Table 1. Factors That Affect Patient-Ventilator Synchrony

Ventilator Factors
Trigger variables: esophageal pressure, flow, or shape signal
Sensitivity setting
Rise-time capability
Design, mode, and settings of the flow delivery system
Flow pattern selected
Design of the exhalation valve
How positive end-expiratory pressure is generated by the software
Extraneous flow (eg, from a nebulizer or added oxygen)
Patient Factors
Sedation level: pain, splinting
Inspiratory effort/respiratory drive; neural timing
Pathology of the respiratory system or abdomen; secretions
Intrinsic positive end-expiratory pressure
Size and type of airway
Presence of leaks

Table 2. Deleterious Effects of Patient-Ventilator Asynchrony

Patient fights the ventilator
More sedation required
Higher work of breathing
Muscle damage
Ventilation-perfusion problems
Dynamic hyperinflation
Delayed or prolonged weaning
Longer stay
Higher costs

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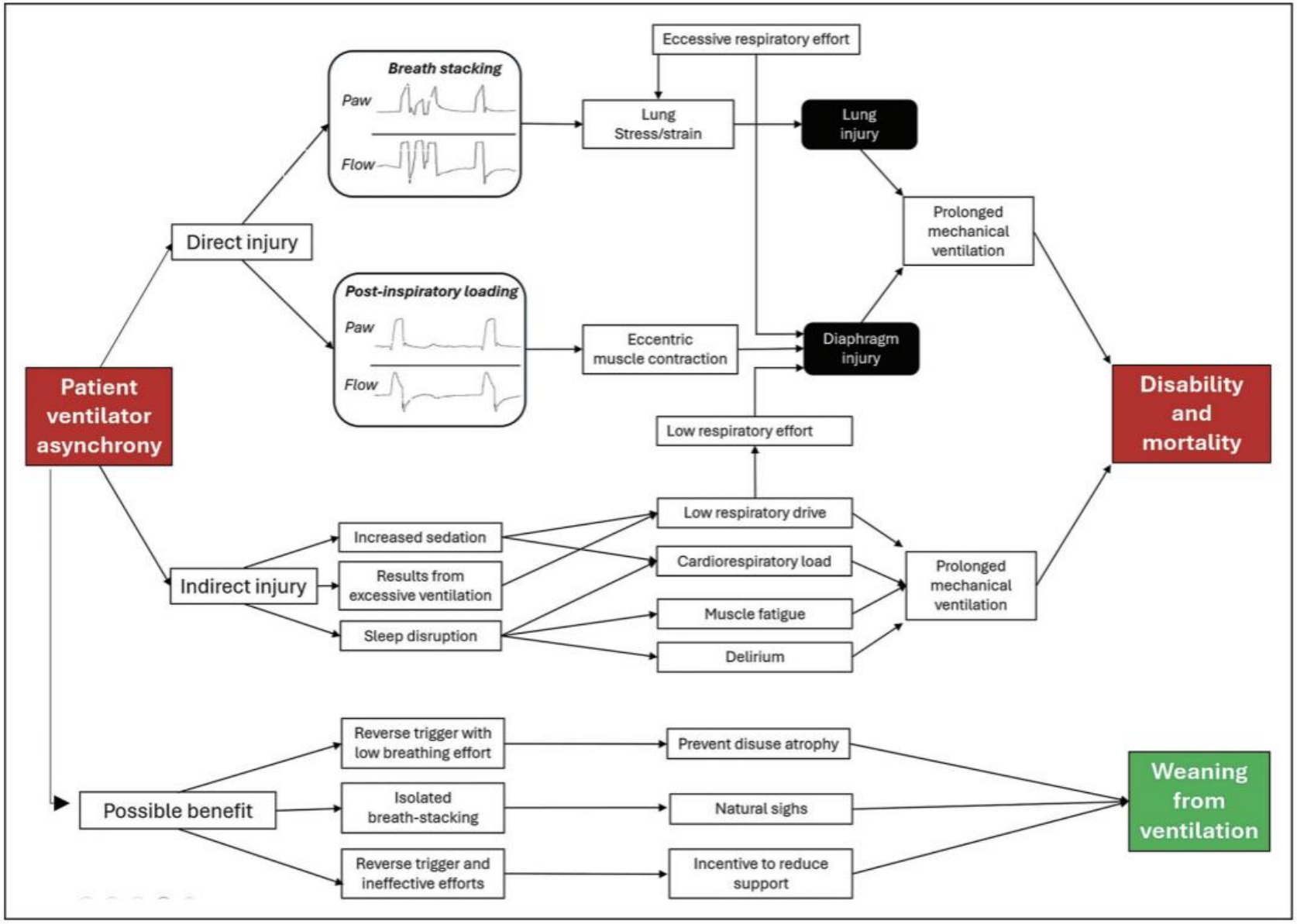
Does Dysynchrony Matter?



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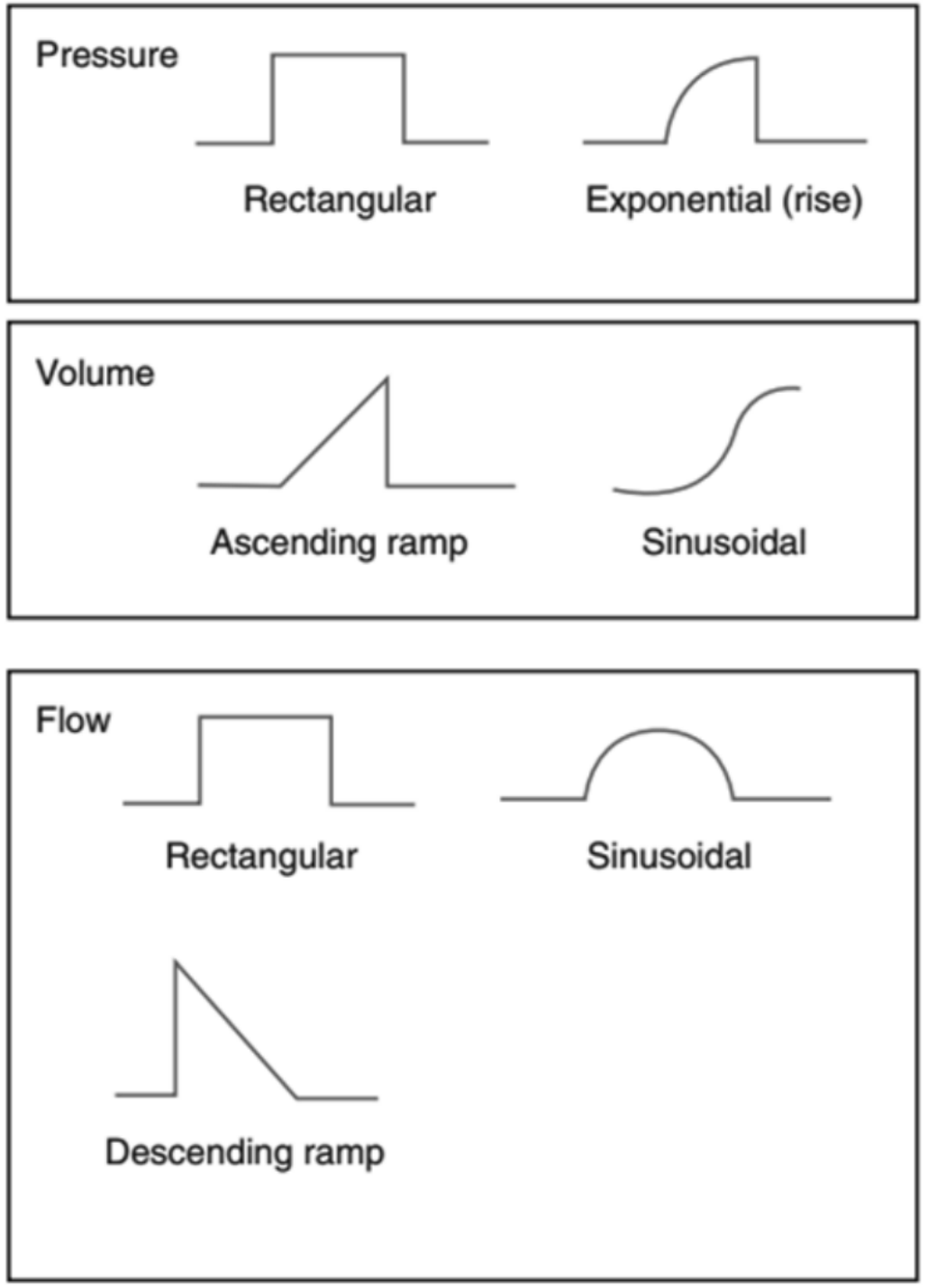
Basic Waveform Types

- Pressure-time waveform
  - Shows airway pressure in cm H_2O
  - Reflects resistance, compliance, and patient effort
- Flow-time waveform
  - Shows gas flow in L/min
  - Positive = inspiration, Negative = expiration
- Volume-time waveform
  - Shows cumulative volume delivered in mL

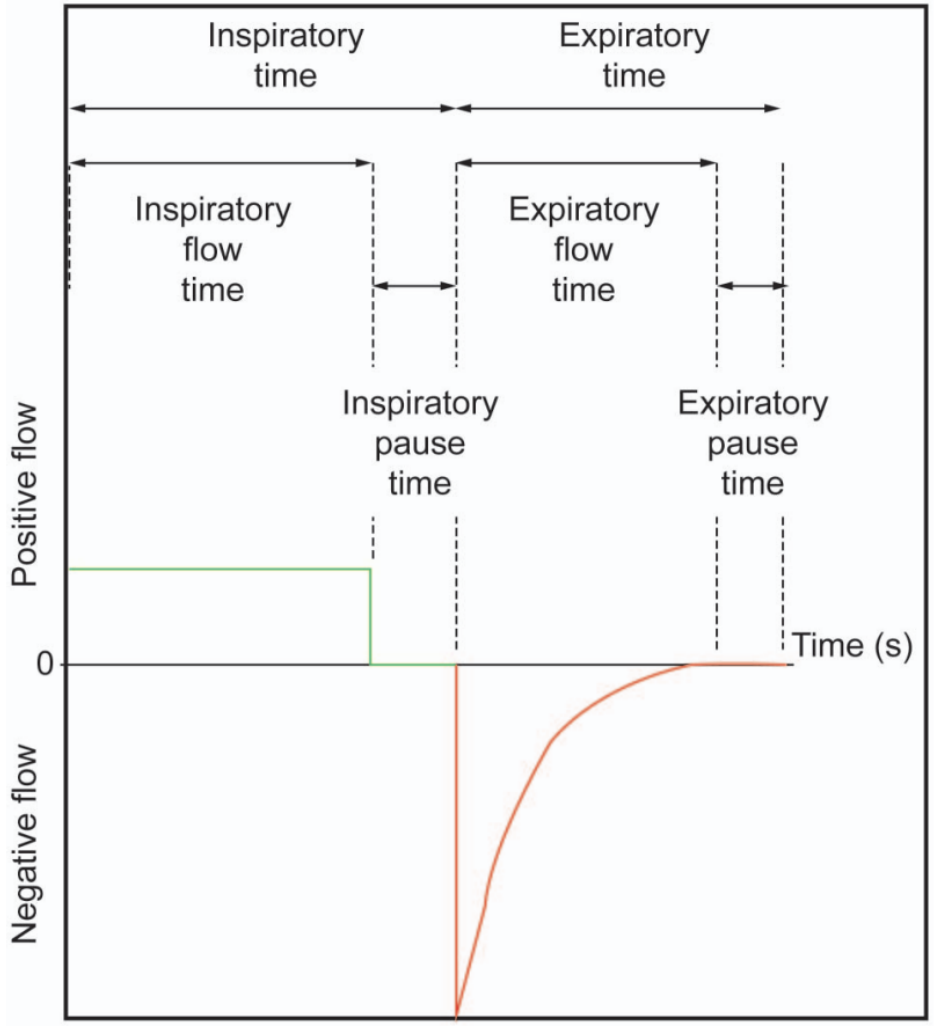


Understanding Trigger-Limit-Cycle

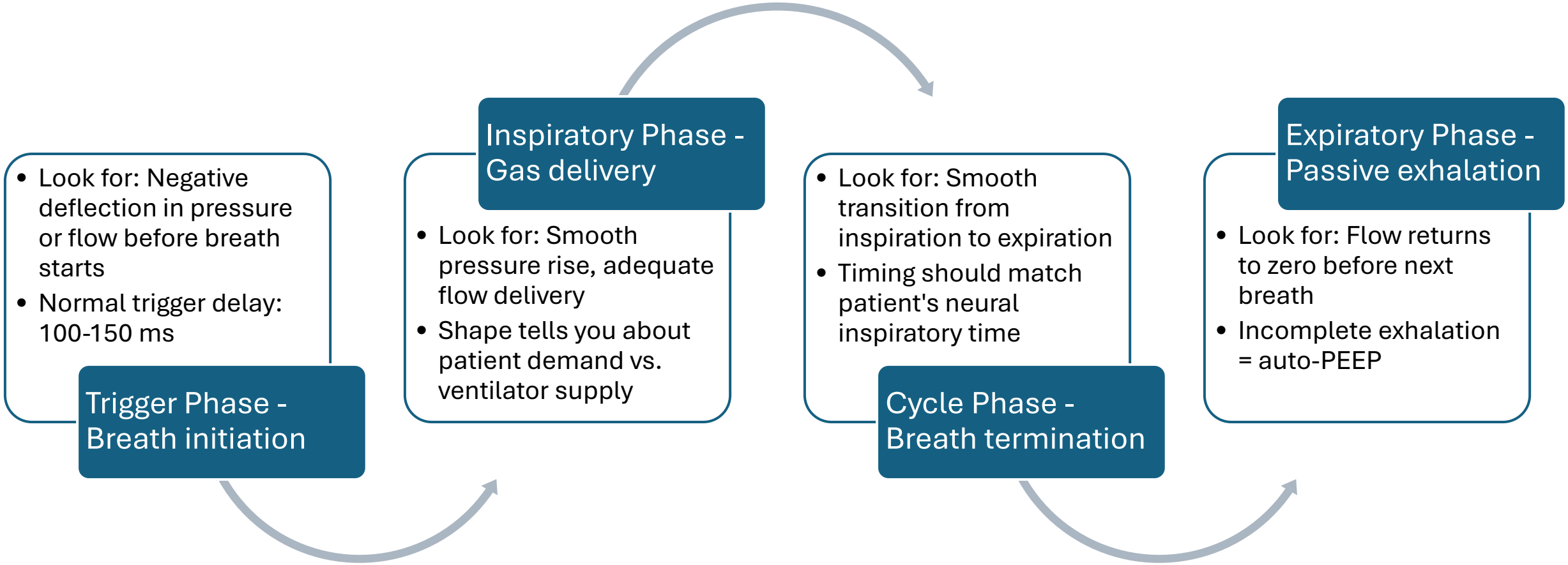
- Trigger - What starts the breath?
  - Time (set rate)
  - Pressure (patient generates -0.5 to -2 cm H_2O)
  - Flow (patient generates 1-5 L/min)
  - Apnea interval

- Limit - What controls gas delivery?
  - Pressure (pressure-control modes)
  - Volume (volume-control modes)
  - Flow (determines delivery pattern)

- Cycling - What ends the breath?
  - Time (pressure-control ventilation)
  - Volume (volume-control ventilation)
  - Flow (pressure-support ventilation, typically 25% of peak flow)



The Four Phases of a Breath



Normal vs. Abnormal

What Normal Looks Like:

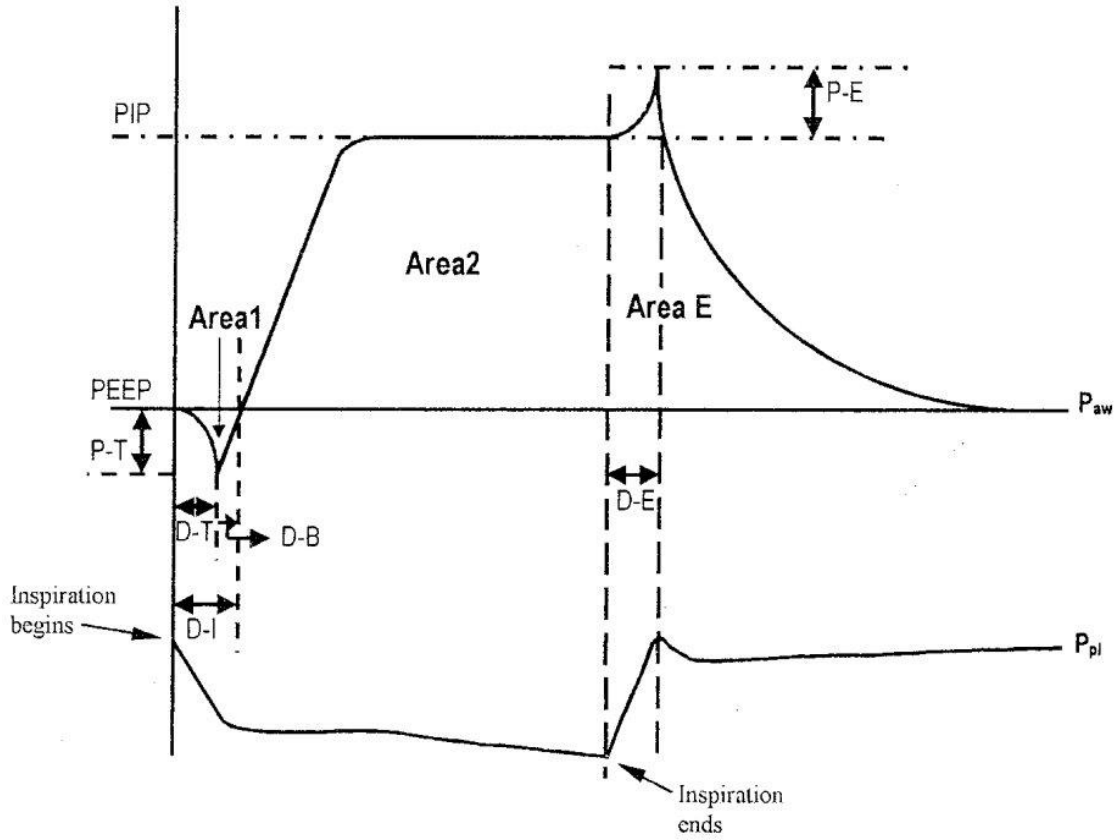
- Smooth pressure rise during inspiration
- Flow returns to zero at end-expiration
- Regular respiratory rate
- Consistent tidal volumes
- Patient and ventilator working together

Red Flags for Asynchrony:

- Scooped or concave pressure waveform
- Flow not returning to zero
- Irregular breathing pattern
- Pressure "bumps" during expiration
- Extra breaths or missed efforts

Asynchrony Overview

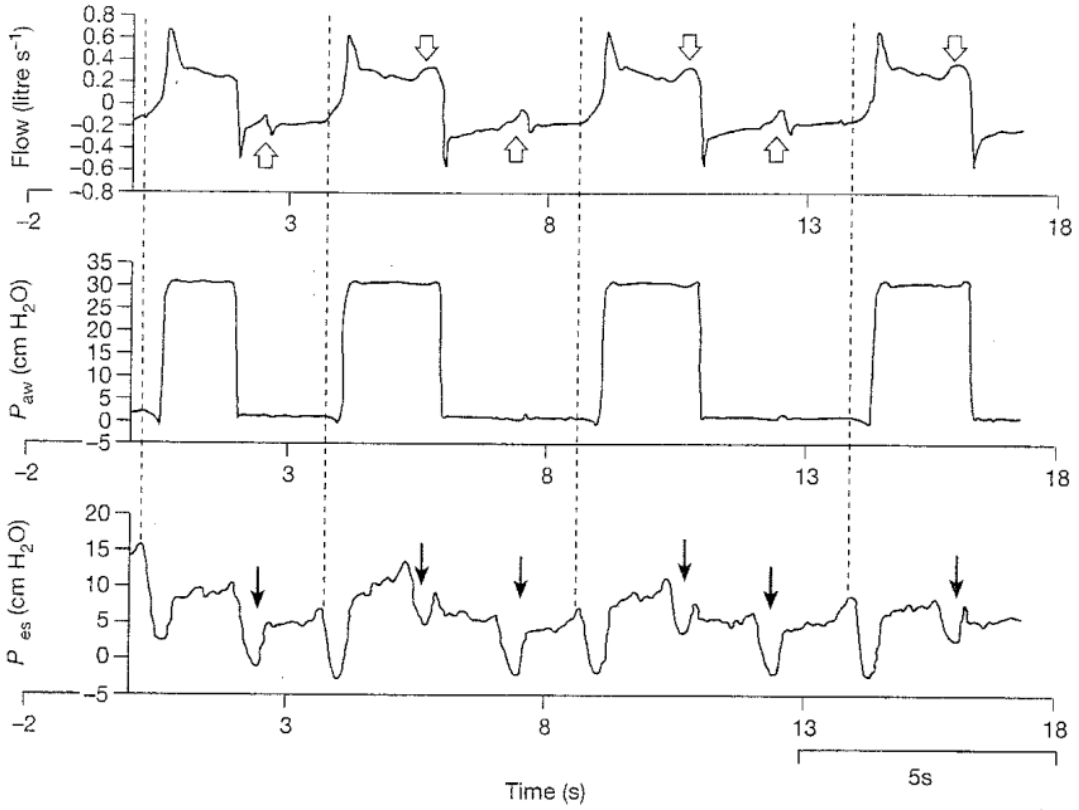
- Trigger Asynchronies:
  - Ineffective triggering (missed efforts)
  - Double triggering
  - Auto-triggering
  - Reverse triggering
- Flow Asynchrony:
  - Flow starvation (inadequate flow)
- Cycling Asynchronies:
  - Premature cycling
  - Delayed cycling



Case 1

- 68-year-old male with COPD exacerbation
- Intubated 24 hours ago
- Mode: Pressure Support 8/PEEP 5
- Patient appears uncomfortable, using accessory muscles
- Respiratory rate 28

Ineffective Triggering - The Missed Effort



- Waveform Characteristics:
  - Small negative deflection in pressure waveform (without breath delivery)
  - Small positive deflection in flow waveform (without breath delivery)
  - Effort "disappears" without ventilator response
- Common Causes:
  - Over-assistance (excessive pressure support)
  - Auto-PEEP (patient must overcome intrinsic PEEP to trigger)
  - Trigger sensitivity set too low
  - Weak inspiratory effort

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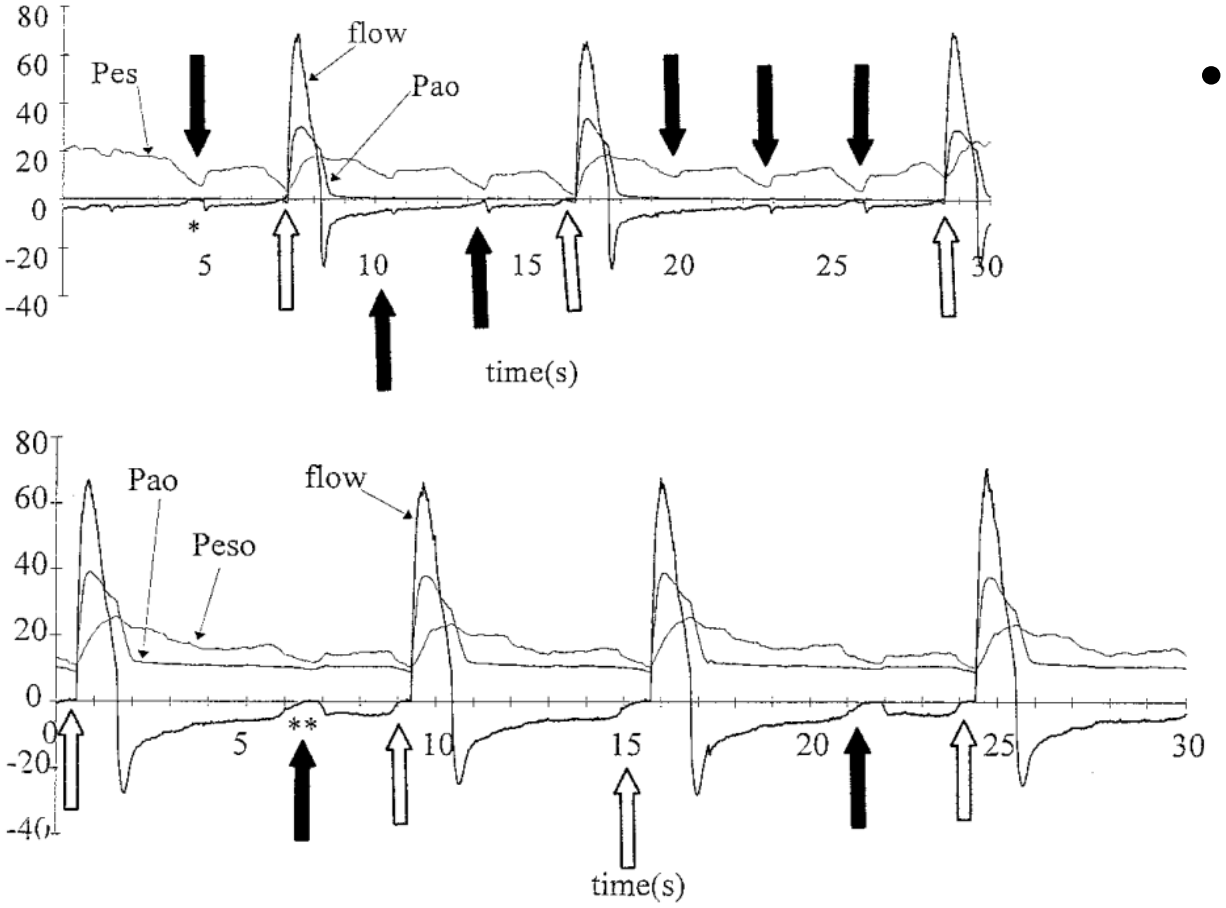
Ineffective Triggering - The Missed Effort



- Clinical Significance:
  - Indicates ventilator over-assistance OR increased work of breathing
  - Associated with longer ventilation duration
  - May indicate need to reduce support or address auto-PEEP
  - May benefit from adding PEEP

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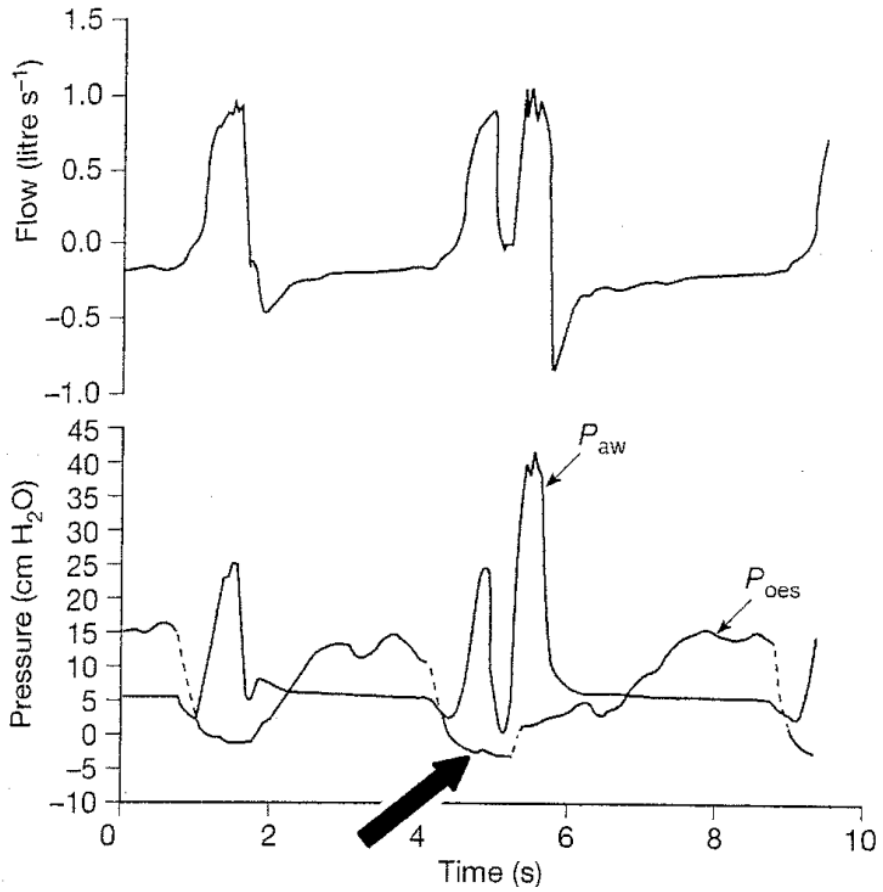
Double Triggering - Two Breaths for One Effort



- Waveform Characteristics:
  - Two complete breath cycles with very short expiratory time between them (50% of average inspiratory time)
  - Expiratory flow does not return to zero between breaths
  - Results in delivery of excessive tidal volume (can exceed 10 mL/kg)
- Common Causes:
  - Insufficient inspiratory time (patient's neural Ti > ventilator Ti)
  - Inadequate tidal volume or pressure support
  - High respiratory drive
  - Common in ARDS patients

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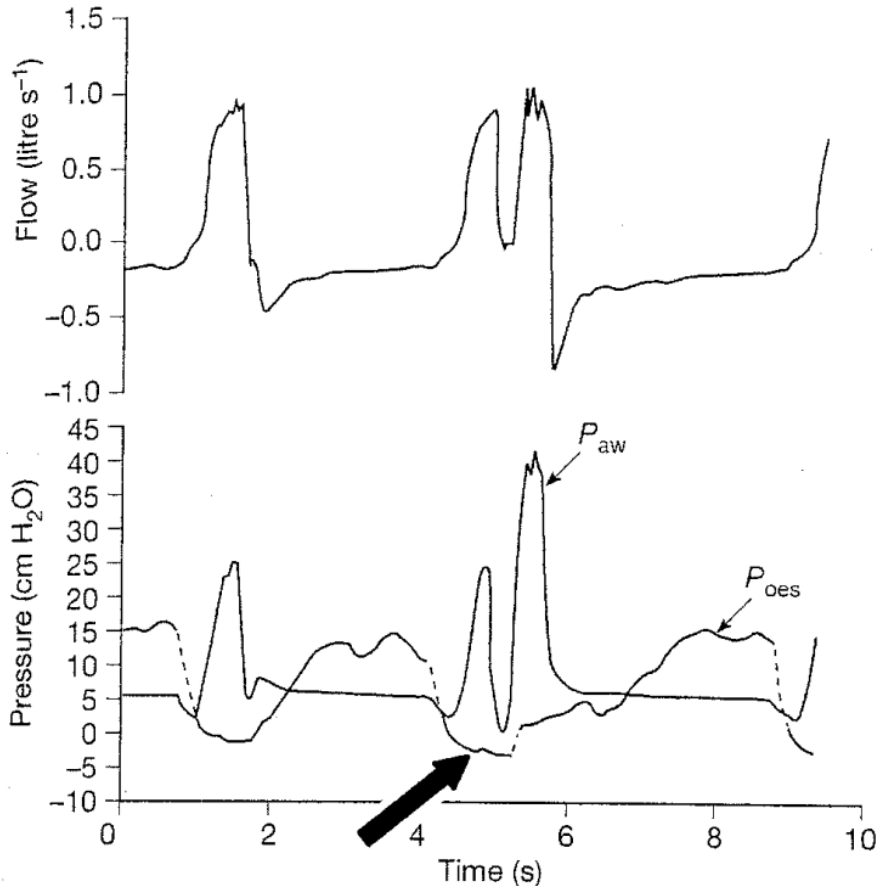
Double Triggering - Two Breaths for One Effort



- Clinical Significance:
  - MOST clinically relevant asynchrony
  - Delivers dangerously high tidal volumes (risk of volutrauma)
  - 40% of double-triggered breaths deliver >10 mL/kg
  - Associated with worse outcomes and longer ventilation

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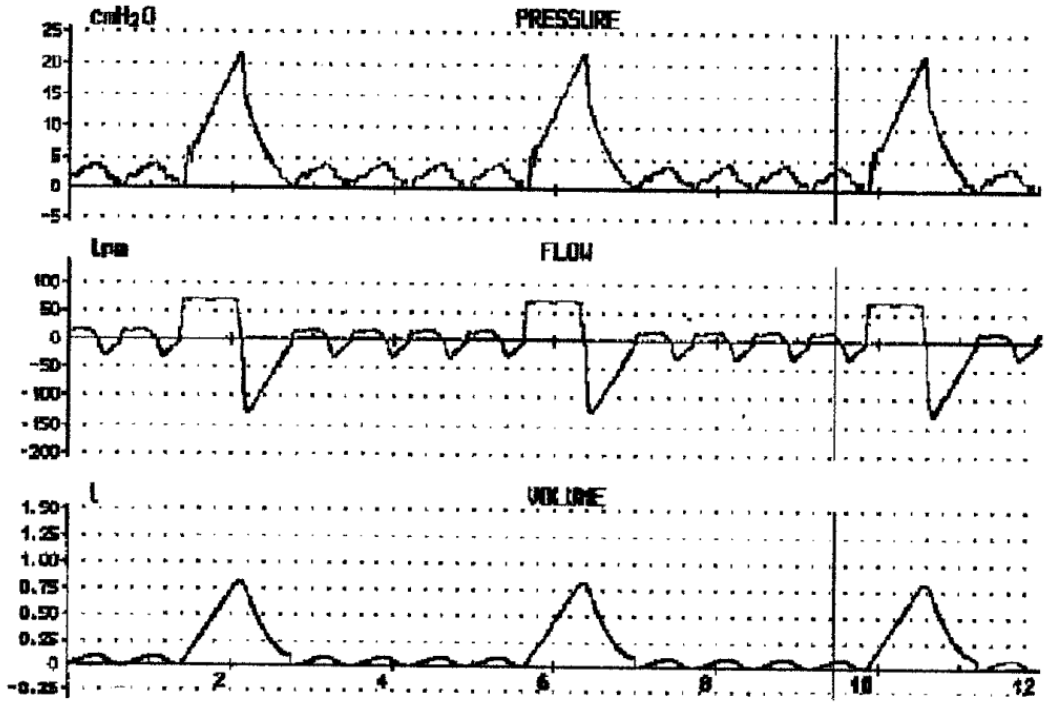
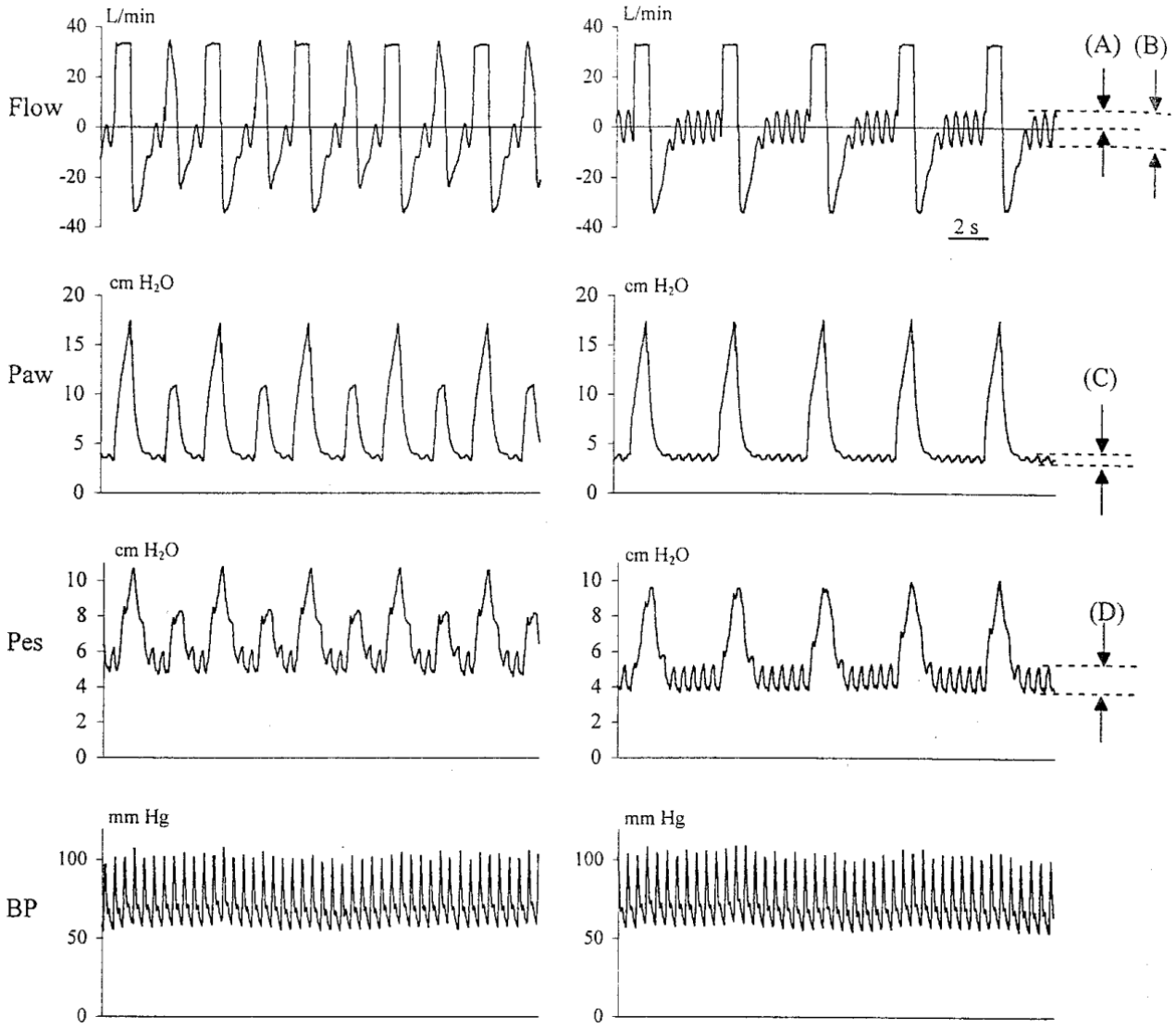
Auto-Triggering - Breaths Without Effort



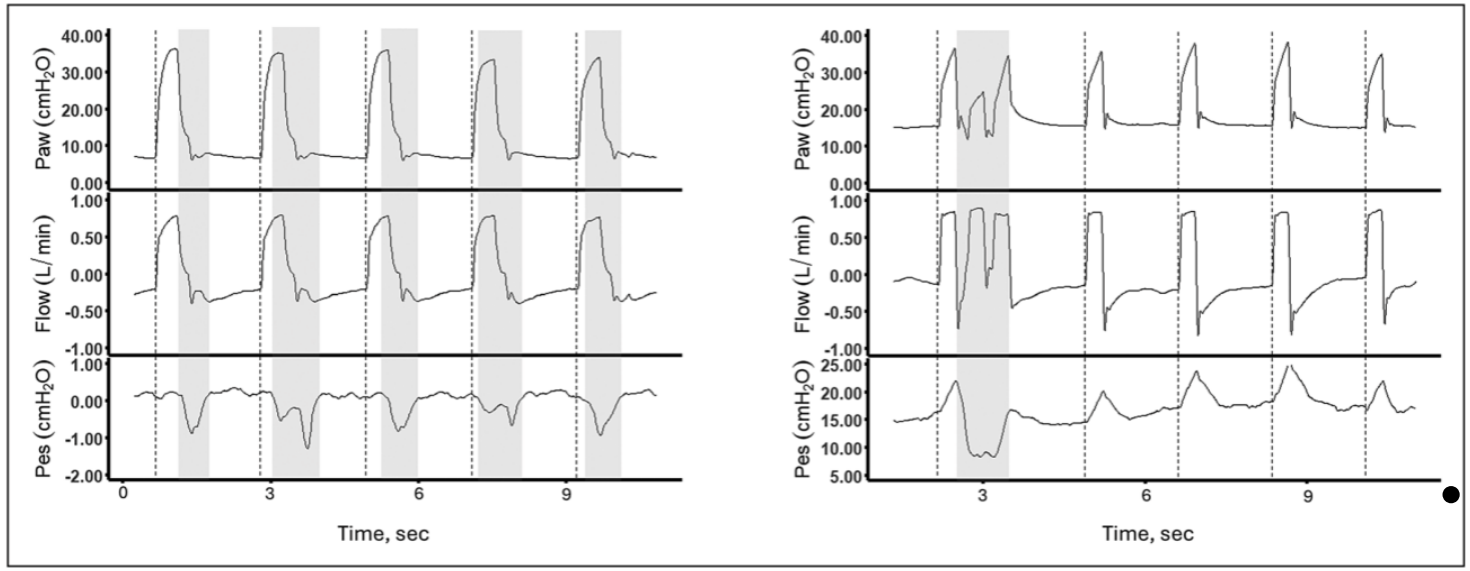
- Waveform Characteristics:
  - Breath delivered without preceding negative pressure or flow deflection
  - Regular pattern of "extra" breaths
  - May see small oscillations in baseline corresponding to heart rate
- Common Causes:
  - Trigger sensitivity set too high (too sensitive)
  - Cardiogenic oscillations
  - Circuit leaks
  - Water in circuit
  - Rarely: brain death (no neural drive, but cardiac oscillations trigger)

Auto-Triggering - Breaths Without Effort



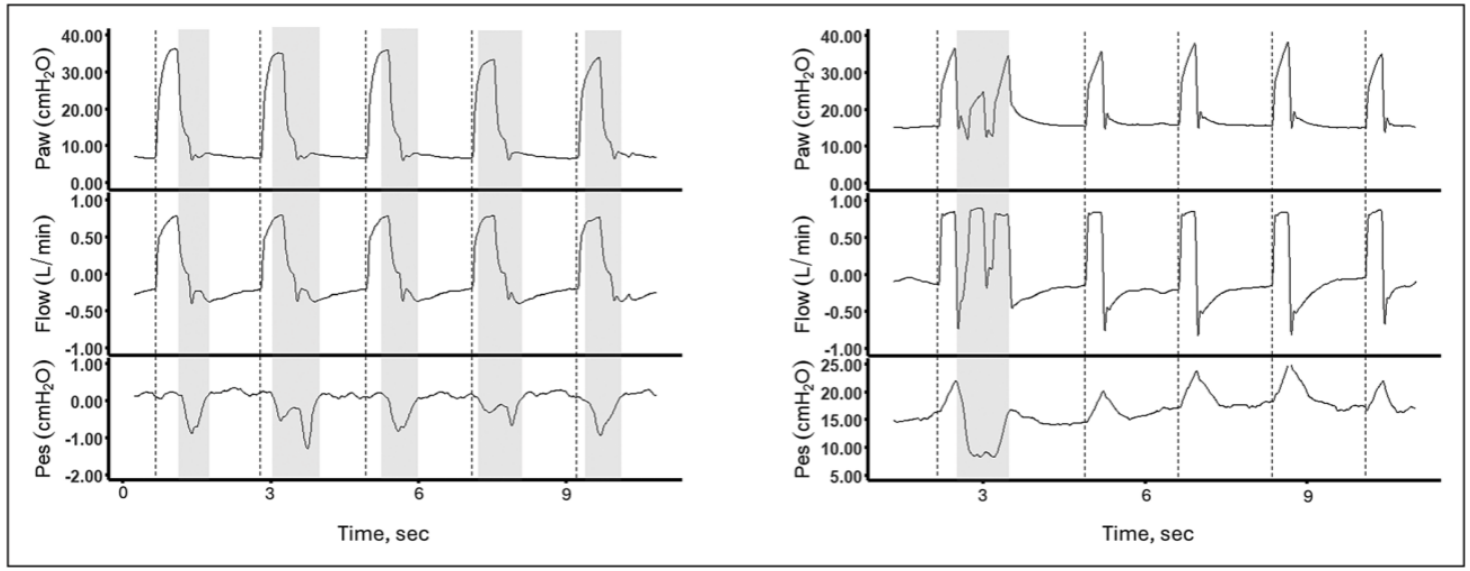
- Clinical Significance:
  - Delivers unnecessary breaths
  - Can cause respiratory alkalosis
  - May lead to diaphragm atrophy (ventilator doing all the work)
  - Increases ventilator days
- Management:
  - Decrease trigger sensitivity (make less sensitive)
  - Address circuit issues (leaks, water)
  - Consider pressure triggering instead of flow triggering

Reverse Triggering - When the Ventilator Triggers the Diaphragm



- Waveform Characteristics:
  - Diaphragm activity occurs AFTER ventilator triggers (not before)
  - May appear similar to premature cycling
  - Can lead to double triggering or breath stacking
  - Requires esophageal manometry or electrical activity monitoring to definitively diagnose
- Common Causes:
  - Deep sedation with preserved respiratory centers
  - Brain injury
  - Early ARDS

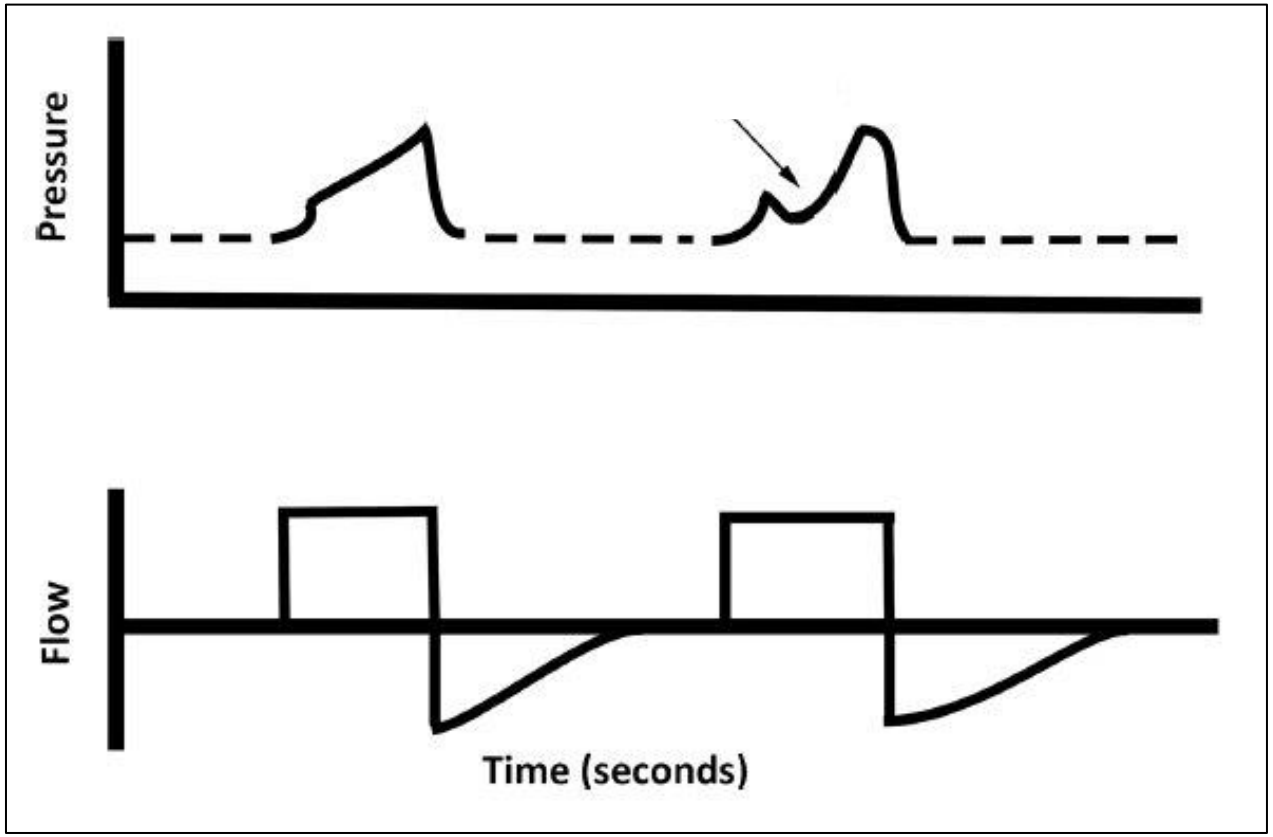
Reverse Triggering - When the Ventilator Triggers the Diaphragm



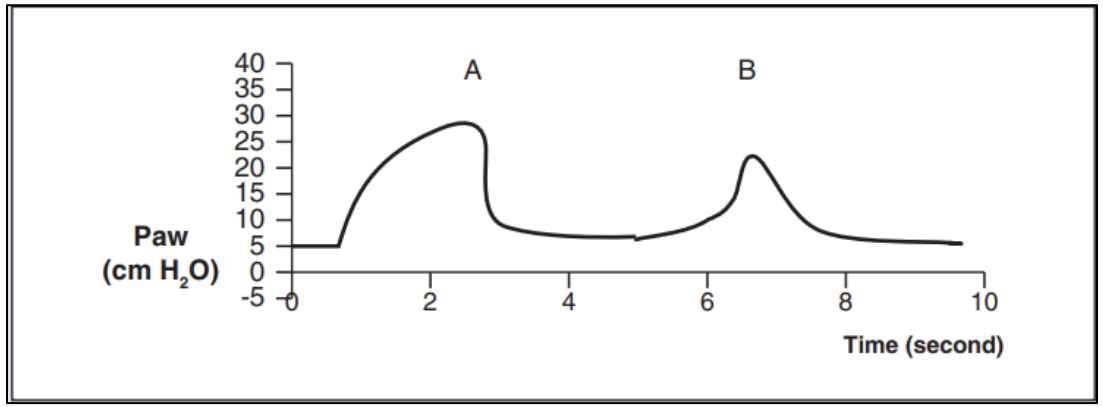
- Clinical Significance:
  - May be protective in some cases (maintains diaphragm activity)
  - Can lead to excessive tidal volumes if breath stacking occurs
  - Particularly relevant in ARDS patients
  - Paradoxically may have positive association with outcomes

Case 2

- 45-year-old male, post-operative day 5
- Recovering from sepsis
- Mode: VC – TV 500, flow rate 40L/min, FiO2 30%
- Patient reports feeling "short of breath"
- Respiratory rate 32, appears anxious

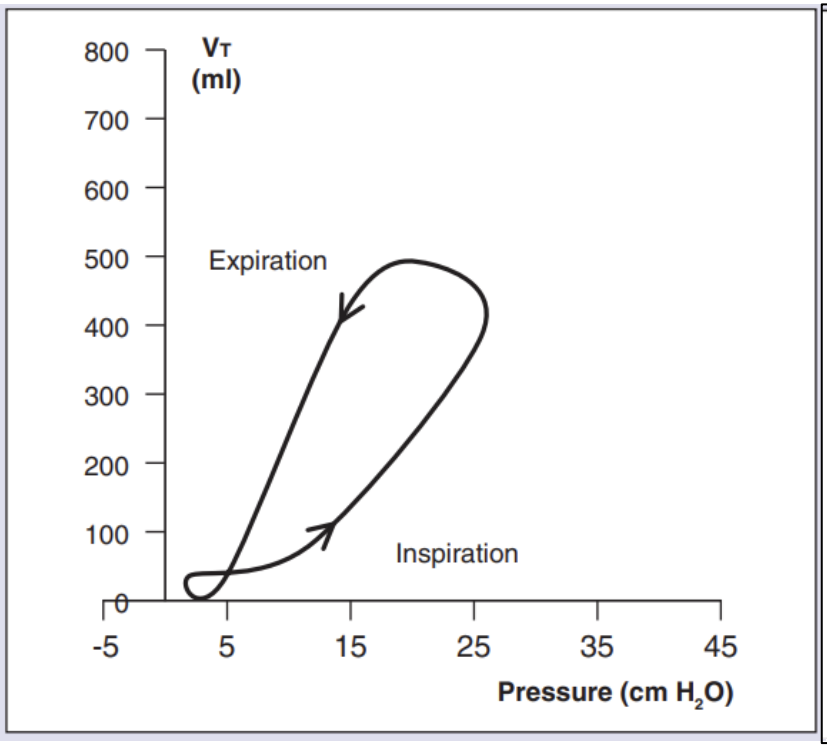


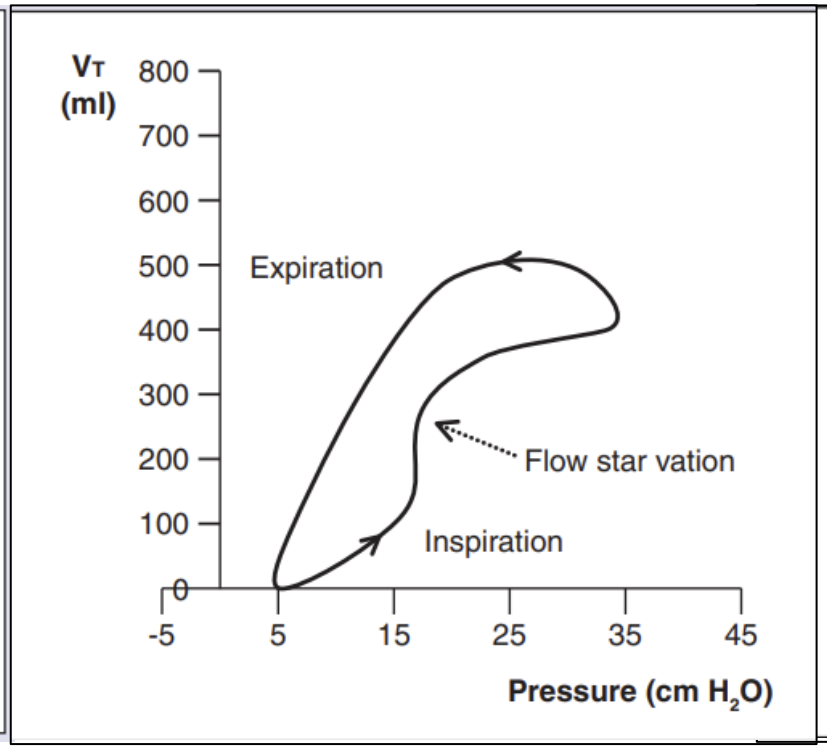
Flow Starvation - Not Enough, Not Fast Enough

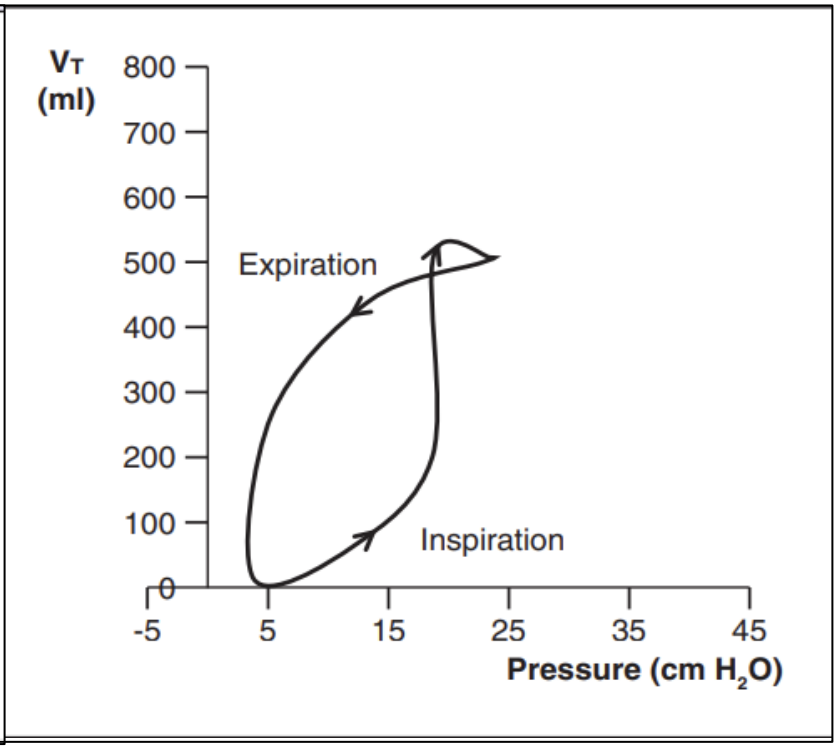


- Waveform Characteristics:
  - "Scooped" or concave airway pressure curve during inspiration
  - Patient pulling against ventilator
  - Pressure fails to reach set level quickly
  - May see continued diaphragm activity throughout inspiration
- Common Causes:
  - Inspiratory flow rate set too low (volume control)
  - Inadequate pressure support level
  - High patient respiratory drive
  - Decelerating flow pattern when patient wants constant flow

Flow Starvation - Not Enough, Not Fast Enough





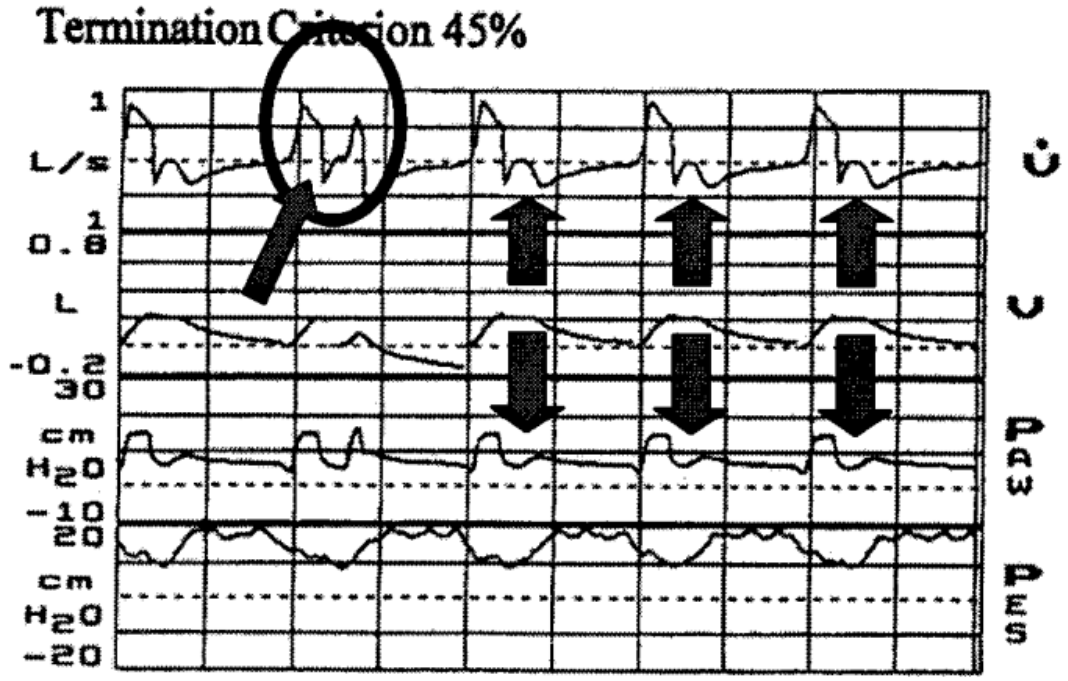


Flow Starvation - Not Enough, Not Fast Enough

- Clinical Significance:
  - Second most common asynchrony (10% of patients)
  - Increases work of breathing, discomfort and dyspnea
  - 11% of flow-limited breaths deliver >10mL/kg

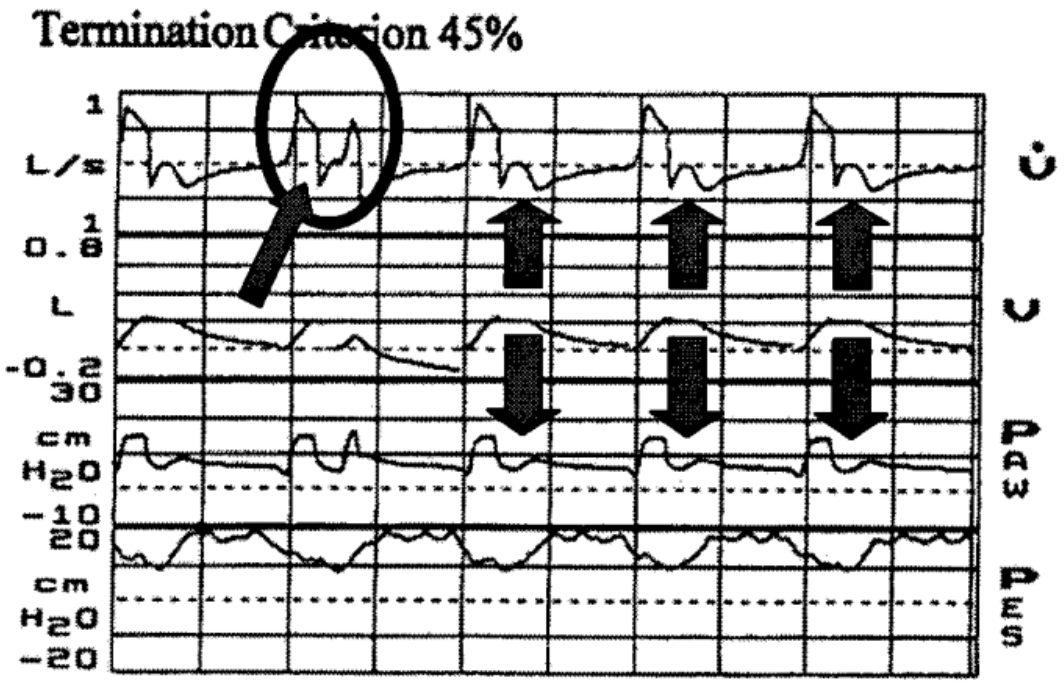
- Management:
  - Increase peak flow rate (volume modes)
  - Increase pressure support level
  - Consider changing flow pattern
  - Assess and treat underlying cause of high drive

Premature Cycling - Breath Ends Too Soon



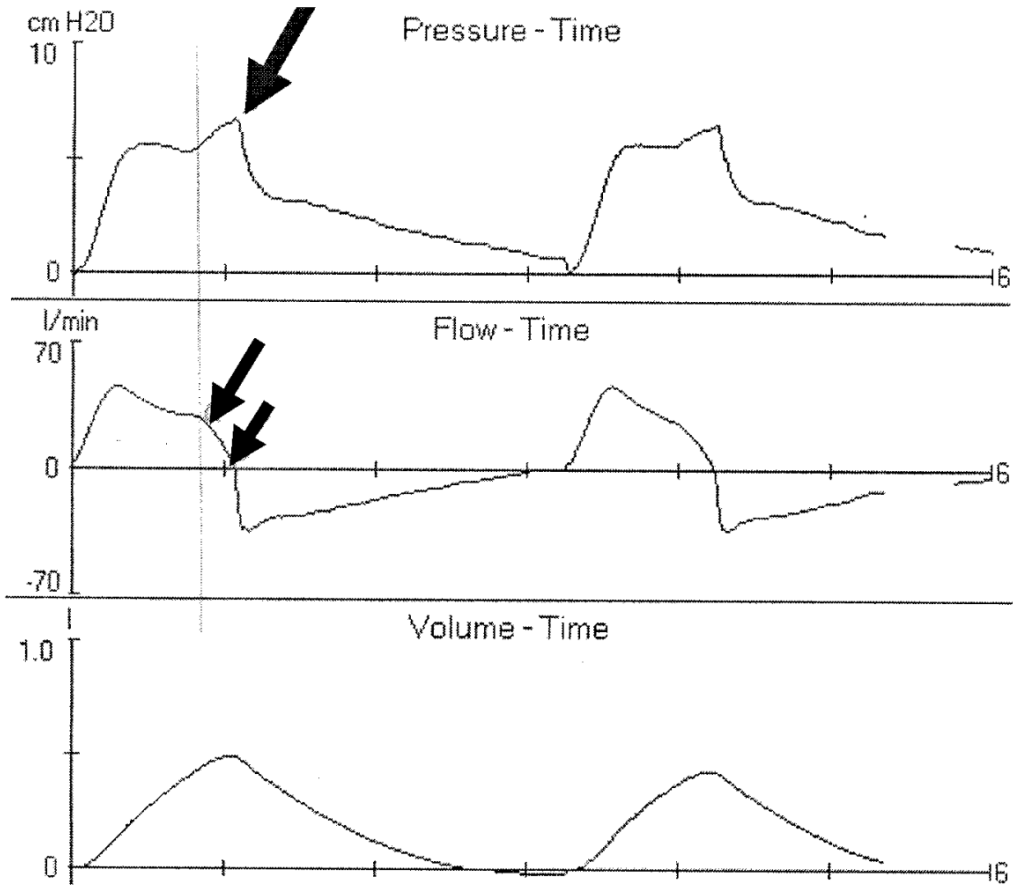
- Waveform Characteristics:
  - Inspiratory flow terminates early
  - Continued patient effort during early expiration
  - "Bump" or rise in pressure during early expiration (patient still trying to inhale)
  - May see active expiratory muscle recruitment
  - Common in restrictive lung disease
- Common Causes:
  - Cycle threshold set too high (PSV cycles off too early)
  - Short inspiratory time setting
  - Rapid flow decay in pressure support
  - Air leak (flow decreases rapidly, triggering early cycle)

Premature Cycling - Breath Ends Too Soon



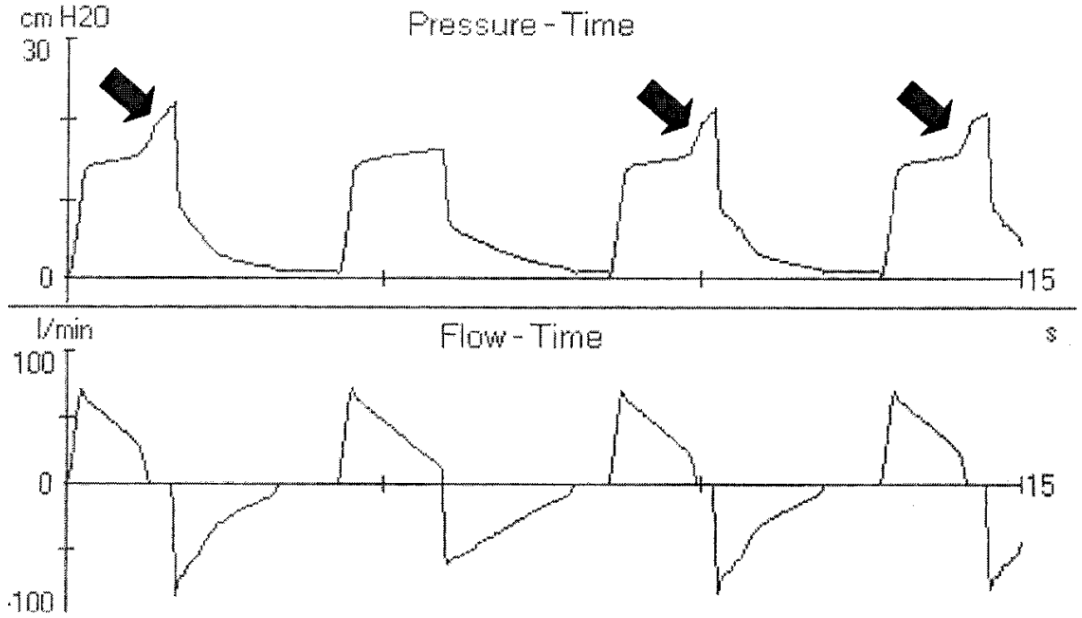
- Clinical Significance:
  - Patient "fighting" the ventilator
  - Increased work of breathing
  - Patient discomfort and dyspnea
  - May trigger double triggering
- Management:
  - Adjust cycle criteria (lower % of peak flow in PSV)
  - Increase inspiratory time
  - Check for and fix leaks
  - Consider different ventilator mode

Delayed Cycling - Breath Goes On Too Long



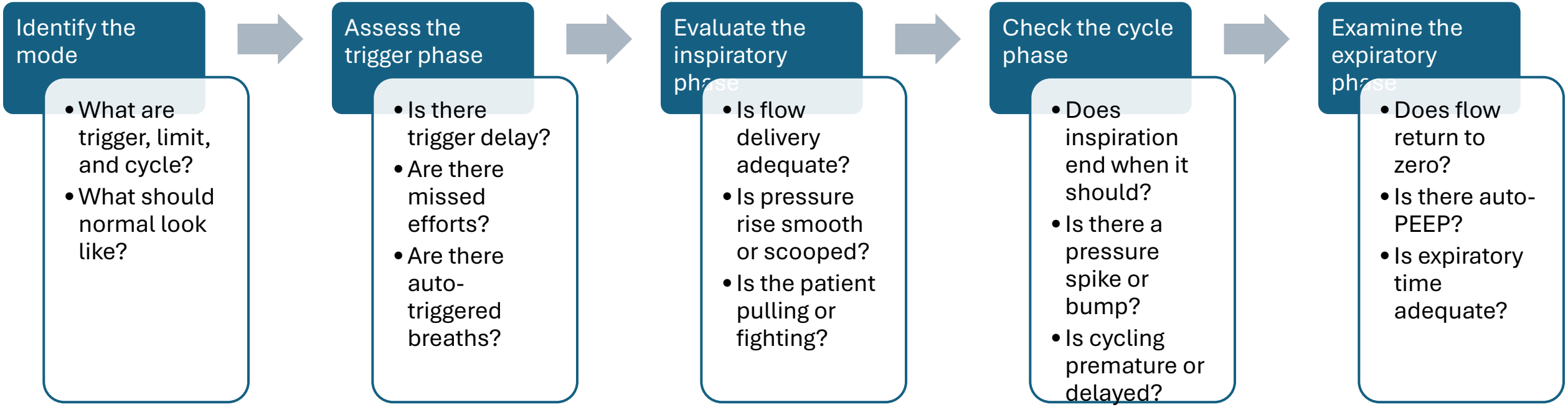
- Waveform Characteristics:
  - Prolonged inspiratory time
  - Active expiration against continued ventilator inspiration
  - Sharp rise or "spike" in pressure at end of inspiration
  - Expiratory muscle activation while ventilator still delivering gas
  - Common in obstructive lung disease (COPD)
- Common Causes:
  - Cycle threshold set too low (PSV cycles off too late)
  - Inspiratory time set too long
  - Slow flow decay in obstructive disease
  - Inadequate expiratory time

Delayed Cycling - Breath Goes On Too Long



- Clinical Significance:
  - Patient actively exhaling while ventilator inhaling
  - Increased work of breathing
  - Patient discomfort
  - May contribute to auto-PEEP
  - Can promote over-sedation to "fix" the problem
- Management:
  - Adjust cycle criteria (higher % of peak flow in PSV)
  - Decrease inspiratory time
  - Ensure adequate expiratory time
  - Treat bronchospasm if present

Systematic Waveform Interpretation



Common Pitfalls to Avoid

Don't:

- Increase sedation without first optimizing ventilator settings
- Ignore small asynchronies (they can worsen)
- Forget to check for auto-PEEP in COPD/asthma patients
- Set triggers too sensitive (causes auto-triggering)
- Set triggers too insensitive (causes trigger delay and work)
- Assume the ventilator is always right
- Forget to look at the patient, not just the screen

Remember

- Three scalars: Pressure, Flow, Volume - learn to read all three
- Four phases: Trigger, Inspiration, Cycle, Expiration - assess each systematically
- Seven asynchronies: Know how to recognize and manage each
- Most important: Double triggering and ineffective triggering
- Patient first: Always correlate waveforms with clinical assessment
- Optimize before sedate: Adjust ventilator settings before increasing sedation
- Practice makes perfect: Regular waveform review improves recognition
- Evidence matters: Asynchrony affects outcomes - your assessment makes a difference

Thank you for your attention and dedication to excellent respiratory care!

Questions?

Case 1

- 68-year-old male with CC exacerbation
- Intubated 24 hours ago
- Mode: Pressure Support 8/PEEP 5
- Patient appears uncomfortable, using accessory muscles
- Respiratory rate 28

Case 1 - Auto-PEEP with ineffective triggering

- Airflow obstruction → slow exhalation
- Insufficient expiratory time
- Patient must generate pressure > auto-PEEP to trigger

Case 1 - Auto-PEEP with ineffective triggering

- Management Strategy:
  - Measure auto-PEEP (expiratory hold maneuver)
  - Increase expiratory time:
    - Decrease respiratory rate (if possible)
    - Decrease inspiratory time
  - Add external PEEP (80% of auto-PEEP) to counterbalance
  - Optimize bronchodilator therapy
  - Consider adjusting trigger sensitivity

Case 1 - Auto-PEEP with ineffective triggering

- Expected Outcome:
  - Reduced work of breathing
  - Fewer ineffective efforts
  - Improved patient comfort

Case 2

- 52-year-old female with ARDS (PaO_2/FiO_2 120)
- Day 3 of mechanical ventilation
- Mode: Volume Control, Vt 400 mL (6 mL/kg), Rate 20, PEEP 12
- Ventilator shows high peak pressures (38 cm H_2O)
- Delivered volumes sometimes >800 mL

Case 2 - Double triggering with breath stacking

- Patient's neural inspiratory time > ventilator inspiratory time
- Set tidal volume insufficient for patient's drive
- High respiratory drive from ARDS

Case 2 - Double triggering with breath stacking

Management Strategy:

- Immediate: Assess total delivered volume (may need deeper sedation urgently)
- Adjust ventilator:
  - Increase tidal volume slightly (if plateau pressure allows)
  - Increase inspiratory time
  - Consider switching to pressure control with longer Ti
- Address respiratory drive:
  - Optimize sedation/analgesia
  - Treat underlying cause (infection, etc.)
  - Consider neuromuscular blockade if severe ARDS
  - Monitor closely: Double triggering can cause volutrauma

Case 2 - Double triggering with breath stacking

Expected Outcome:

- Elimination of double triggering
- Lung-protective ventilation maintained
- Reduced risk of ventilator-induced lung injury