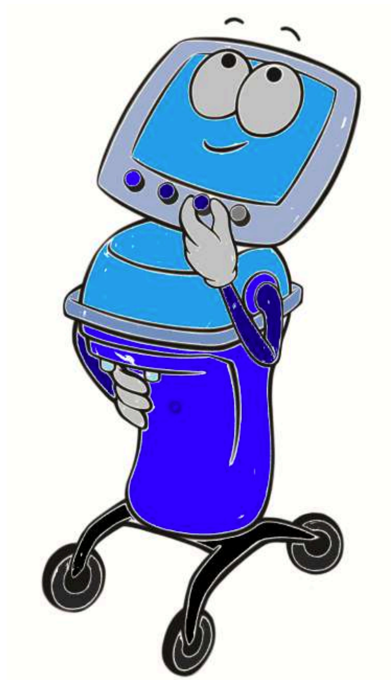
Basics of Mechanical Ventilation for the COVID-19 Patient



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Financial Disclosures

None

Talk Objectives

- discuss the rationale of positive pressure ventilation for patients with ARDS secondary to COVID-19

- review the basics of volume-controlled ventilation

- explain how to set and adjust the important parameters in volume-controlled ventilation for COVID-19 patients with ARDS

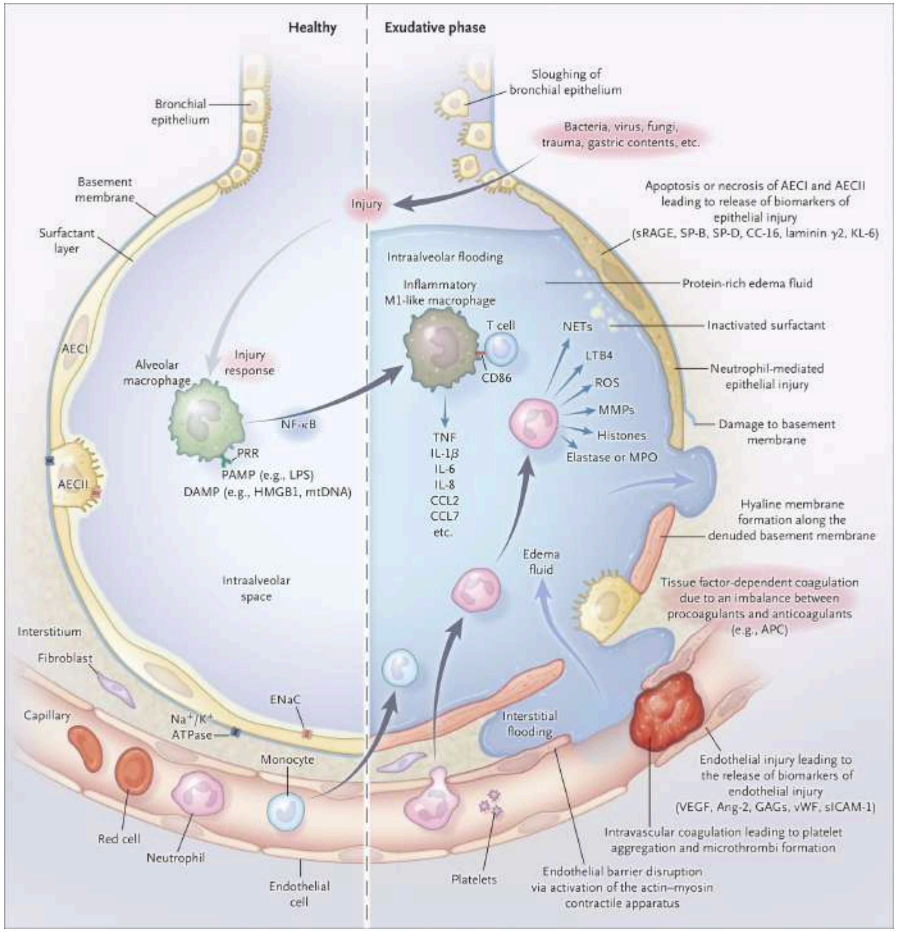
COVID-19 Causes ARDS

ARDS Definition:

- acute
- bilateral opacities
- PaO_2/F_IO_2 ratio < 300 mmHg with PEEP $\geq$ 5 cmH_2O
- not completely explained by cardiac failure or volume overload

ARDS Pathophysiology

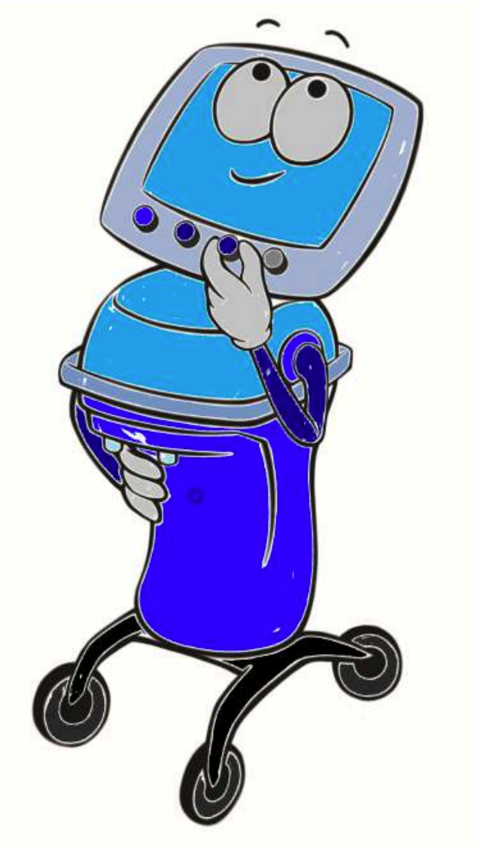
- lung injury and inflammation create leaky capillaries and leaky alveoli
- alveoli fill up with fluid
- gas exchange impaired
- alveoli collapse
- lungs become stiffer
- patients ultimately develop respiratory failure



Thompson, NEJM 2017

Ventilator Support in ARDS

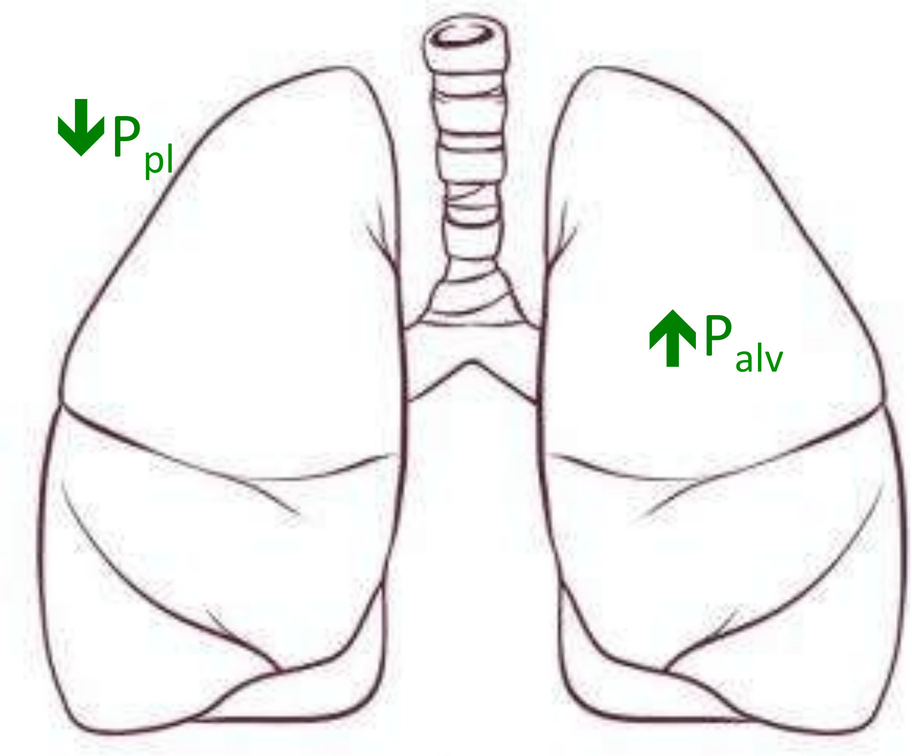
- deliver high amounts of oxygen
  - high F_IO_2
- provide positive pressure to reduce work of breathing
  - ventilator **PUSHES** air in so muscles of inspiration do not have to work as hard to **SUCK** air in
- provide positive end-expiratory pressure (PEEP)
  - prevents open alveoli from collapsing



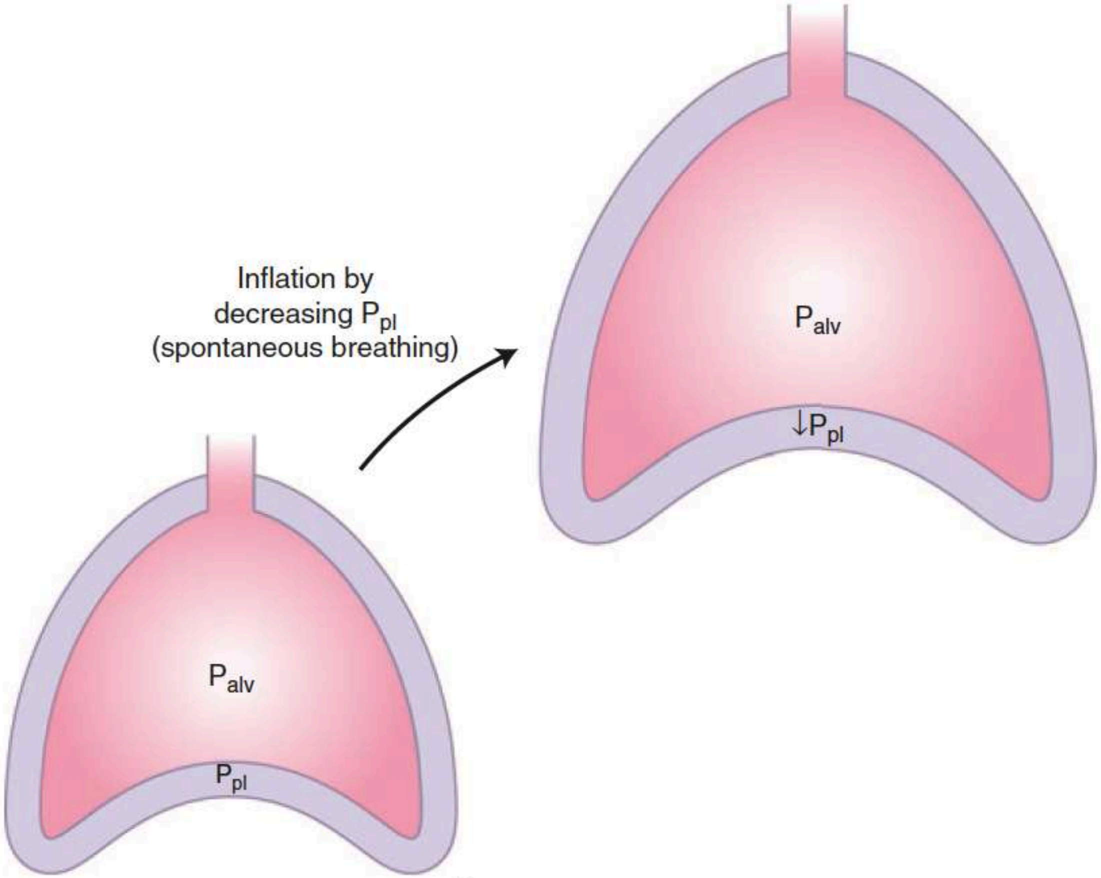
How to Inflate Lungs

a) increase pressure inside of the lungs (P_{alv})

b) decrease the pressure outside of the lungs (P_{pl})

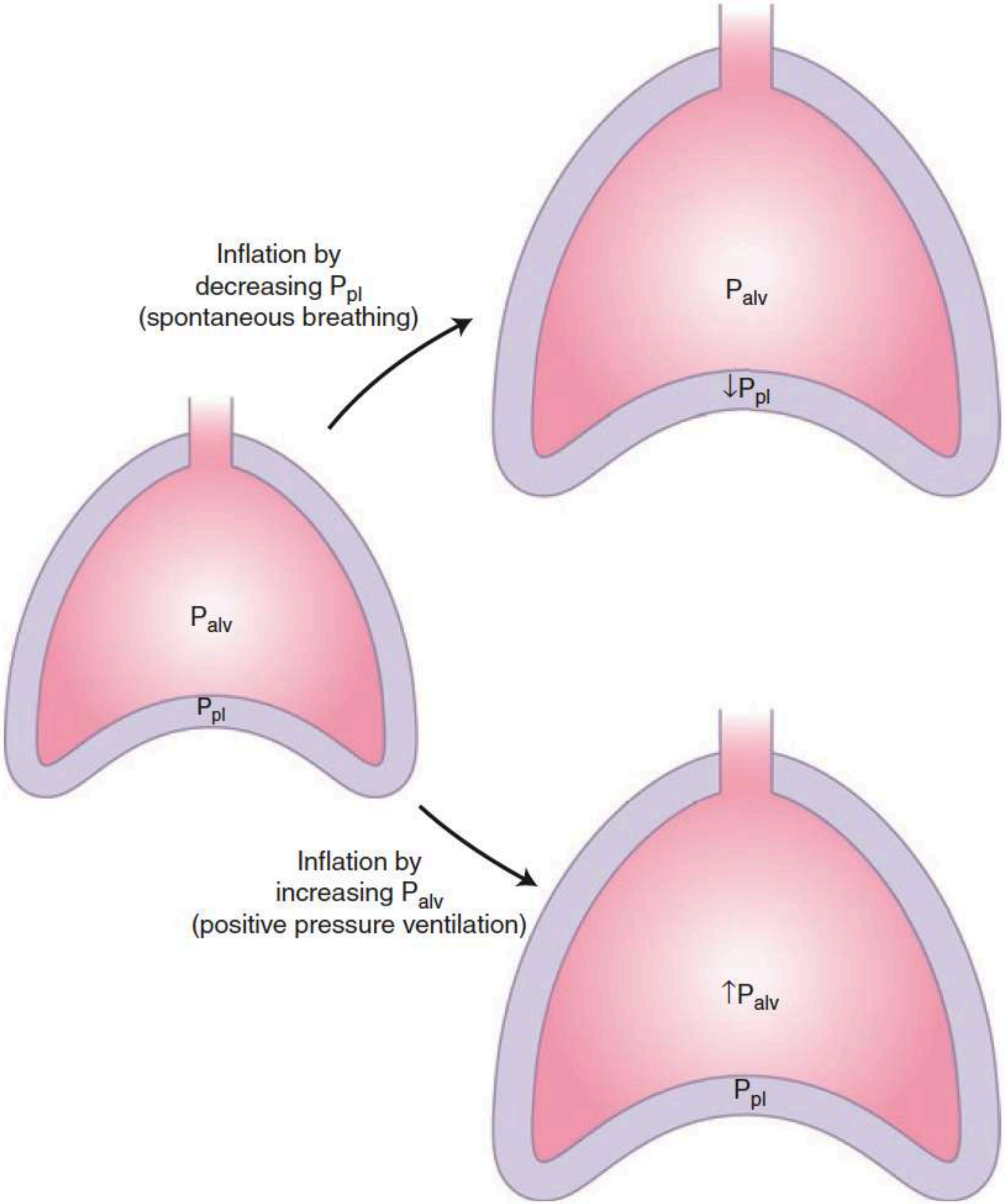


P_{alv} = alveolar pressure
P_{pl} = pleural pressure



spontaneous ventilation

Poor, Basics of Mechanical Ventilation, 2018



spontaneous ventilation

positive pressure ventilation

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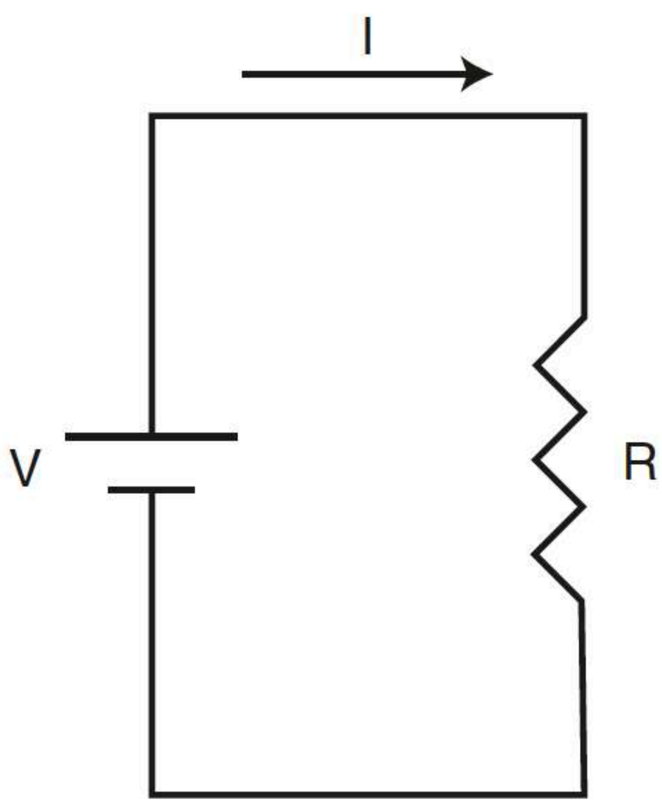

$$V = I \times R$$

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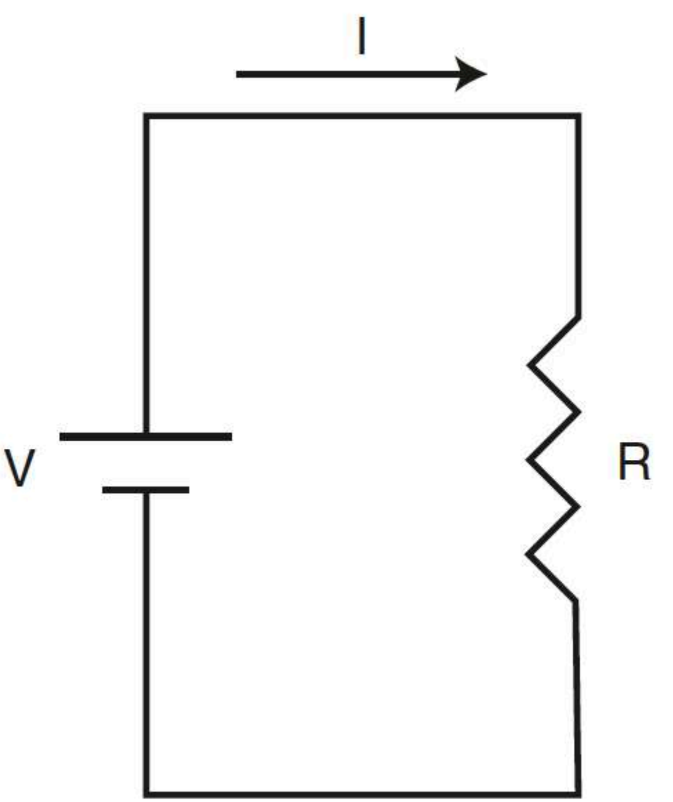

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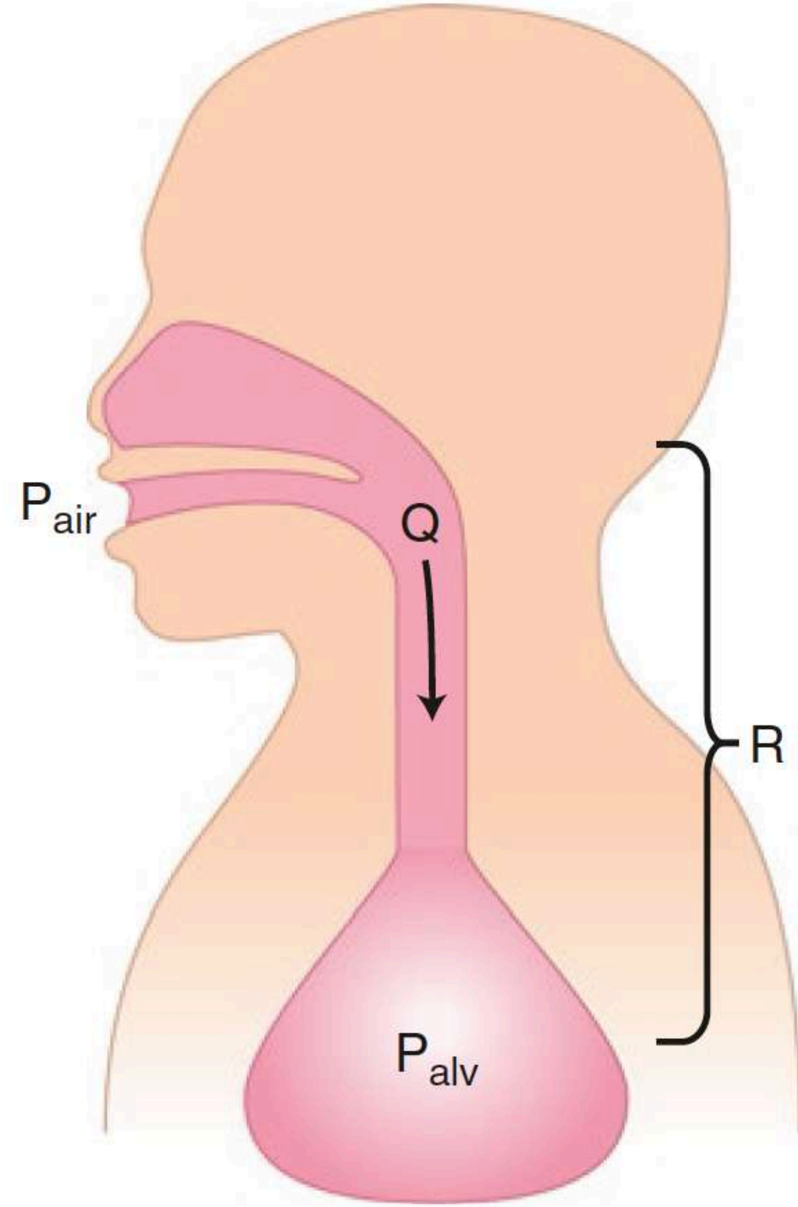

$$P_{air} - P_{alv} = Q \times R$$

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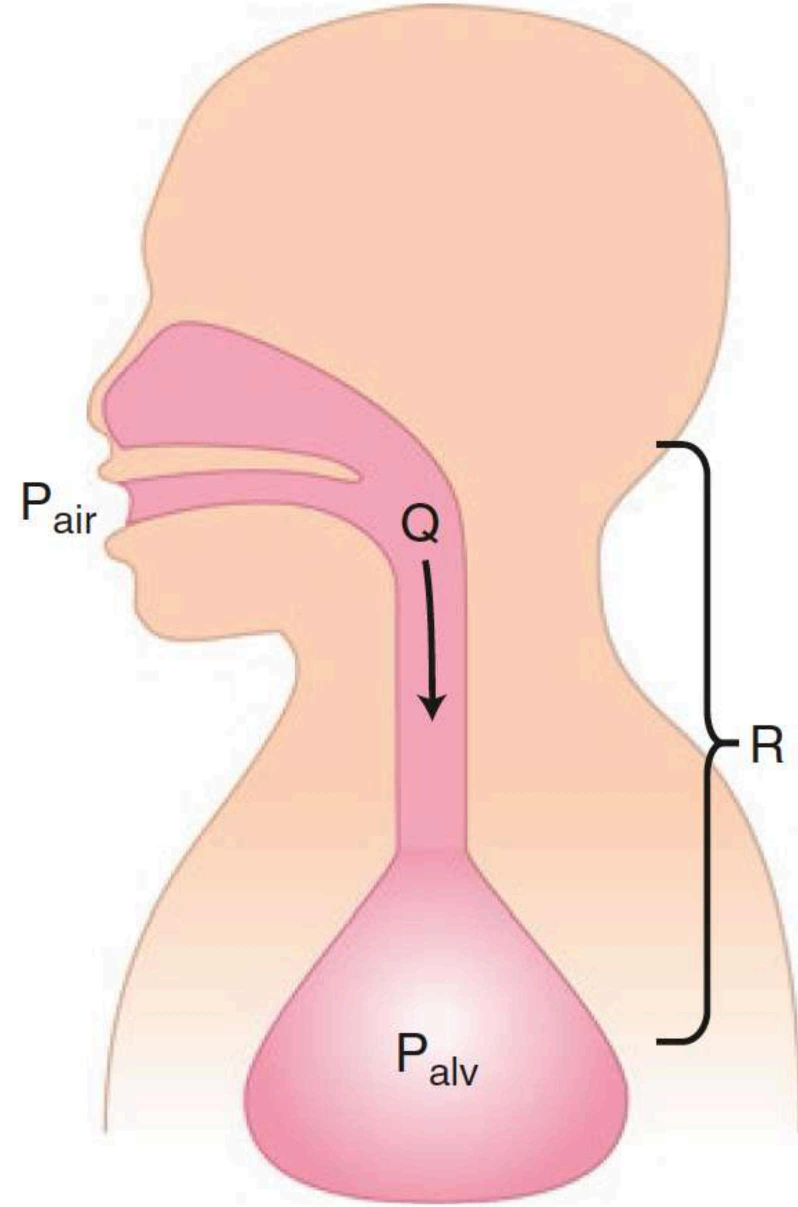
$$Q= P_{air} - P_{alv} /R$$



$$P_{air} - P_{alv} = Q \times R$$

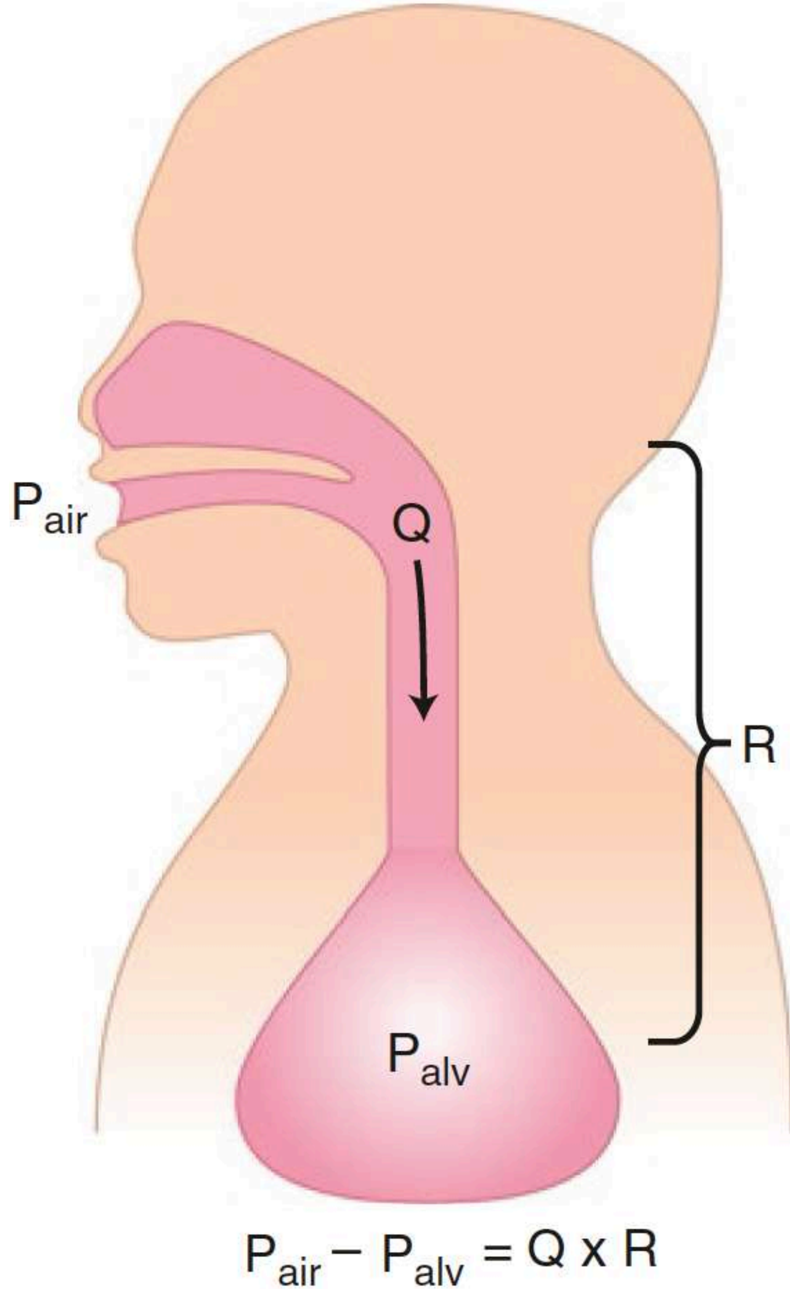
P_{air} = proximal airway pressure
P_{alv} = alveolar pressure
Q = flow
R = resistance

Poor, Basics of Mechanical Ventilation, 2018

spontaneous ventilation

$Q = P_{air} - P_{alv} / R$

Suck air into lungs



P_{air} = proximal airway pressure
P_{alv} = alveolar pressure
Q = flow
R = resistance

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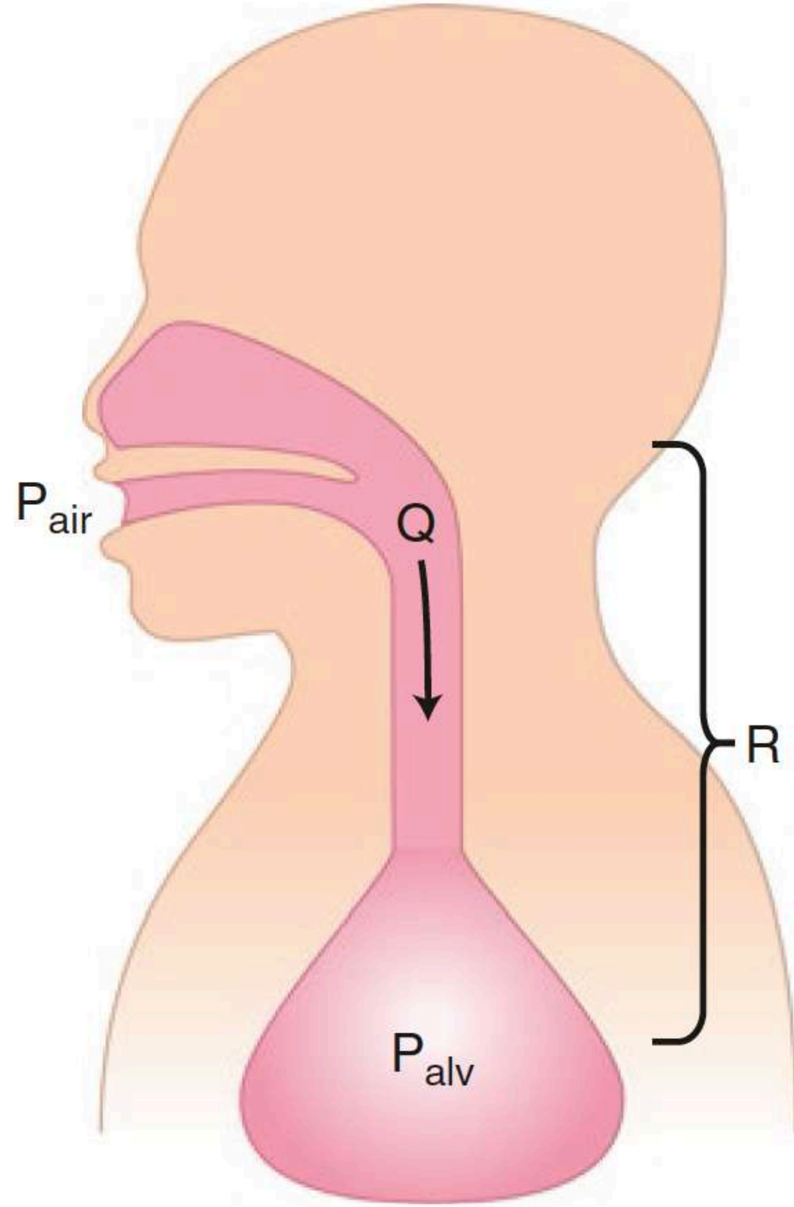
positive pressure ventilation

$$Q = P_{air} - P_{alv} / R$$

Push air into lungs



$$P_{air} - P_{alv} = Q \times R$$

P_{air} = proximal airway pressure
P_{alv} = alveolar pressure
Q = flow
R = resistance

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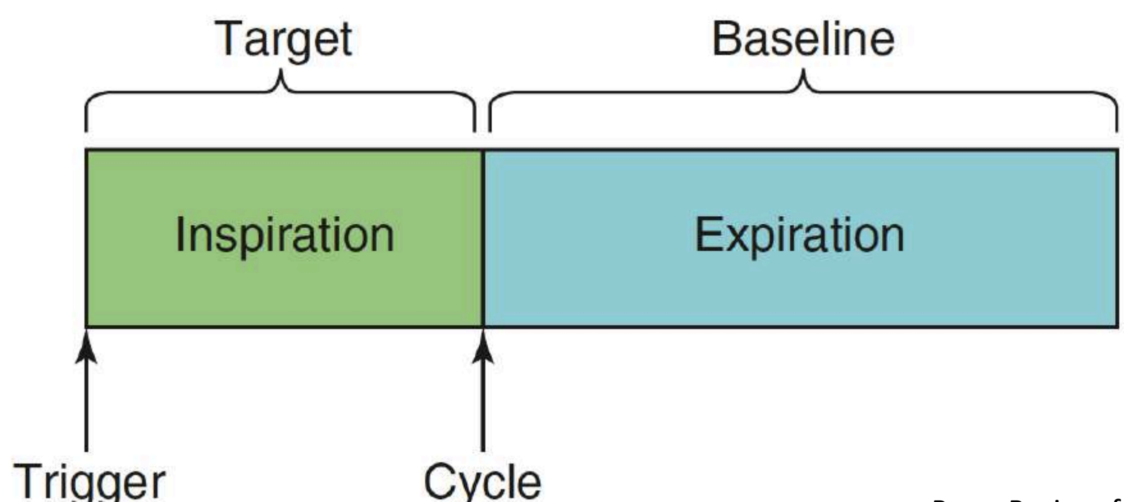
Regardless of the mode of ventilation...

- the ventilator increases airway pressure for a set time
  - airflow into the patient
  - culminates in delivered tidal volume
- “phase variables” determine the mode of ventilation
  - ventilator instructions
  - determine “when” and “how” breaths delivered

$$Q = P_{air} - P_{alv} / R$$

Phase Variables:
"Anatomy of a Breath"

- trigger → when inspiration begins
- target → how flow is delivered during inspiration
- cycle → when inspiration ends
- baseline → proximal airway pressure during expiration



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Modes of Ventilation

trigger

target

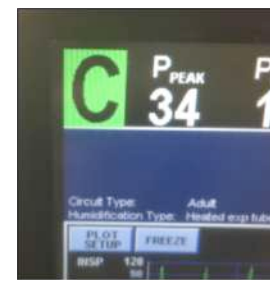
cycle

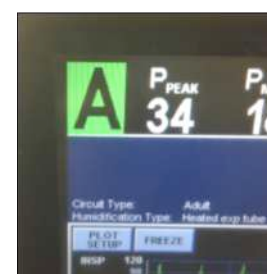
What mode of ventilation should I use?

For the sake of simplicity, use **volume-controlled ventilation (VCV)**

Trigger

- Who initiates the breath?
  - ventilator
  - patient
- ventilator-triggered
  - aka **<u>CONTROL</u>**
  - variable that is set → time
  - set respiratory rate (frequency = 1/time)
  - RR 12 bpm is one breath every 5 seconds
- patient-triggered
  - aka **<u>ASSIST</u>**
  - flow or pressure changes sensed by ventilator





Assist-Control → Hybrid Trigger

- assist trigger + control trigger = assist-control (A/C)

“A/C” refers only to the trigger.

Volume-controlled ventilation uses A/C as the trigger mechanism.

How Much Assist? How Much Control?

control respiratory rate

- 10 bpm
- breath every 6 sec

neural respiratory rate

- 20 bpm
- breath every 3 sec

What percentage of the breaths will be assist, what percentage will be control?

100% ASSIST

Control rate clock resets after an “assist” breath.

How Much Assist? How Much Control?

control respiratory rate

- 10 bpm

neural respiratory rate

- 20 bpm
- breath every 3 sec

How Much Assist? How Much Control?

control respiratory rate

- 30 bpm
- breath every 2 sec

neural respiratory rate

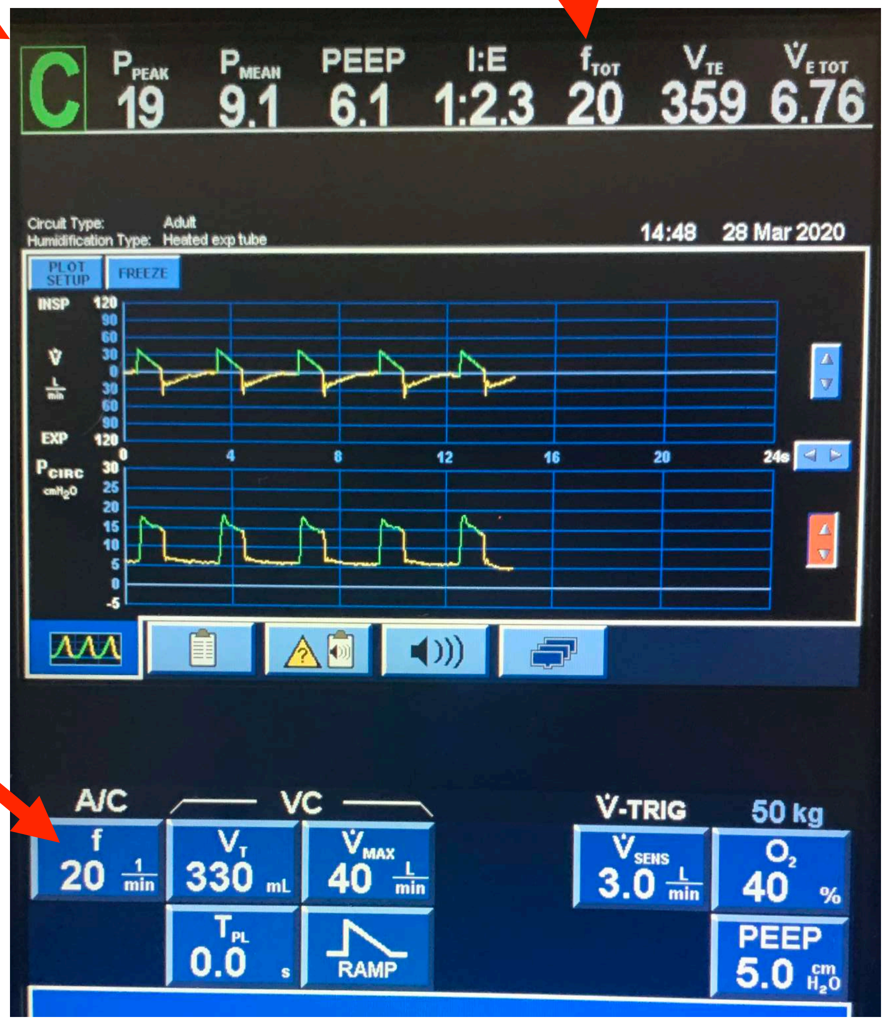
- 20 bpm
- breath every 3 sec

What percentage of the breaths will be assist, what percentage will be control?

100% CONTROL

last breath was a “control” breath

actual respiratory rate

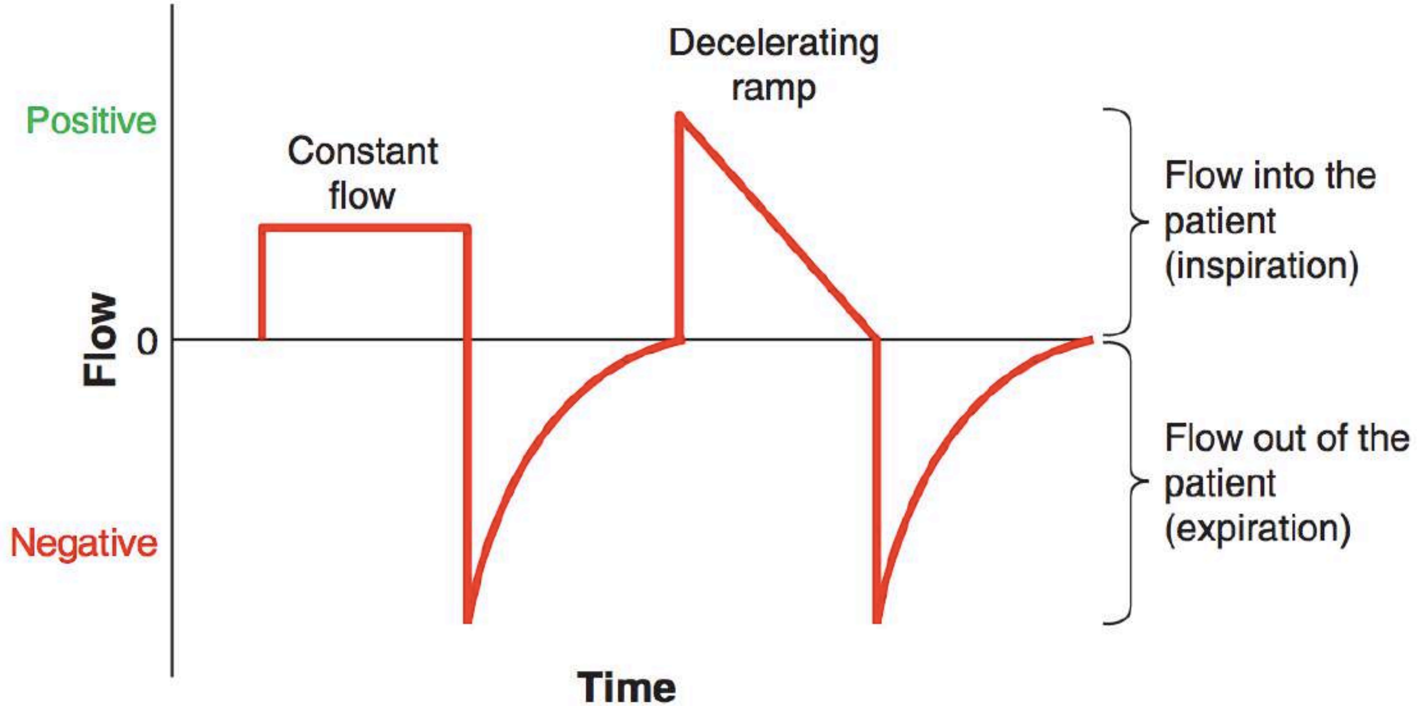


control respiratory rate

Target

How is flow during inspiration determined?

- flow rate is set in volume-controlled ventilation



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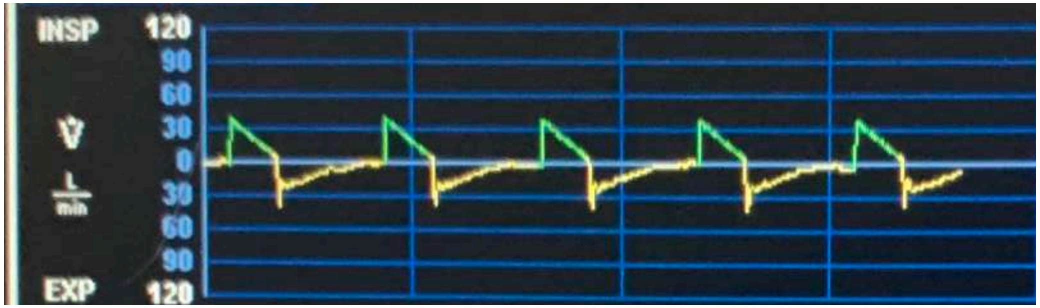
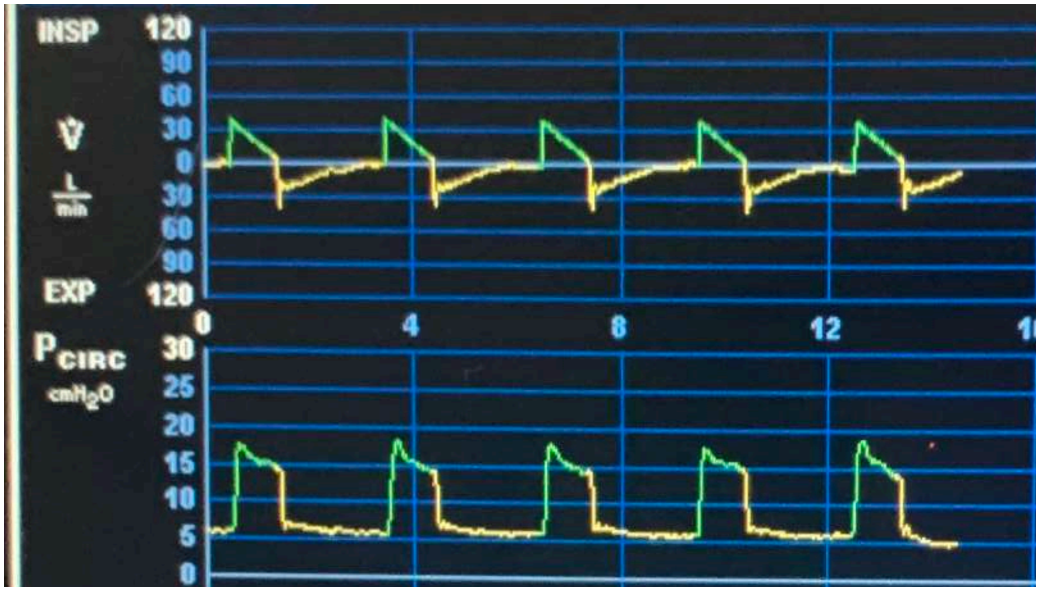
C
PPEAK 19
PMEAN 9.1
PEEP 6.1
I:E 1:2.3
fTOT 20
VTE 359
V̇E TOT 6.76
Circuit Type: Adult
Humidification Type: Heated exp tube
14:48 28 Mar 2020
INSP
EXP
PCIRC cmH2O
A/C
VC
V̇-TRIG
50 kg
f 20 1/min
VT 330 mL
V̇MAX 40 L/min
V̇SENS 3.0 L/min
O2 40 %
TPL 0.0 s
RAMP
PEEP 5.0 cmH2O
peak inspiratory flow rate
decelerating ramp shape

VCV is a Flow-Targeted Mode



VCV is a Flow-Targeted Mode



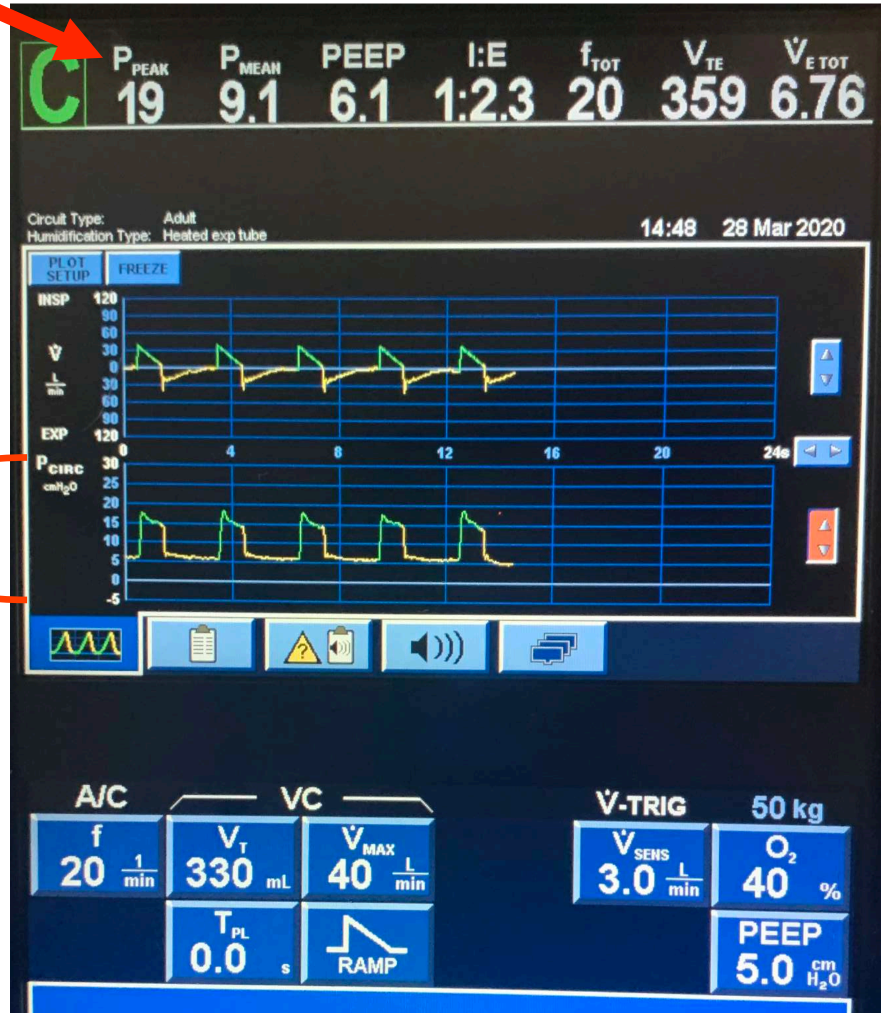
P_{air} will change with changes in respiratory system

$$Q = P_{air} - P_{alv} / R$$

Q will not change with changes in respiratory system

peak pressure

pressure waveform



Target

$$Q = P_{air} - P_{alv} / R$$

biting endotracheal tube

$$Q = P_{air} - P_{alv} / R$$

flow-targeted mode

flow unchanged

$$Q = P_{air} - P_{alv} / R$$

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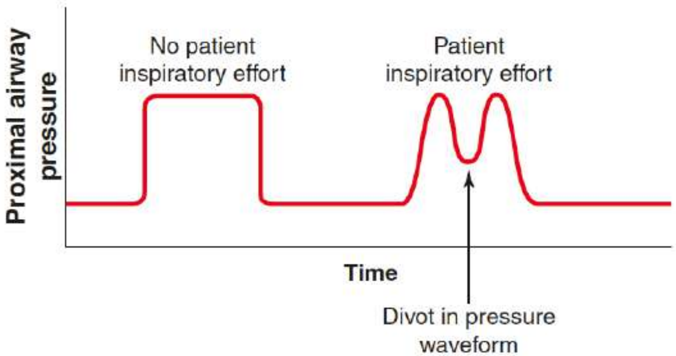
Target

$$Q= P_{air} - P_{alv} /R$$



sustained inspiratory effort

$$P_{air} - P_{alv} /R \downarrow$$

flow-targeted mode

flow unchanged

$$Q= P_{air} \downarrow - P_{alv} /R \downarrow$$

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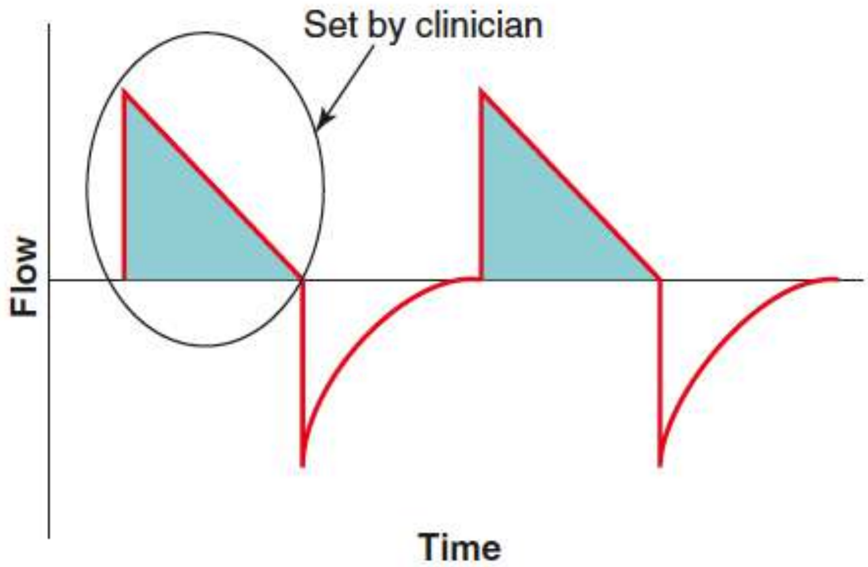
Cycle

When does inspiration end?

- volume is set in volume-controlled ventilation



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exhaled tidal volume
returning to ventilator

tidal volume

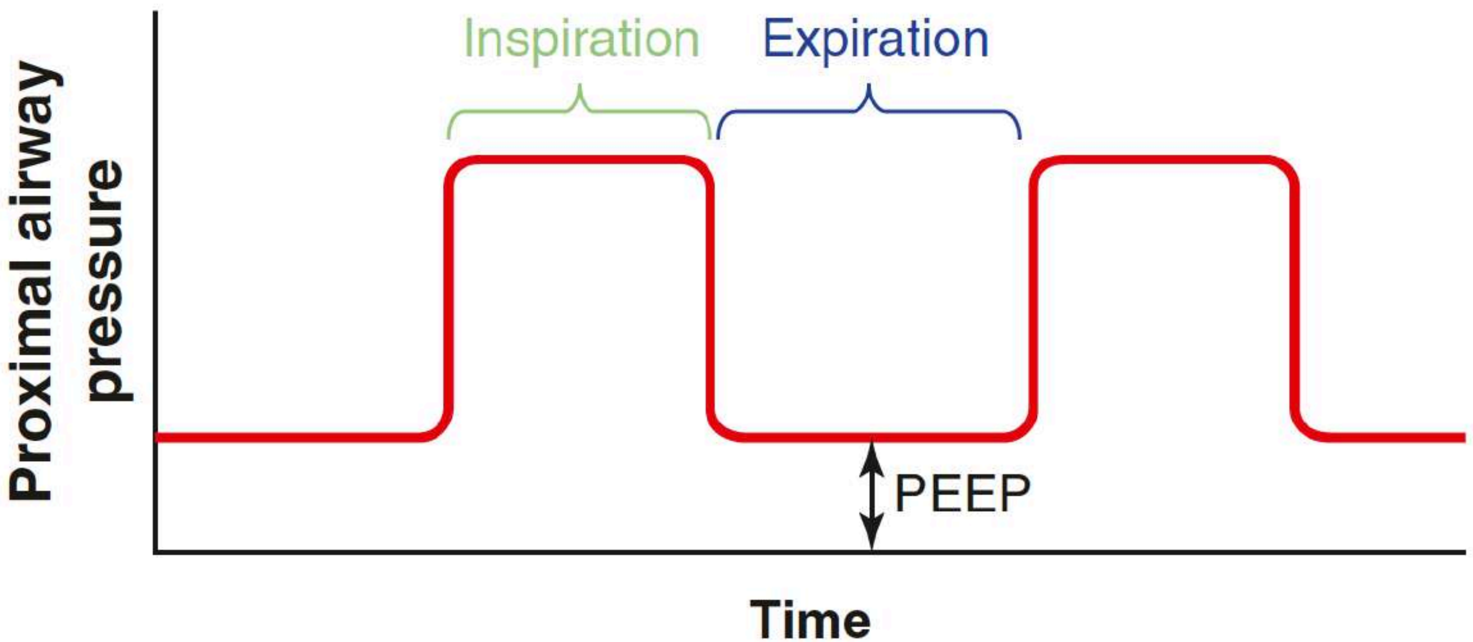
Low Tidal Volume Ventilation

- high tidal volume in ARDS causes lung stretch and further lung damage
  - "volutrauma"

- low tidal volume ventilation is essential
  - set tidal volume to 6 cc/kg of **ideal body weight**
  - can be uncomfortable for patients (will likely need sedation, and sometimes even paralysis)

Baseline

- What is proximal airway pressure during expiration?
- aka PEEP



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PEEP in ARDS

- repetitive opening and closing of alveoli causes further lung damage
  - "atelectrauma"

- PEEP prevents open alveoli from closing

- maintaining alveoli open will improve gas exchange

ARDSnet

NIH NHLBI ARDS Clinical Network
Mechanical Ventilation Protocol Summary

INCLUSION CRITERIA: Acute onset of

1. $PaO_2/FiO_2 \leq 300$ (corrected for altitude)
2. Bilateral (patchy, diffuse, or homogeneous) infiltrates consistent with pulmonary edema
3. No clinical evidence of left atrial hypertension

PART I: VENTILATOR SETUP AND ADJUSTMENT

1. Calculate predicted body weight (PBW)
   Males = 50 + 2.3 [height (inches) - 60]
   Females = 45.5 + 2.3 [height (inches) -60]
2. Select any ventilator mode
3. Set ventilator settings to achieve initial V_T = 8 ml/kg PBW
4. Reduce V_T by 1 ml/kg at intervals ≤ 2 hours until V_T = 6ml/kg PBW.
5. Set initial rate to approximate baseline minute ventilation (not > 35 bpm).
6. Adjust V_T and RR to achieve pH and plateau pressure goals below.

OXYGENATION GOAL: PaO_2 55-80 mmHg or SpO_2 88-95%
Use a minimum PEEP of 5 cm H_2O. Consider use of incremental FiO_2/PEEP combinations such as shown below (not required) to achieve goal.

Lower PEEP/higher FiO2

FiO_2	0.3	0.4	0.4	0.5	0.5	0.6	0.7	0.7
PEEP	5	5	8	8	10	10	10	12

FiO_2	0.7	0.8	0.9	0.9	0.9	1.0
PEEP	14	14	14	16	18	18-24

Higher PEEP/lower FiO2

FiO_2	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.5
PEEP	5	8	10	12	14	14	16	16

FiO_2	0.5	0.5-0.8	0.8	0.9	1.0	1.0
PEEP	18	20	22	22	22	24

PLATEAU PRESSURE GOAL: ≤ 30 cm H_2O
Check Pplat (0.5 second inspiratory pause), at least q 4h and after each change in PEEP or V_T.
If Pplat > 30 cm H_2O: decrease V_T by 1ml/kg steps (minimum = 4 ml/kg).
If Pplat < 25 cm H_2O and V_T< 6 ml/kg, increase V_T by 1 ml/kg until Pplat > 25 cm H_2O or V_T = 6 ml/kg.
If Pplat < 30 and breath stacking or dys-synchrony occurs: may increase V_T in 1ml/kg increments to 7 or 8 ml/kg if Pplat remains ≤ 30 cm H_2O.

Use the High PEEP Ladder

Higher PEEP/lower FiO2

FiO_2	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.5
PEEP	5	8	10	12	14	14	16	16

FiO_2	0.5	0.5-0.8	0.8	0.9	1.0	1.0
PEEP	~~18~~	~~20~~	~~22~~	~~22~~	~~22~~	~~24~~

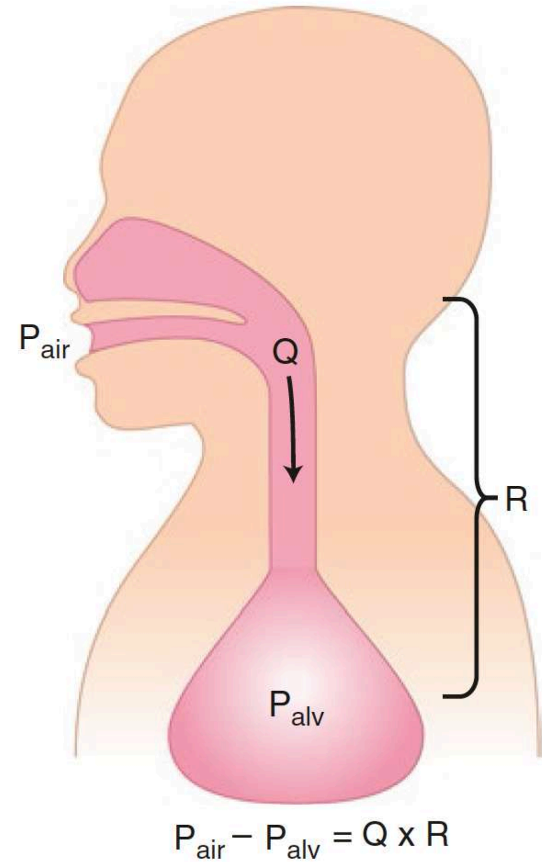
16

- COVID-19 patients appear to be very "PEEP-responsive"
- do not increase PEEP above 16 cm H_2O without guidance from a critical care physician

C
P PEAK 19
P MEAN 9.1
PEEP 6.1
I:E 1:2.3
f TOT 20
V TE 359
V̇ E TOT 6.76
Circuit Type: Adult
Humidification Type: Heated exp tube
14:48 28 Mar 2020
PLOT SETUP
FREEZE
INSP
EXP
P CIRC
A/C
VC
f 20 1/min
V T 330 mL
V̇ MAX 40 L/min
T PL 0.0 s
RAMP
V̇-TRIG
50 kg
V̇ SENS 3.0 L/min
O2 40 %
PEEP 5.0 cm H2O
F_IO_2
PEEP

Plateau Pressure (P_{pl})

- estimate of the maximum pressure in the alveolus during the respiratory cycle
- to measure P_{pl}, perform inspiratory pause maneuver
  - after tidal volume is delivered, expiratory valve remains shut and air does not leave patient
  - pressure measured at end of maneuver is called "plateau pressure"
- high P_{pl} can lead to "barotrauma"
  - pneumothorax, pneumomediastinum
  - goal P_{pl} in ARDS is $\leq$ 30 cm H_2O



Plateau Pressure

plateau pressure

Your COVID-19 Patient Just Got Intubated

- place on volume-controlled ventilation
- set respiratory rate to 20 bpm
- set tidal volume to 6 cc/kg of **<u>ideal body weight</u>**
- set F_IO_2 to 100%
- set PEEP to 15 cm H_20
- check plateau pressure (P_{pl})
  - if P_{pl} > 30 cm H_2O, reduce tidal volume to 5 cc/kg
  - if P_{pl} still > 30 cm H_2O, call for help
- ensure patient is well sedated
- check ABG or VBG 30 minutes after settings adjusted to ensure appropriate pH
  - if pH < 7.2, increase RR (maximum of 35 bpm)

Your COVID-19 Patient is Improving

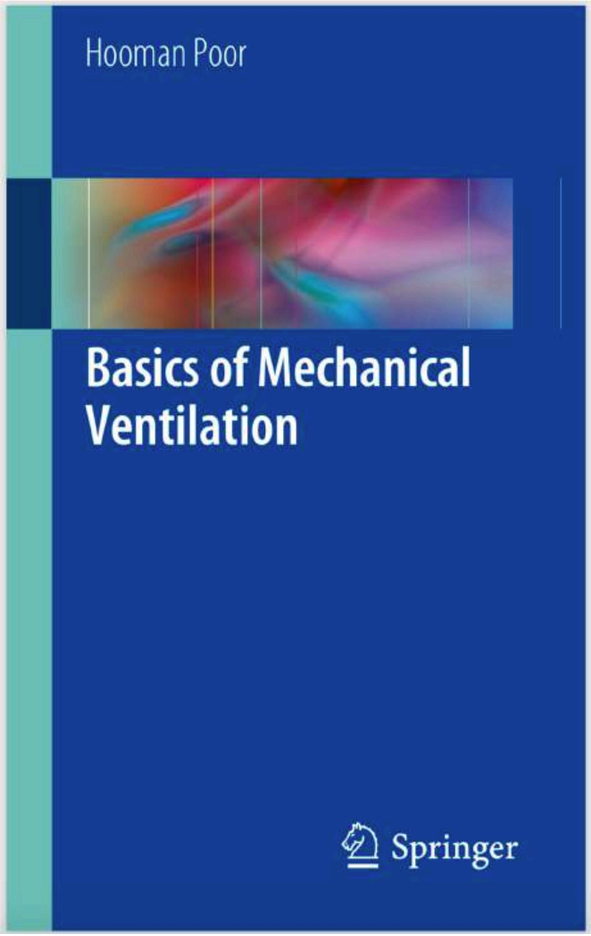
- wean F_IO_2 and PEEP as per the ARDSnet ladder to ensure SpO_2 88-95%
- wait at least 12 hours between changes in PEEP

Higher PEEP/lower FiO2

FiO_2	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.5
PEEP	5	8	10	12	14	14	16	16

FiO_2	0.5	0.5-0.8	0.8	0.9	1.0	1.0	
PEEP	~~18~~	~~20~~	~~22~~	~~22~~	~~22~~	~~24~~	16

Further Reading



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Good Luck!


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I'm afraid it can no longer breathe on its own.
7-2-12
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