NEWER VENTILATORY MODES: RATIONALE & CLINICAL APPLICATION

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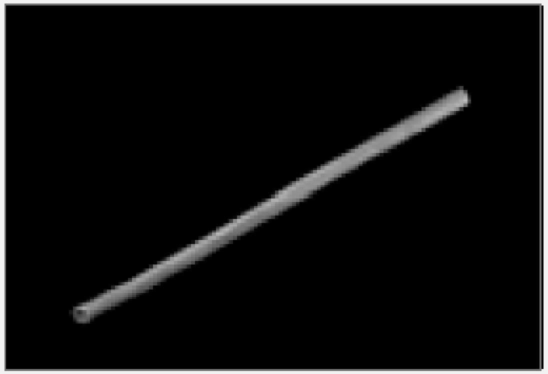
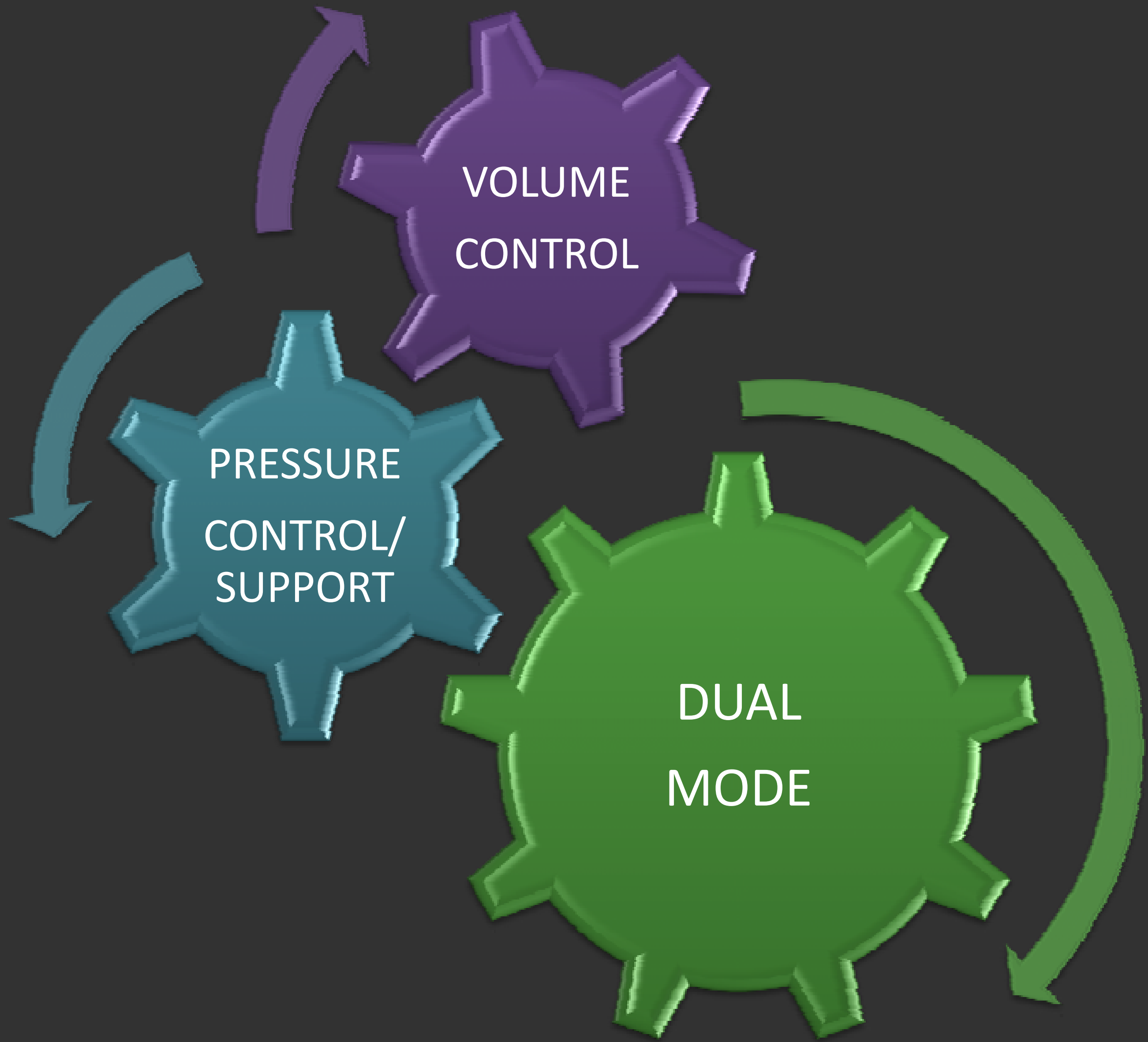
1st Published Scientific Paper on Mechanical Ventilation

"But that life may ... be restored to the animal, an opening must be attempted in the trunk of the trachea, in which a tube of reed or cane should be put; you will then blow into this, so that the lung may rise again and the animal take in air. ... And as I do this, and take care that the lung is inflated in intervals, the motion of the heart and arteries does not stop..."

Andreas Wesele Vesalius, 1543



EVOLUTION OF MECHANICAL VENTILATORS



Classifying Modes of Ventilation

A. Start

Trigger mechanism:

What starts the breath?

B. Limits

What is controlled and what is variable?

C. End

Cycle mechanism:

What causes the breath to end?

Targeting

Control

- Flow →

- Pressure

Target

- Time → **Volume control**

- Pressure

- Volume

Targeting

Control	**Target**	
• Flow	• Time	**Time-cycled pressure control**
• Pressure	• Pressure	
	• Volume	

Targeting

Control

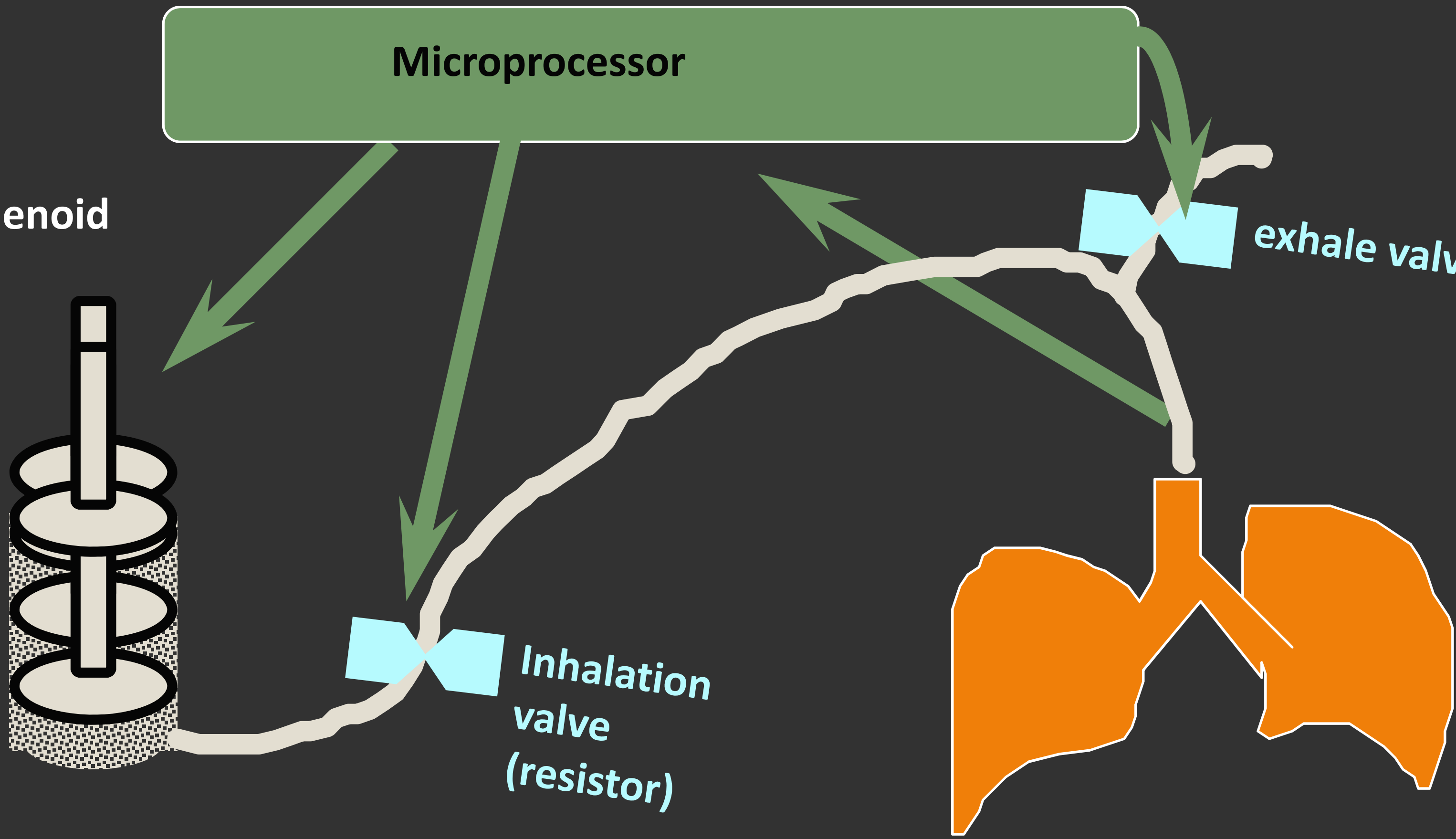
- Flow
- Pressure

Target

- Time
- Pressure
- Volume

Volume targeted pressure control

Microprocessor Control

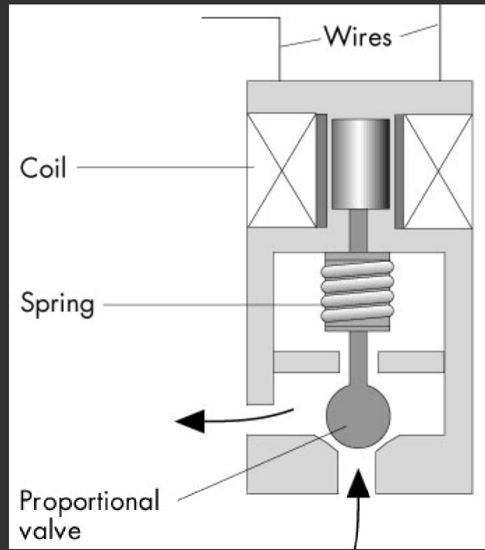


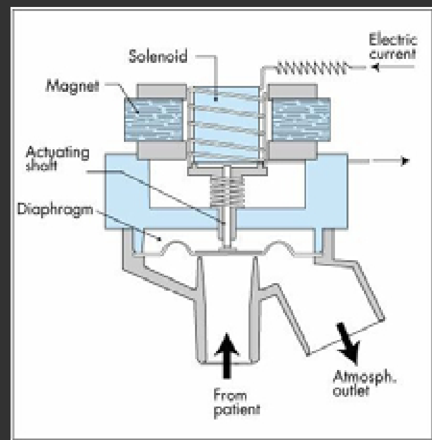
Pressure 3500 cm H_20

Tidal volume 500 ml
Pressure 35 cm H_20

New Modes of Mechanical Ventilation: *Background*

- Introduction of the microprocessor-controlled ventilator
  - Better control of flow & exhalation valves
  - Increased monitoring capabilities
  - Increased pt-ventilator interaction
  - “Dual modes” of ventilation introduced





From Mosby’s R. C. Equip., 6th ed. 1999.

The Problem: Conventional Ventilation

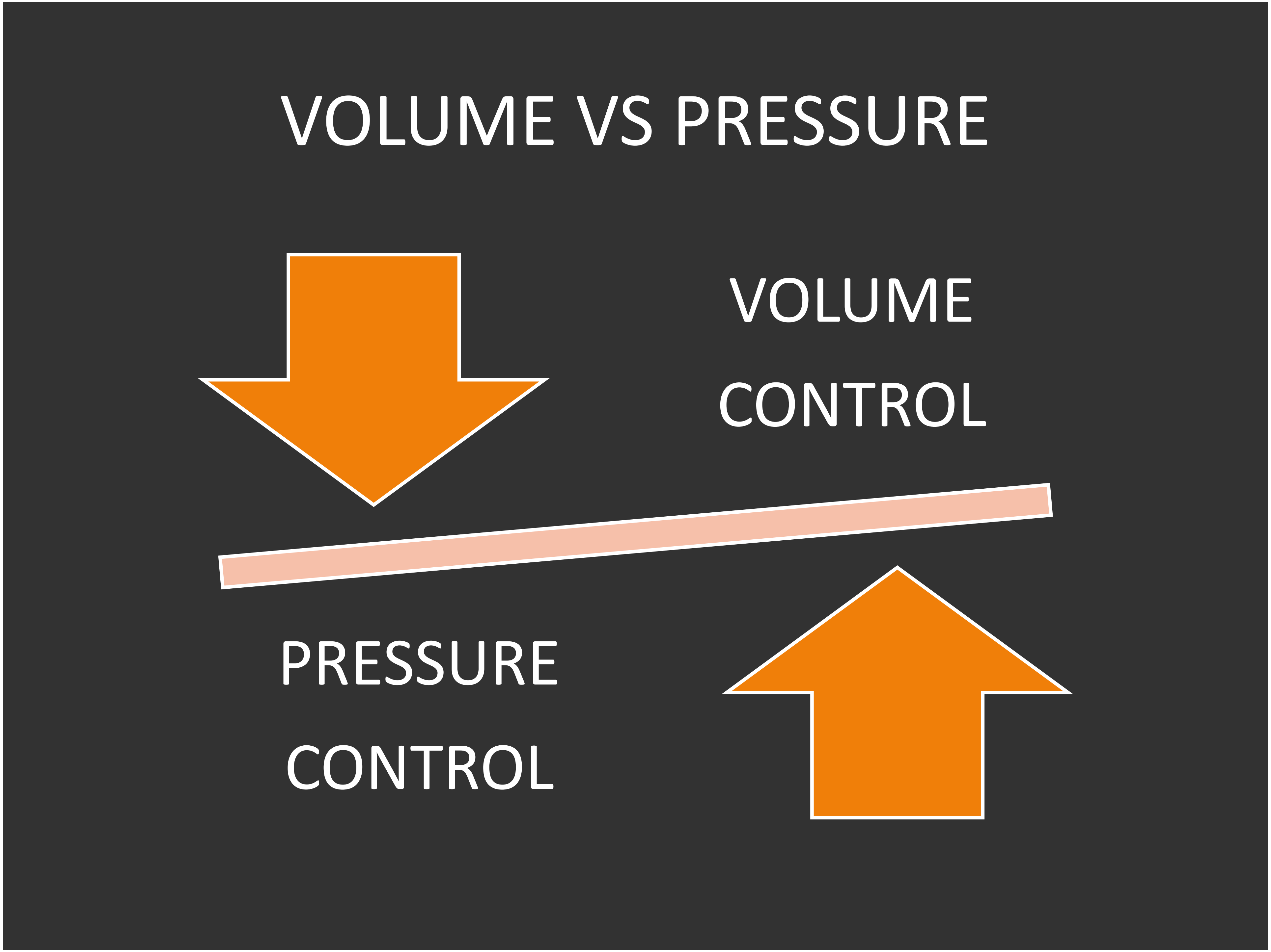
Ideal Mode of Ventilation

Delivers a breath that:

- **Synchronizes with the patient’s spontaneous respiratory effort**
- **Maintains adequate and consistent tidal volume and minute ventilation at low airway pressures**
- **Responds to rapid changes in pulmonary mechanics or patient demand**
- **Provides the lowest possible WOB**

Why new modes?

- Conventional modes are uncomfortable
- Need for heavily sedation & paralysis
- Patients should be awake and interacting with the ventilator
- To enable patients to allow spontaneous breath on inverse ratio ventilation
- Lung protective ventilation : VILI
- Scientific jargon : Number of studies on ventilatory modes exceed the number of patients treated !


VOLUME VS PRESSURE
VOLUME
CONTROL
PRESSURE
CONTROL

Newer Methods of Ventilatory Support: dual modes

- 1st generation dual modes: VAPS, Press. Aug., PRVC & VS
  - Allow variable flow delivery and pressure "targeted" ventilation approach
  - Attempt to deliver a set tidal volume (TV)
  - Allow peak airway pressure to vary breath to breath

New Modes of Mechanical Ventilation:

Examples of the first dual modes

- Volume Assured Pressure Support (VAPS) & Pressure Augmentation
- Pressure Regulated Volume Control (PRVC) & similar modes
- Volume Support Ventilation (VS or VSV) & similar modes

VAPS: **V**olume **A**ssured **P**ressure **S**upport

- Combines volume ventilation & pressure support
  - (for mech., vol. limited breaths only)
- Uses TV, peak flow, and pressure sup./control settings
- Targets PS level with <u>at least</u> set peak flow first
- Continues until flow decreases to set peak flow, then:
  - If TV not delivered, peak flow maintained until vol. limit
  - If TV or more delivered, breath ends

Benefits of VAPS

- Lower peak airway pressure
- Reduced patient work of breathing
- Improved gas distribution
- Less need for sedation
- Improved patient comfort

Applications of VAPS

- A patient who requires a substantial level of ventilatory support and has a vigorous ventilatory drive to improve gas distribution and synchrony
- A patient being weaned from the ventilator and having an unstable ventilatory drive to supply a back-up tidal volume as a "safety net" in case the patient's effort or/and lung mechanics change

Pressure Regulated Volume Control (PRVC)

- Combines volume ventilation & pressure <u>control</u>
  - (for mech., time-cycl. breaths only)
- Set TV is "targeted"
- Ventilator estimates vol./press. relationship each breath
- Ventilator adjusts level of pressure control *breath by breath*

Synonyms of PRVC

- Pressure-regulated volume control (PRVC; Siemens 300; Siemens Medical Systems)

- Adaptive pressure ventilation (APV; Hamilton Galileo; Hamilton Medical, Reno, NV)

- Autoflow (Evita 4; Drager Inc., Telford, PA)

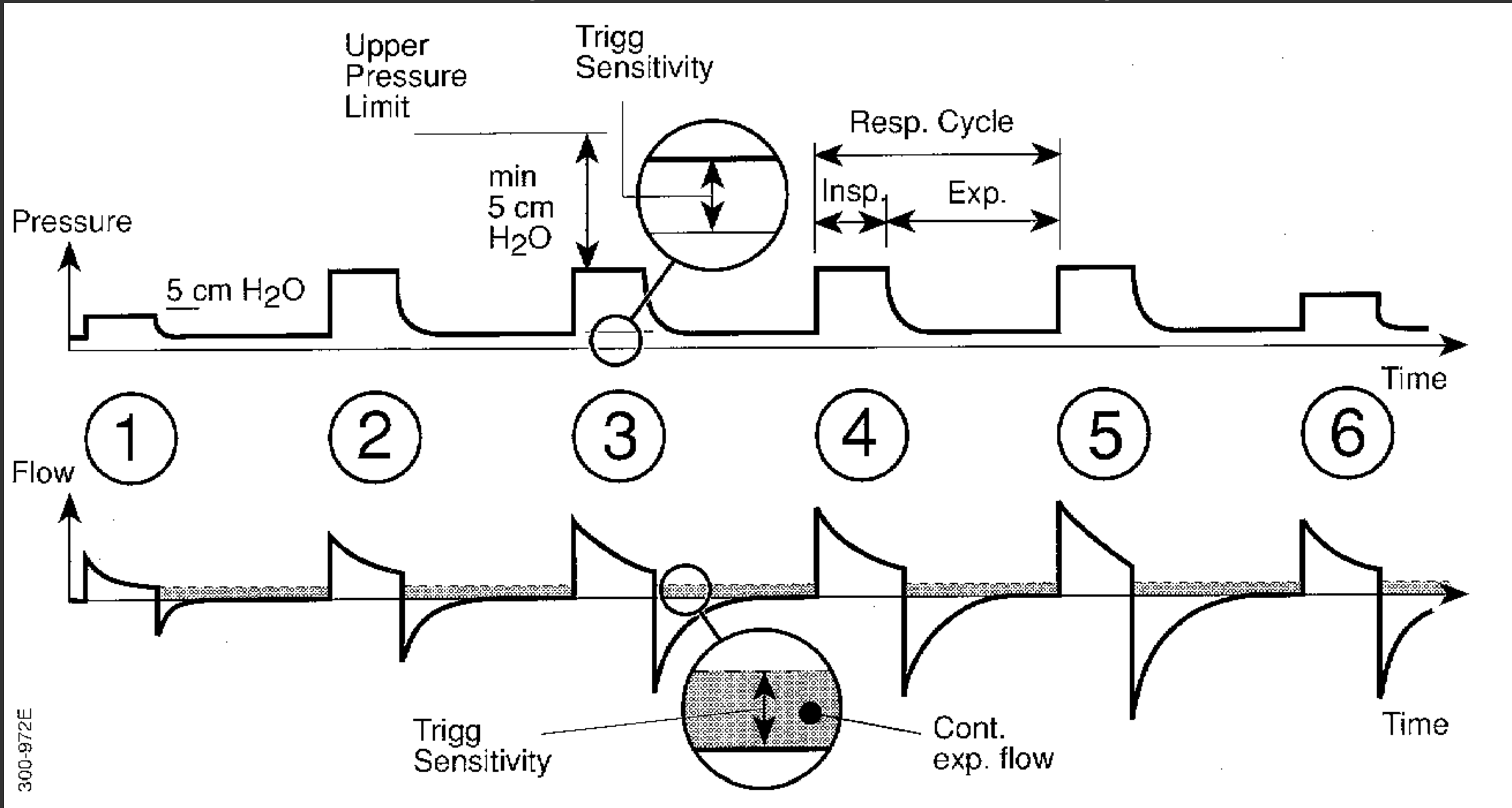
Settings for PRVC

- Minimum respiratory rate
- Target tidal volume
- Upper pressure limit: 5 cm H_2O below pressure alarm limit
- FIO_2
- Inspiratory time or I:E ratio
- Rise time
- PEEP

Pressure Regulated Volume Control

- First breath = 5-10 cm H2O above PEEP
- V/P relationship *measured*
- Next 3 breaths, pressure increased to 75% needed for set TV
- Then up to +/- 3 cm H2O changes per breath
- Time ends inspiration

Pressure Regulated Volume Control
(Siemens Servo 300)



- From Siemens prod. literature

Advantage of PRVC

- Decelerating inspiratory flow pattern
- Pressure automatically adjusted for changes in compliance and resistance within a set range
  - Tidal volume guaranteed
  - Limits volutrauma
  - Prevents hypoventilation
- Maintaining the minimum Ppk that provides a constant set VT
- Automatic weaning of the pressure as the patient improves

Disadvantage of PRVC

- Pressure delivered is dependent on tidal volume achieved on last breath
- Intermittent patient effort → variable tidal volumes
- Asynchrony with variable patient effort

Richard et al. Resp Care 2005Dec

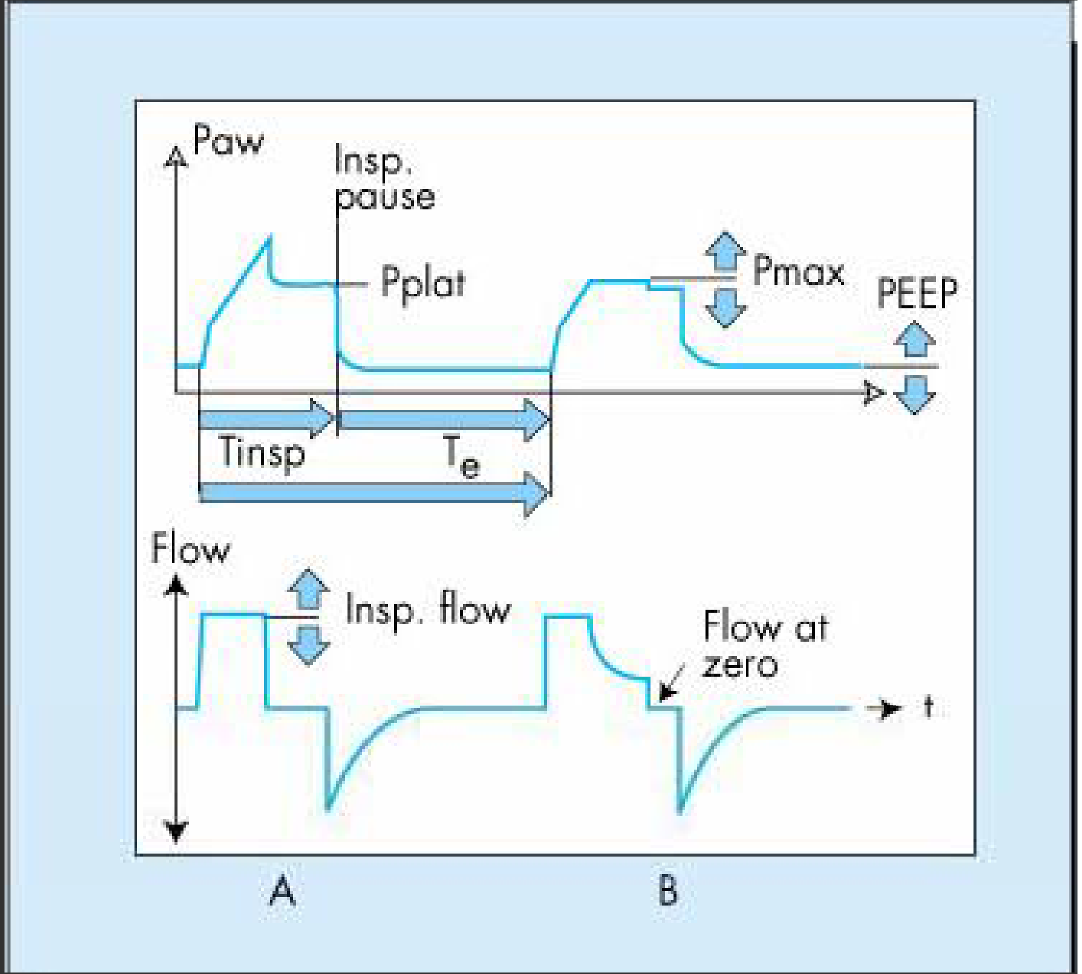
- Less suitable for patients with asthma or COPD

Newer Ventilator Dual Modes:

- AutoFlow:Drager ventilators Evita 4, Evita 2 dura
- Adaptive Support Ventilation (ASV): Hamilton Galileo

Newer Ventilator Dual Modes: Drager vent's AutoFlow

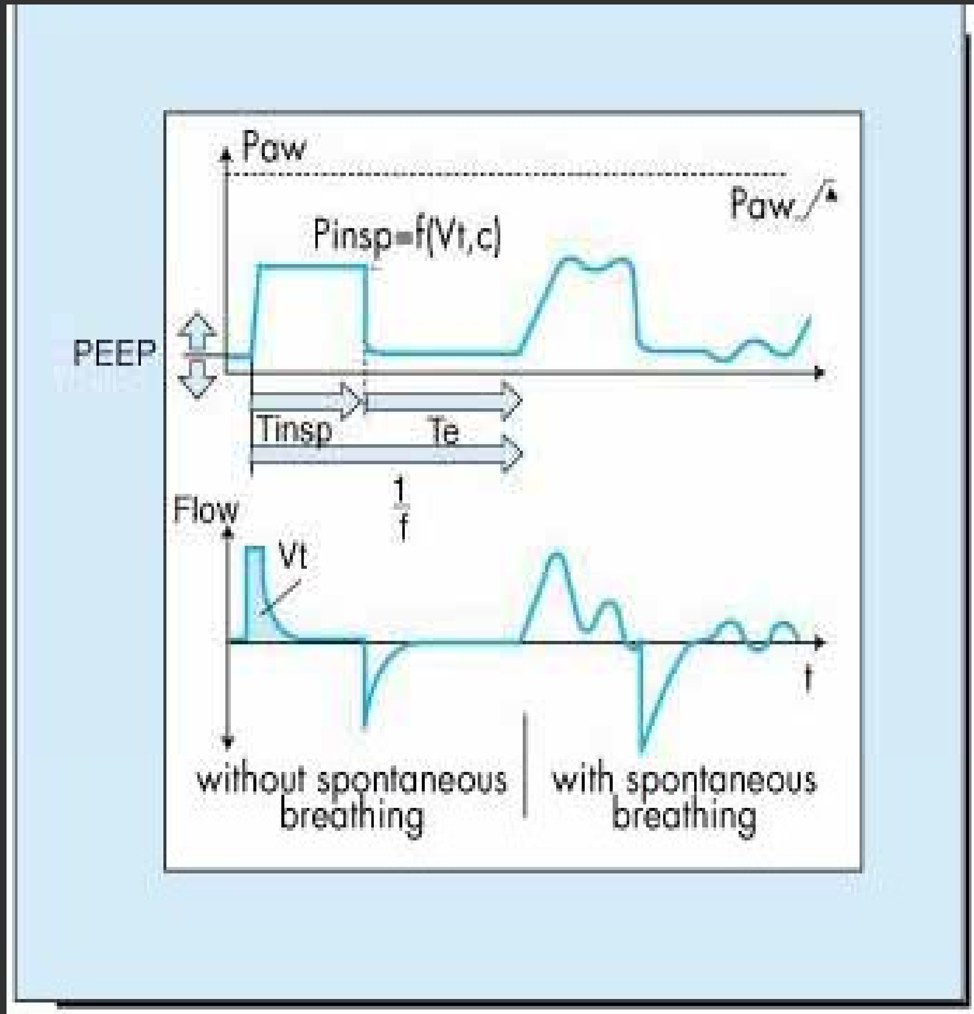
- First breath uses set TV & I-time
  - Pplateau measured
- Pplateau then used
- V/P measured each breath
- Press. changed if needed (+/- 3)
- Then similar to PRVC



From Drager & Mosby's R. C. Equip., 6th ed. 1999.

Newer Ventilator Dual Modes: Drager vent's AutoFlow

- Allows spont. breathing:
  - expiration *and*
  - *inspiration*
- Exp. efforts at peak insp. pressure open exh. valve; Ppeak maintained
- Active exhalation valve is a key feature



From Drager & Mosby's R. C. Equip., 6th ed. 1999.

CLOSED LOOP SYSTEM

- Closed-loop system able to provide automatic readjustment of VT and/or respiratory rate dependent on parameters achieved in last breath
- Goldilocks Principle

  Critical Care Medicine 4/00 by MacIntyre N

  - Proportional assist ventilation (PAV)
  - Neurally adjusted ventilatory assistance (NAVA)
  - Knowledge-based system (KBS
  - Adaptive support ventilation (ASV)

Crit Care Clin 23 (2007) 223–240

Adaptive Support Ventilation (ASV) -- a new concept in mechanical ventilation

- ASV very versatile mode, easy-to-use and extremely safe mode of ventilation (Int Care Med 2005;31:192)
- Ventilates virtually all intubated patients - whether active or passive and regardless of lung disease – based on ventilation strategy tailored to individual condition (Int Care Med 2004;30:84)
- Requires fewer user interactions and gives fewer alarms (Anesth Analg 2003;97:1743-50)
- Facilitates shorter ventilation times

  (Cartiothorac Vasc Anesth 2003;17:571-75)

ASV working principle

- Clinician enters pt. data & % support
- Vent. calculates needed min. vol. & best rate/TV to produces *least work*
- Targeted TV's given as press. control or press. support breaths
  - If pt.'s f > "set" by vent., mode is PS
  - If pt.'s f < "set" by vent., mode is PC-SIMV/PS
  - If patient is apneic, all breaths are PC
- Rate where WOB is minimal: $RR = \sqrt{[1 + 4\pi^2 RCe \cdot (V_A/V_D) - 1]/2\pi^2 RCe}$
- Press. adjusts in +/- 2 cm H_2O to achieve TV

ASV Input

- **Ideal body weight:** determines dead space
- **High-pressure alarm:** 5 cm H_2O above PEEP to 10 cm H_2O below set Pmax
- **Mandatory RR**
- **PEEP**
- **FiO2**
- **Insp time (0.5–2 secs), exp time (3 ×** RCe to 12 secs)

ASV : MONITORING

ASV target graphics screen:

1. Minute volume curve showing target volume
2. Safety frame showing limits for lung protective ventilation
3. Current tidal volume-respiratory frequency
4. The optimal tidal volume-respiratory frequency combination with which the patient will be ventilated

ASV Evidence

- ASV Evidence
- ASV(N=18) vs SIMV + PS (N=16)
- Standard management for rapid extubation after cardiac surgery
- ↓Ventilatory settings manipulations
- ↓High-inspiratory pressure alarms
- Outcome: same

Anesth Analg 2003;97:1743–50.

ASV Evidence

- Partial ventilatory support: ASV provided
- MV comparable to SIMV-PS.
- ASV: central respiratory drive& inspiratory load↓
- Improved patient-ventilator interactions
- Decreased sedation use
- Helpful mode in weaning
- Versatile mode

Critical Care Medicine 2002

Intensive Care Med 2005;31:S168.
Intensive Care Med 2008;34:75–81.

Proportional Assist Ventilation

- PAV - currently on PB 840 in US prototype ventilators, Drager Evita 4 & Respironics BiPAP Vision
- Muscle pressure = (normal elastance x volume) + (normal resistance x flow) + abnormal load
- Pmus + Pappl = PEEPi + Pres + Pel
- The goal is to maintain a constant fraction of work per breath done by ventilator(% SUPPL)
- PAV/PAV+

Crit Care Clin 23 (2007) 223–240

Proportional Assist Ventilation

- Automatically adjusts flow, volume and pressure needed each breath
- PAV requires only PEEP & FiO2, % volume assist(reduces work of elastance), % flow assist(reduces work of resistance's)

PAV : ALGORITHM

- Four breath start-up
- Each includes an end-inspiratory maneuver that yields patient's compliance and resistance
- First breath delivered using predicted resistance for artificial airway and conservative estimate for patient's resistance and compliance based on IBW
- Each valid measurement is then factored in until fifth breath, which is first *PAV+ breath*
- Measurements for compliance and resistance are then taken randomly every 4-10 breaths.
- Flow and volume assessed every 5 milliseconds

Proportional Assist Ventilation

- Real-time assessment of WOB

Effort is amplified by a factor of **4** with a proportionality ratio of **3:1**

PAV : BENEFITS

- Comfort : Think about power steering in a car
- Improves synchrony b/w neural & machine inflation time: **Neuroventilatory coupling**
- Lower peak airway pressure
- Less need for paralysis and/or sedation
- Increases sleep efficiency
- Non invasive use of PAV in COPD & Kyphoscoliotic patients: delivered through nasal mask; improves dyspnea score (BiPAP vision TM)

Clin Chest Med 29 (2008) 329–342

PAV : LIMITATIONS

- Patient controls breathing pattern- worsening of respiratory alkalosis
- Patient triggered mode
  - (Unless back-up mode present)
- Cannot compensate for leaks (prototypes)

Knowledge-based weaning system (KBW) : SMARTCARE™

- Clinical data from patient interpreted in real time to adjust level of PSV to maintain RR, VT, and PetCO2 within a predefined range(comfort zone)
- Level of PS adjusted automatically and eventually reduced to minimal level at which SBT is analyzed
- KBW first able to predict patient's readiness to be weaned in 51% of cases, with a failure rate (as defined by reintubation) of 29%

Intensive Care Med 2005;31(10):1446–50.

KBW: APPLICATIONS

- Recent multicenter RCT compared KBW and standard weaning procedures - total duration of MV reduced by nearly 4 days (from 12 days to 7.5 days
- Limitations

  AmJ Respir Crit Care Med 2006;174(8): 894–900.

  – transient system interruption or voluntarily stop because of worsening of clinical condition(ACMV)
  – CO2 sensor dysfunction
- Weaning tool in medical patients mechanically ventilated for more than 24 hours and not so-easy to wean

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Neurally Adjusted Ventilatory Assist

NAVA: new mode of mechanical ventilation that delivers ventilatory assist in proportion to inspiratory neural effort, which offers delivery of ventilatory assist with better integration into respiratory control feedback loop

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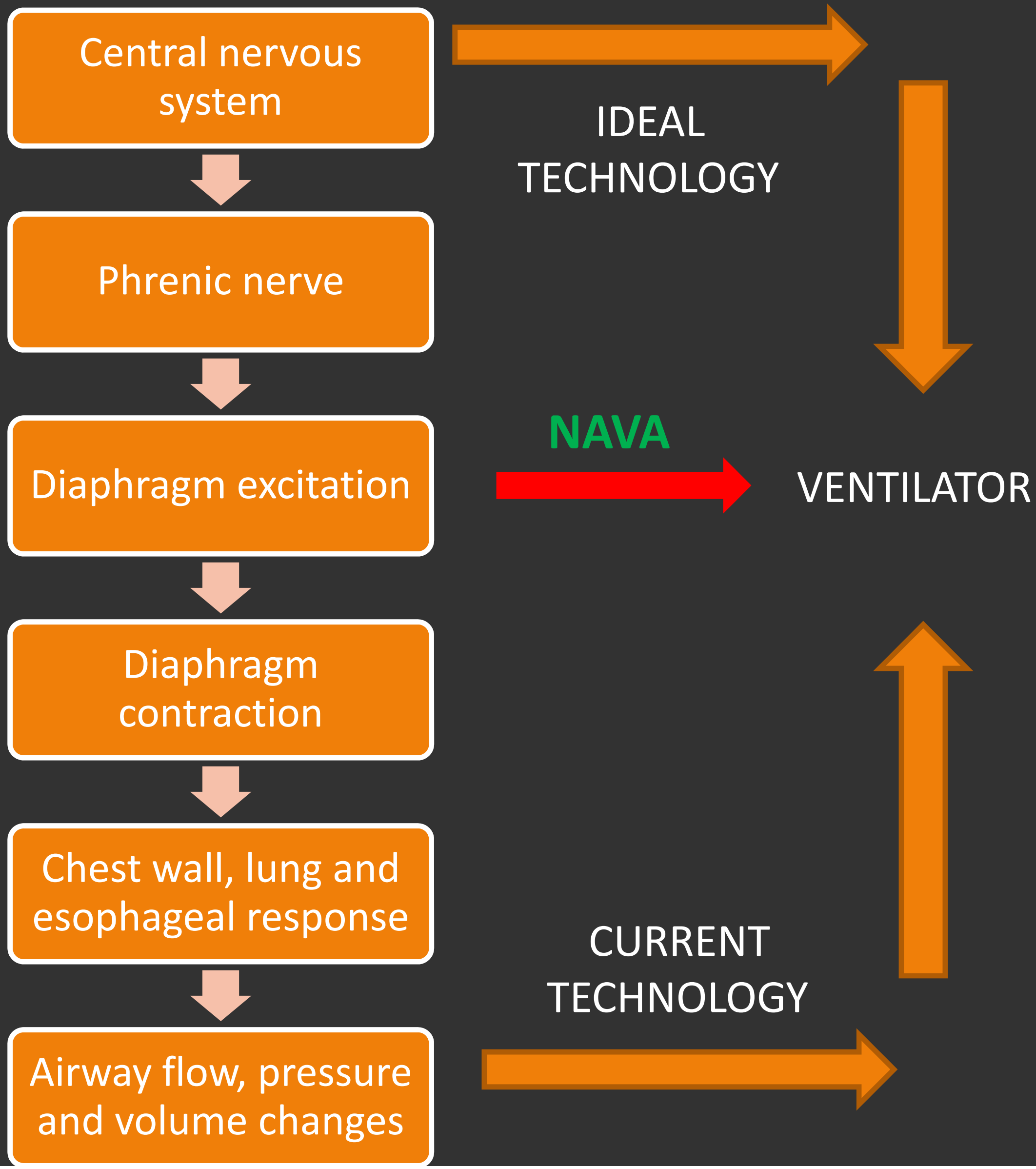

Potential Benefits of NAVA

Benefits of NAVA

- Improve patient ventilator interaction
- Cycle on and off synchrony

Meet patient demands breath to breath

- Enhance respiratory monitoring from Edi signal
- Evaluate severity of illness and WOB
- Sedation Levels
- Diaphragmatic Function

LIMITATIONS

- Inserting an esophageal catheter : relatively invasive
- Very few clinical data available so far with NAVA
- Use of sedatives, analgesics, and other central depressants or stimulants : impact on Eadi
- Interpretation of waveforms and execution requires skill and expertise

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CLOSED LOOP : AT A GLANCE

Main characteristics of proportional assist ventilation (PAV), neurally adjusted ventilatory assist (NAVA), knowledge based system (KBS), and adaptive support ventilation (ASV)

	PAV	NAVA	KBS	ASV
Principle	Pinsp Proportional to $flow_{insp}$	Pinsp proportional to EMG_{dia}	Pinsp to maintain RR in comfort zone	Pinsp and RR to minimize the WOB
Breaths type	≃PSV	≃PSV	PSV	PSV, PCV, P-SIMV
Passive patients	NO	NO	NO	YES
Active patients	YES	YES	YES	YES
Automatic weaning	NO	NO	YES	YES

Abbreviations: EMG_{dia}, diaphragmatic electromyographic activity; $Flow_{insp}$, inspiratory flow; PCV, pressure controlled ventilation; P-SIMV, pressure controlled intermittent mandatory ventilation; PSV, pressure support ventilation; RR, respiratory rate; WOB, work of breathing.

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Open Lung Concept : HFOV and APRV

- Represent open-lung strategies designed to recruit and maintain adequate end-expiratory lung volume, attenuate atelectrauma, and improve oxygenation
- Ideal in achieving lung protection and mitigating VALI
- Very low tidal volumes with HFOV and ability to maintain spontaneous breathing with APRV
- In early ALI/ARDS: better primary mode of lung-protective ventilation
- In rescue situations when conventional ventilation is no longer adequate and safe

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High Frequency Ventilation

- Defined by FDA
  - Ventilator that delivers more than 150 breaths/minute
- Delivery of “sub-tidal volumes”
  - Usually less than or equal to anatomical dead space volume
- HFV devices are unique and differ on delivery method

HF RATIONALE & DEVICES

	Jets	Oscillators	Conventional
Frequencies available	Up to 600 beats/min	300–3,000 beats/min	2–60 breaths/min
Delivered tidal volumes	< or > V_D	< V_D	> > VD
Expiration	Passive	Active	Passive
Baseline pressure manipulated by	Extrinsic PEEP valve	Bias flow	Extrinsic PEEP Valve
Potential for intrinsic PEEP	+ + +	+ +	+
Necessary $f \times V_T$ product for effective V_A	>> Conventional	>> Conventional	—
Peak airway pressures	< Conventional	< Conventional	—
Mean airway pressures	≤ or > conventional*	≤ or > conventional*	—

*Standing waves can create high alveolar/airway pressure relationships near lung resonance frequencies.

Chest 2007; 131:1907–16

HFOV : Clinical studies in ALI and ARDS

- Case series in ‘‘rescue’’ situations, where conventional ventilation has arguably failed
- Only two published RCT where HFO compared with conventional MV in adult ALI and ARDS

Derdak et al [33]	Randomized controlled trial	148 patients Age 50 years PaO_2/FiO_2 ratio 113 OI 25 APACHE II 22	30-day mortality: 37% (HFOV) versus 52% (CMV)	HFOV group CMV 2.7 HFOV 6.0	Similar in both groups Oxygenation/ventilation failure (20)
Bollen et al [34]	Randomized controlled trial	61 patients Age 81 years PaO_2/FiO_2 ratio 109 OI 22 APACHE II 21	30-day mortality: 43% (HFOV) versus 33% (CMV)	HFOV group CMV 2.1 HFOV not reported	Similar in both groups Oxygenation/ventilation failure (8)

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HFOV INDICATIONS & SETTINGS

Oxygenation failure:

- FIO2 > 0.7 and PEEP ≥ 14 cm H2O

Ventilation failure :

- pH < 7.25 with tidal volume ≥ 6 mL/kg predicted body weight
- Plateau airway pressure ≥ 30 cm H2O

Initial HFO settings

- Bias flow 40 L/min
- Inspiratory time 33%
- mPaw 34 cm H2O
- FIO2 1.0

Contraindications to HFO.

- Known severe air flow obstruction.
- Intracranial hypertension

Crit Care Med 2007; 35:1649–1654

HFOV : LIMITATIONS

- Incidences of pneumothorax and hemodynamic instability similar in two RCT
- Another concern is heavy sedation and frequent paralysis, which patients may require during HFOV
- Potentially actually improves patient outcomes : awaits findings from future trials

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APRV

- A mode of ventilation along with spontaneous ventilation to promote lung recruitment of collapsed and poorly ventilated alveoli
- Continuous positive airway pressure with short, intermittent releases
- The short release along with spontaneous breathing promote CO_2 elimination
- Release time is short to prevent the peak expiratory flow from returning to a zero baseline
- Always implies inverse ratio ventilation

AKA

- BiVent – Servo
- APRV – Drager
- BiLevel – Puritan Bennett
- APRV – Hamilton
- ? Duo PAP- Hamilton

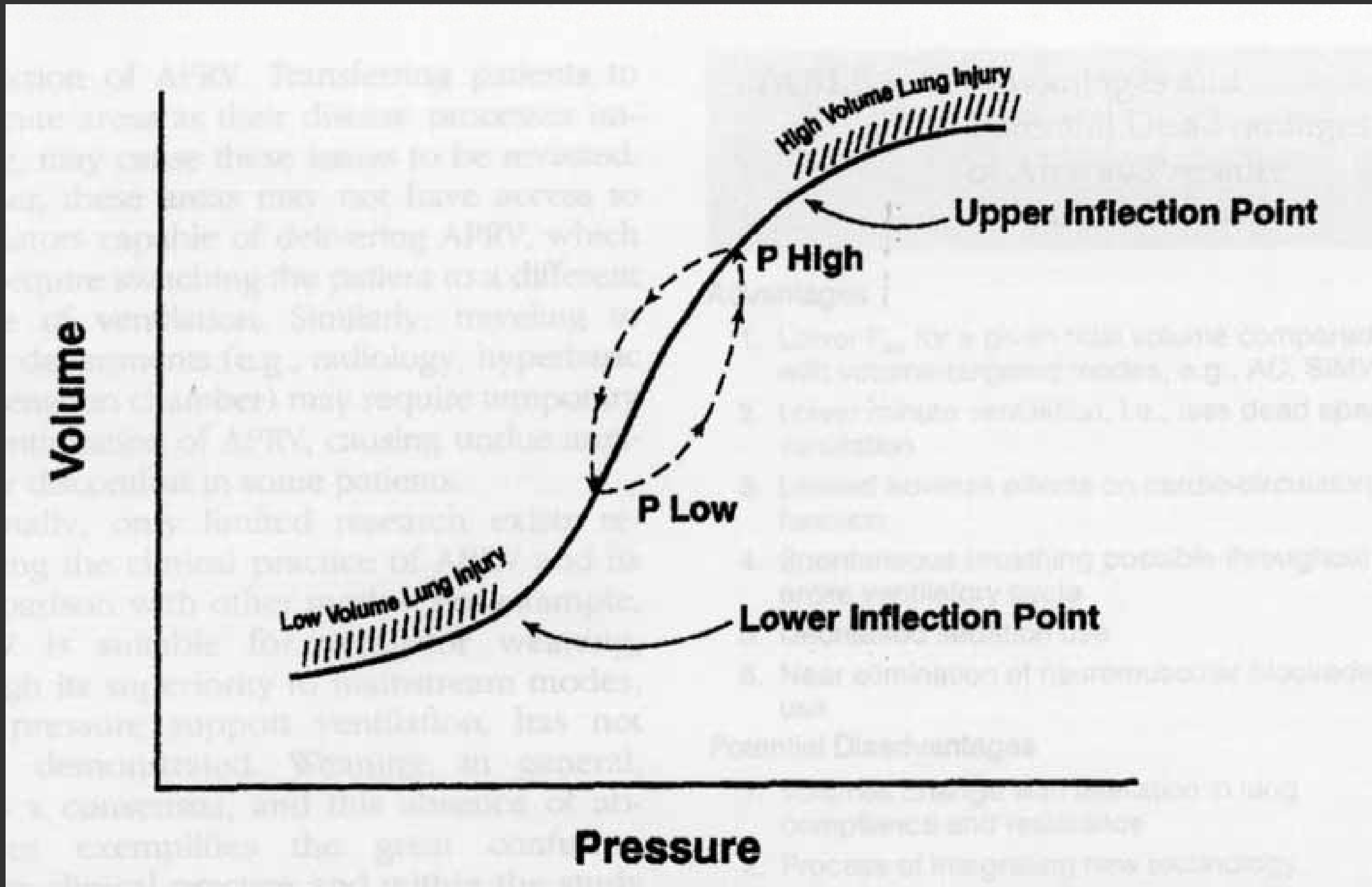
Possible Contraindications

- Unmanaged increases in intracraneal pressure.
- Large bronchopleural fistulas
- Possibly obstructive lung disease
- Technically, it may be possible to ventilate nearly any disorder

Terminology

- **P High** – the upper CPAP level. Analogous to MAP (mean airway pressure) and thus affects oxygenation
- **PEEP/Plow** is the lower pressure setting.
- **T High**- is the inspiratory time IT(s) phase for the high CPAP level (P High).
- **T PEEP or T low**- is the release time allowing CO_2 elimination

APRV : RATIONALE



Frawley, P & Habashi N, APRV – Theory And Practise, AACN Clinical Issues, 2001

APRV: Initial Settings

P high 20-30 cm H_2O(= PLATEAU) , according to the following chart.

P/F	MAP(Phigh)
<250	15-20
<200	20-25
<150	25-28

T high range 4-6 sec.

T low = 0.5 -.8 sec and
P low = 0 – 5 cm

T High/T low- 12-16 releases

T High (s)	T low (s)	Freq(<20)
3.0	0.5	17
4.0	0.5	13
5.0	0.5	11
6.0	0.5	9

APRV : ADJUSTMENTS

Increase PaO_2

- Increase F_IO_2
- Increase P High in 2 cm H_2O increments
- Increase T high slowly (0.5 sec/change)
- Recruitment Maneuvers
- *Maybe* shorten T low

CO_2 Elimination

Decrease T High

- Means more release/min

Increase P High

- 2-3 cm H_2O/change

Increase T low

Weaning From APRV

1. FiO_2 SHOULD BE WEANED FIRST. (Target < 50% with SpO_2 appropriate.)
2. Reducing P High, by 2 cmH_20 increments until the P High is below 20 cmH_2O.
3. Increasing T High to change vent set rate by 5 releases/minute
4. The patient essentially transitions to CPAP with very few releases.
5. Patients should be increasing their spontaneous rate to compensate.

APRV Benefits

- Preservation of spontaneous breathing and comfort with most spontaneous breathing occurring at high CPAP
- ↓WOB
- ↓Barotrauma
- ↓Circulatory compromise
- Better V/Q matching
- Less sedation & analgesia

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Disadvantage of APRV

- APRV does not completely support CO_2 elimination, but relies on spontaneous breathing
- Volumes change with alteration in lung compliance and resistance
- If spontaneous efforts not matched during transition from P_{high} to P_{low} and P_{low} to P_{high}, may lead to increased work load and discomfort for the patient
- Limited staff experience with this mode may make implementation of its use difficult

MMV

- Mandatory Minute Ventilation (PS ± VC)
- A modified version of SIMV
  - During SIMV patient always receives set number of mandatory breaths
  - During MMV if patient's spontaneous MV ≥ set MV mandatory breaths disappear
- Clinical situations where it is useful:
  - Post operative patients
  - Periodic apnea
- Set low minute alarm appropriately

New Modes of Mechanical Ventilation: Other neat stuff

- Auto mode switching: more support to less and less to more (without alarms)
  - Servo 300's Auto Mode:
    - VC or PRVC ⇔ VS;   or   PC ⇔ PS
- Automatic tube compensation: Drager Evita 4
- May be useful with pressure support
- Adds additional pressure to overcome resistance imposed by tube diameter and flow
- Settings:
  - Tube type (ETT, Trach)
  - Degree of compensation (set @ 100%)
- Those who have failed previous extubation attempts
- The "difficult to wean" patient

New Modes of Mechanical Ventilation: Summary

- Older modes & ventilators:
  - passive, operator-dependant tools
- New modes on new generation ventilators:
  - adaptively interactive
  - goal oriented
  - patient centered
- ''Not all that glitters is gold ''