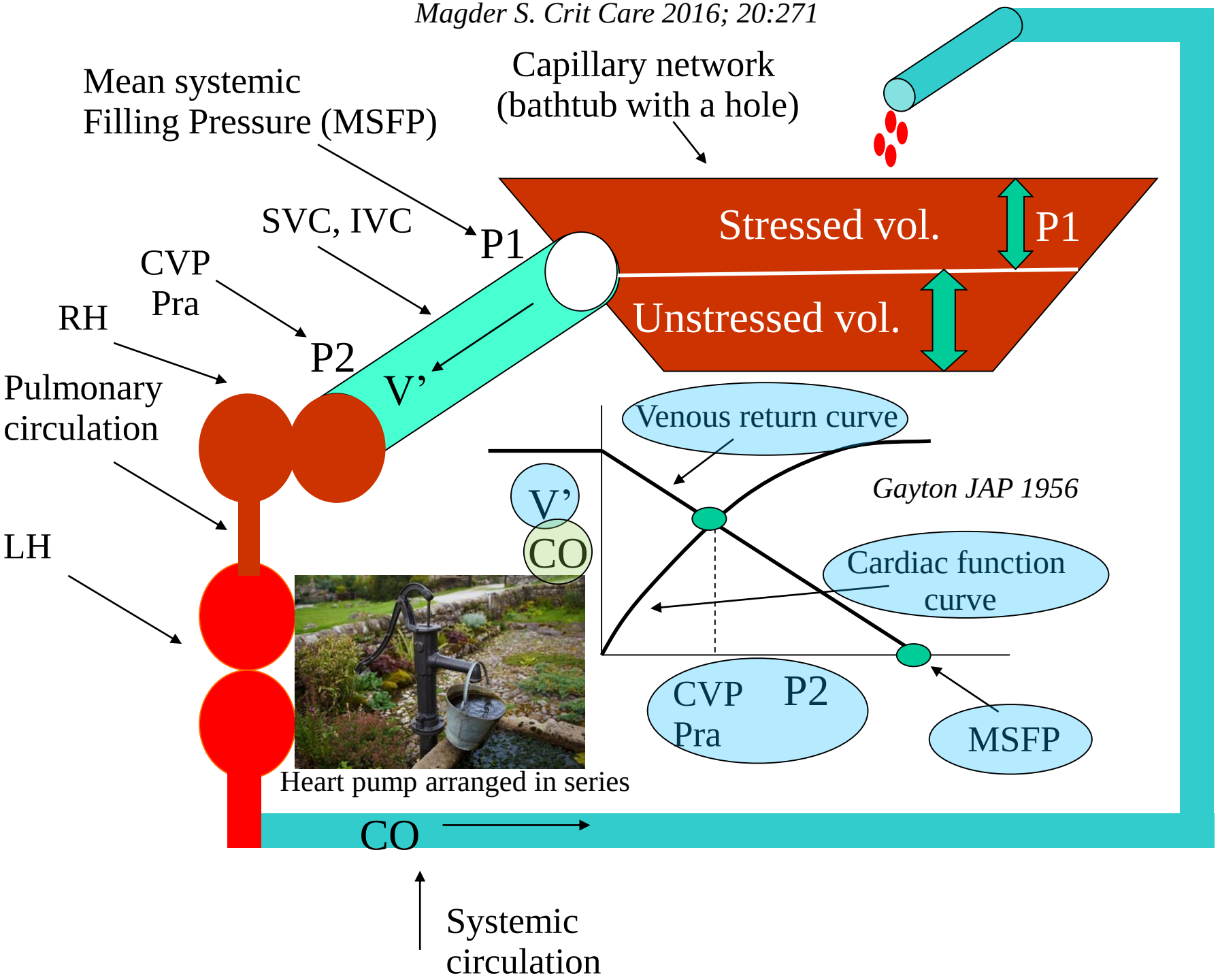
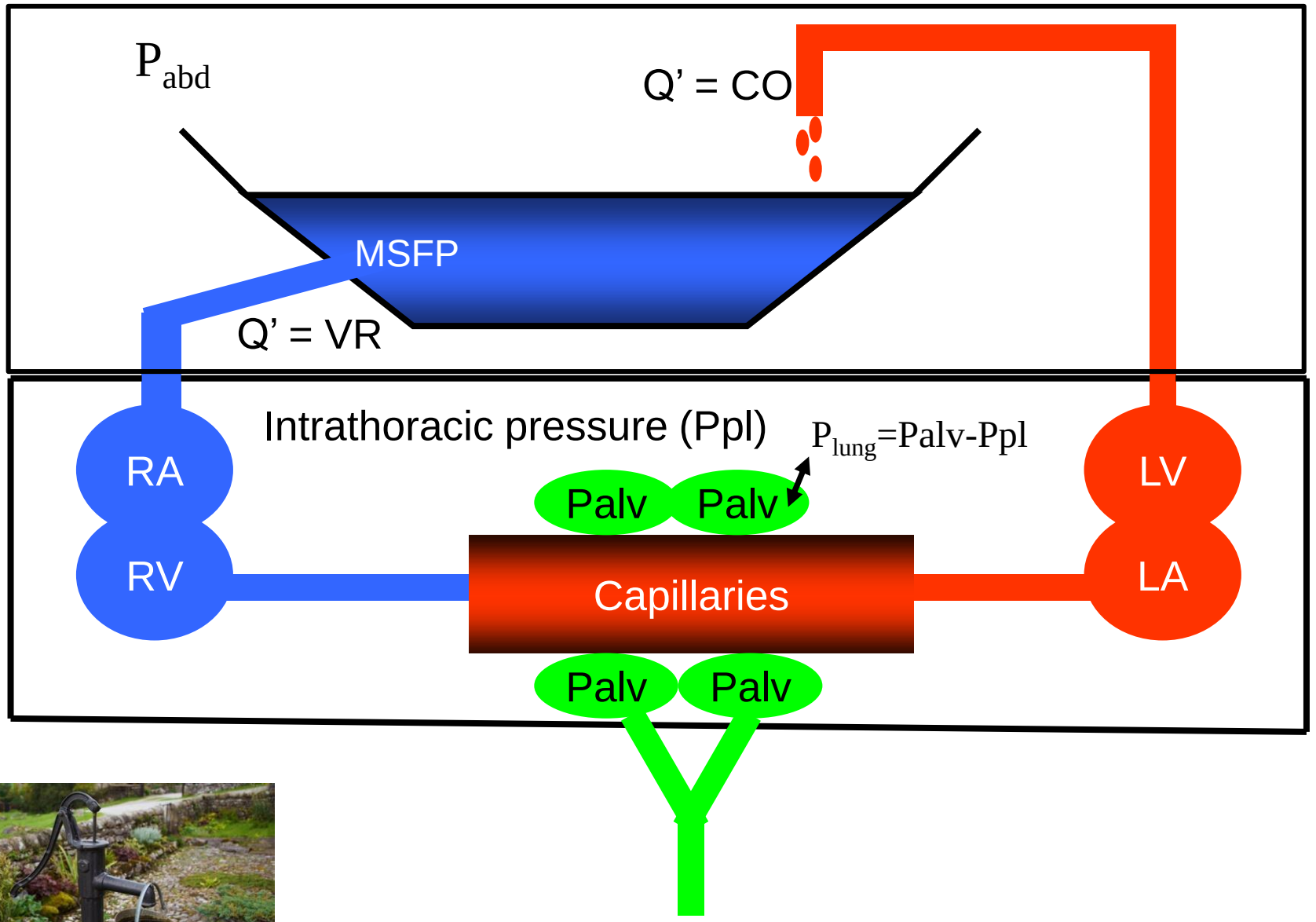
Heart-lung interaction - Its role in pulmonary circulation

(Spontaneous breathing –mechanical ventilation)

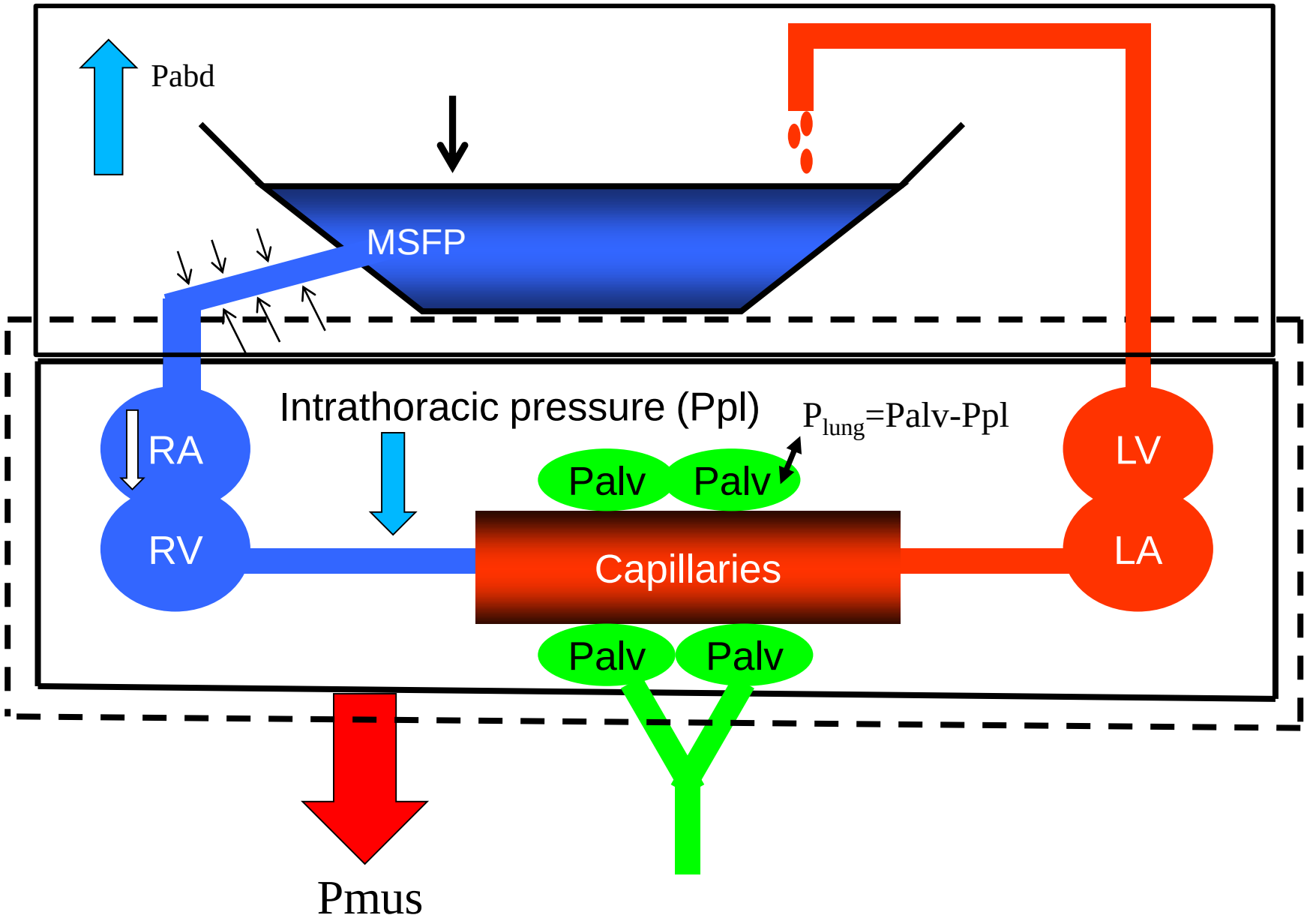
D. Georgopoulos, Professor of Medicine,
Department of Intensive Care Medicine,
University Hospital of Heraklion,
University of Crete, Greece

Magder et al. Crit Care Med 1998;26:1061
Magder S. Crit Care 2016; 20:271

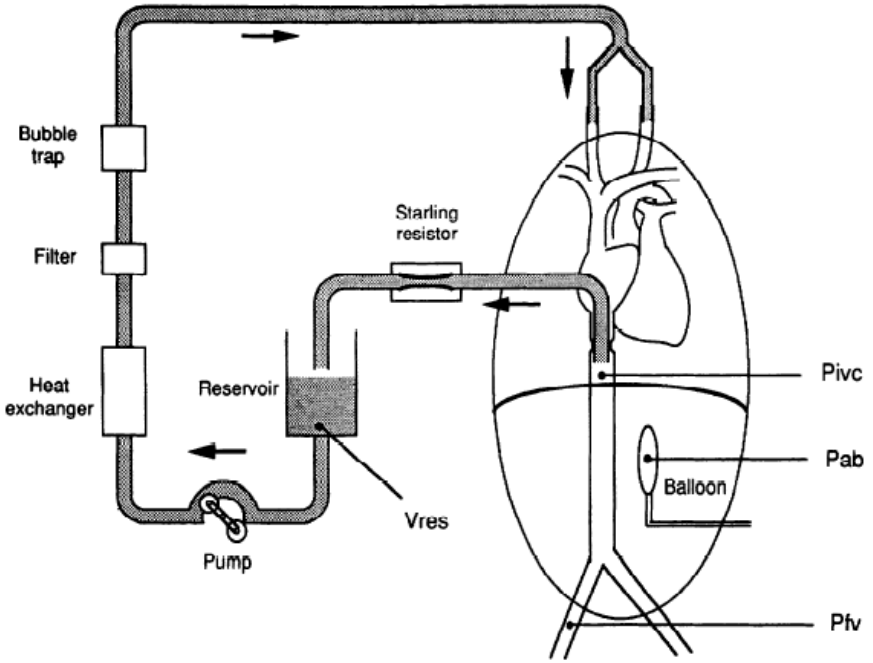




Venous return (VR) = Cardiac output (CO)

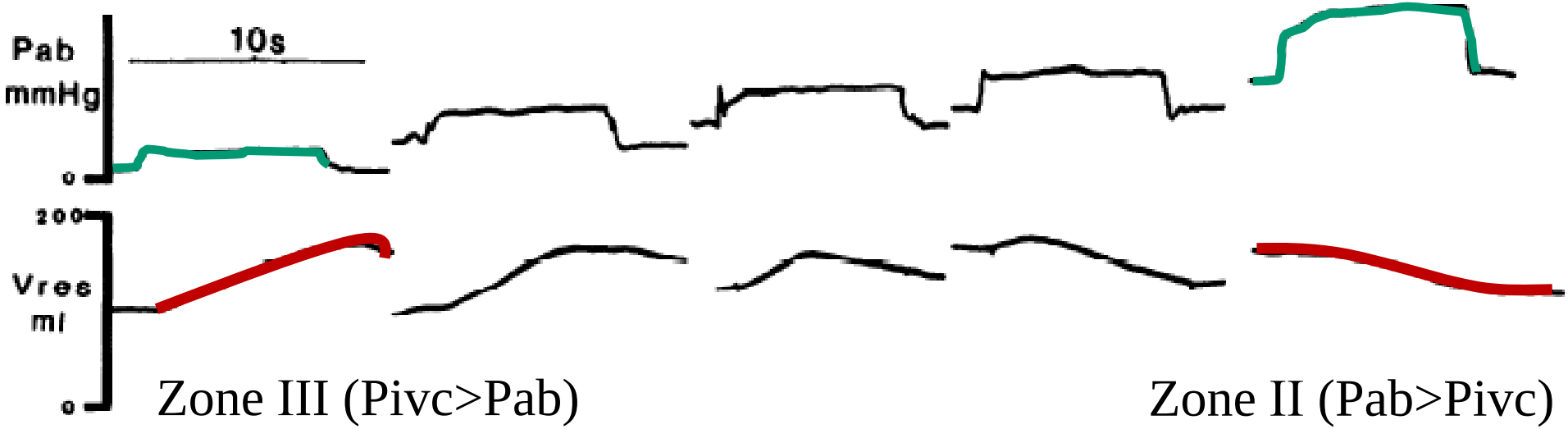

Pabd
MSFP
Intrathoracic pressure (Ppl)
P_{lung}=Palv-Ppl
RA
RV
Palv
Palv
Capillaries
LV
LA
Palv
Palv
Pmus

Takata et al. J Appl Physiol 1990;69:1961



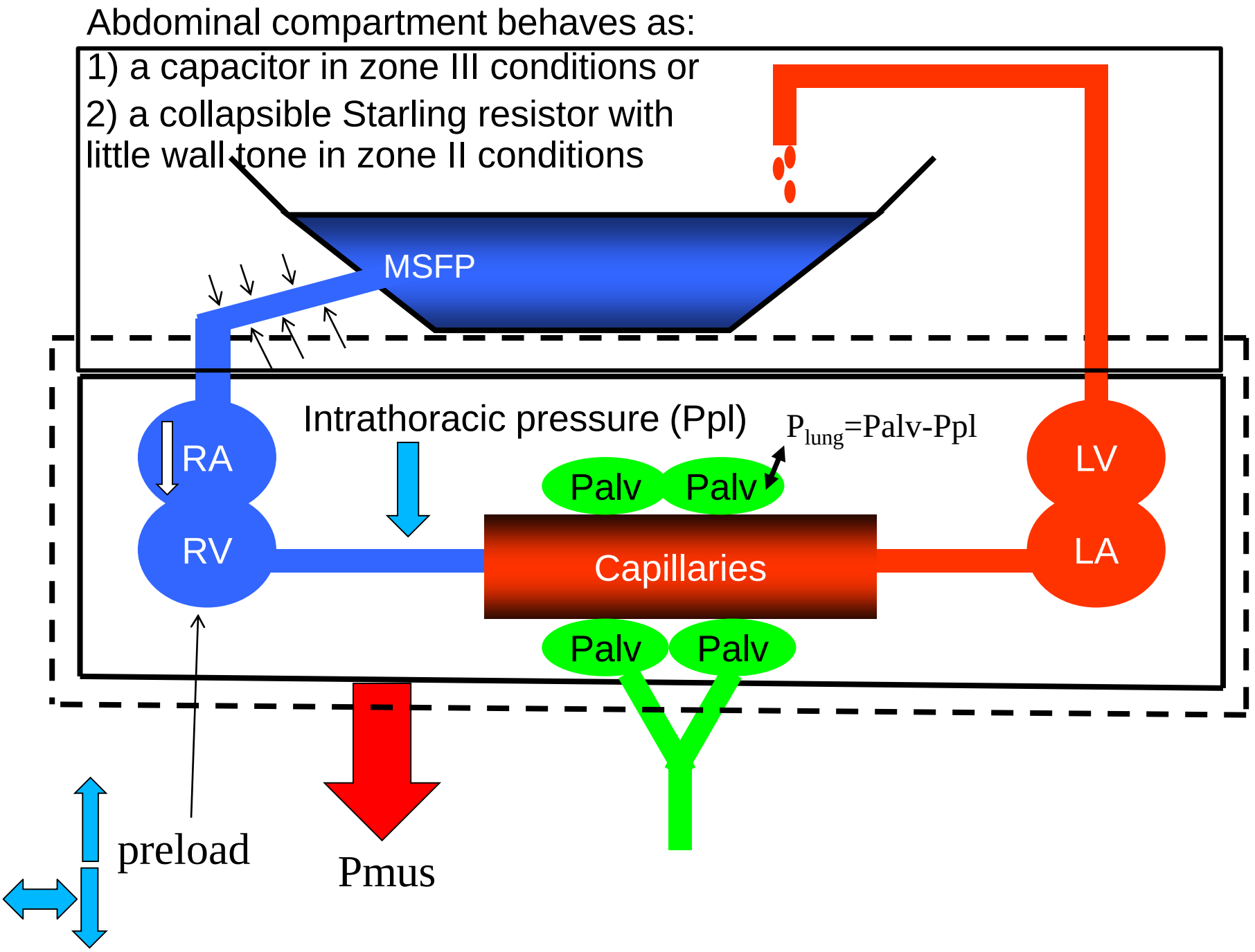
8 sec Phrenic nerve stimulation

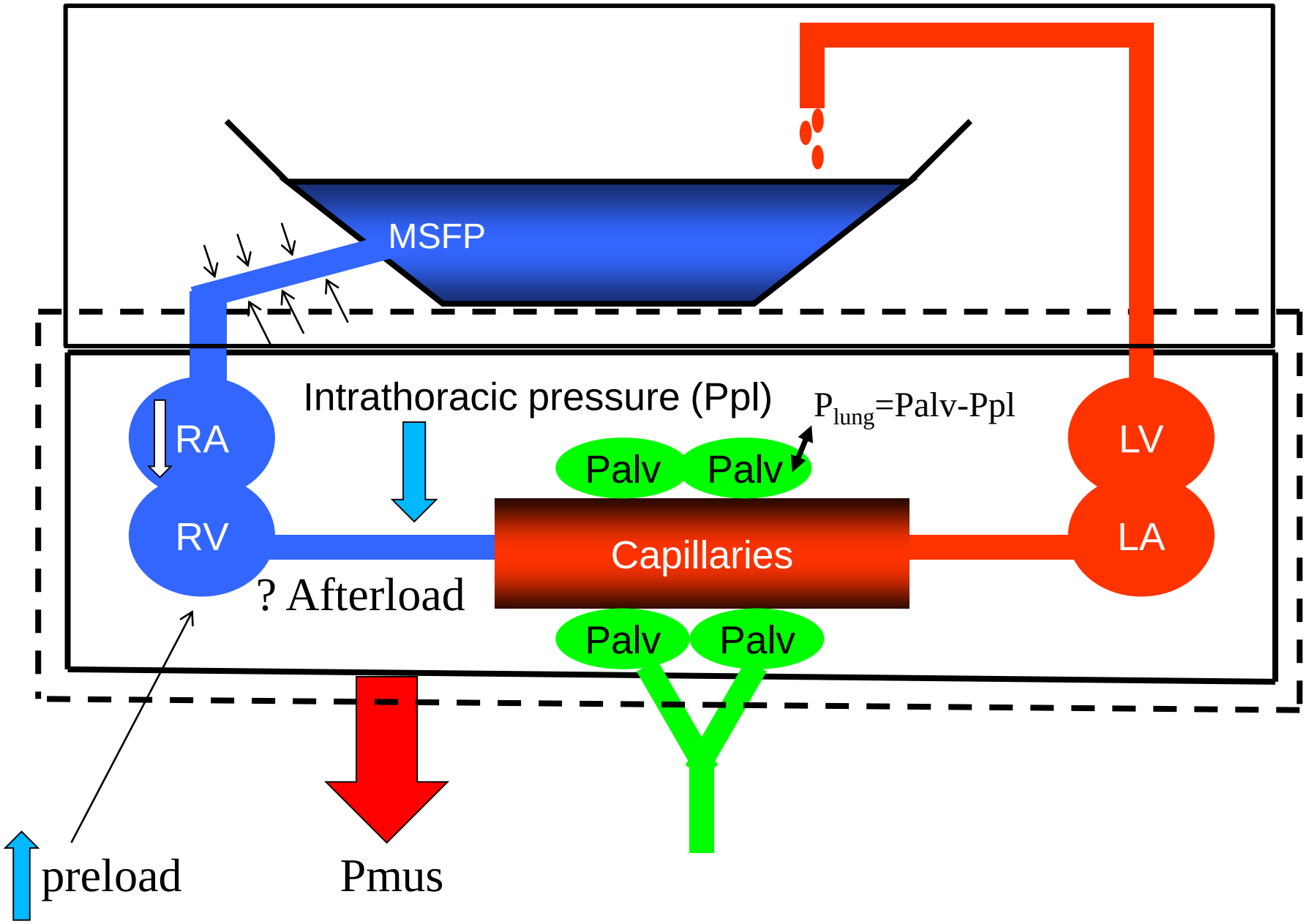
Abdominal hypertension



Zone III (Pivc>Pab)

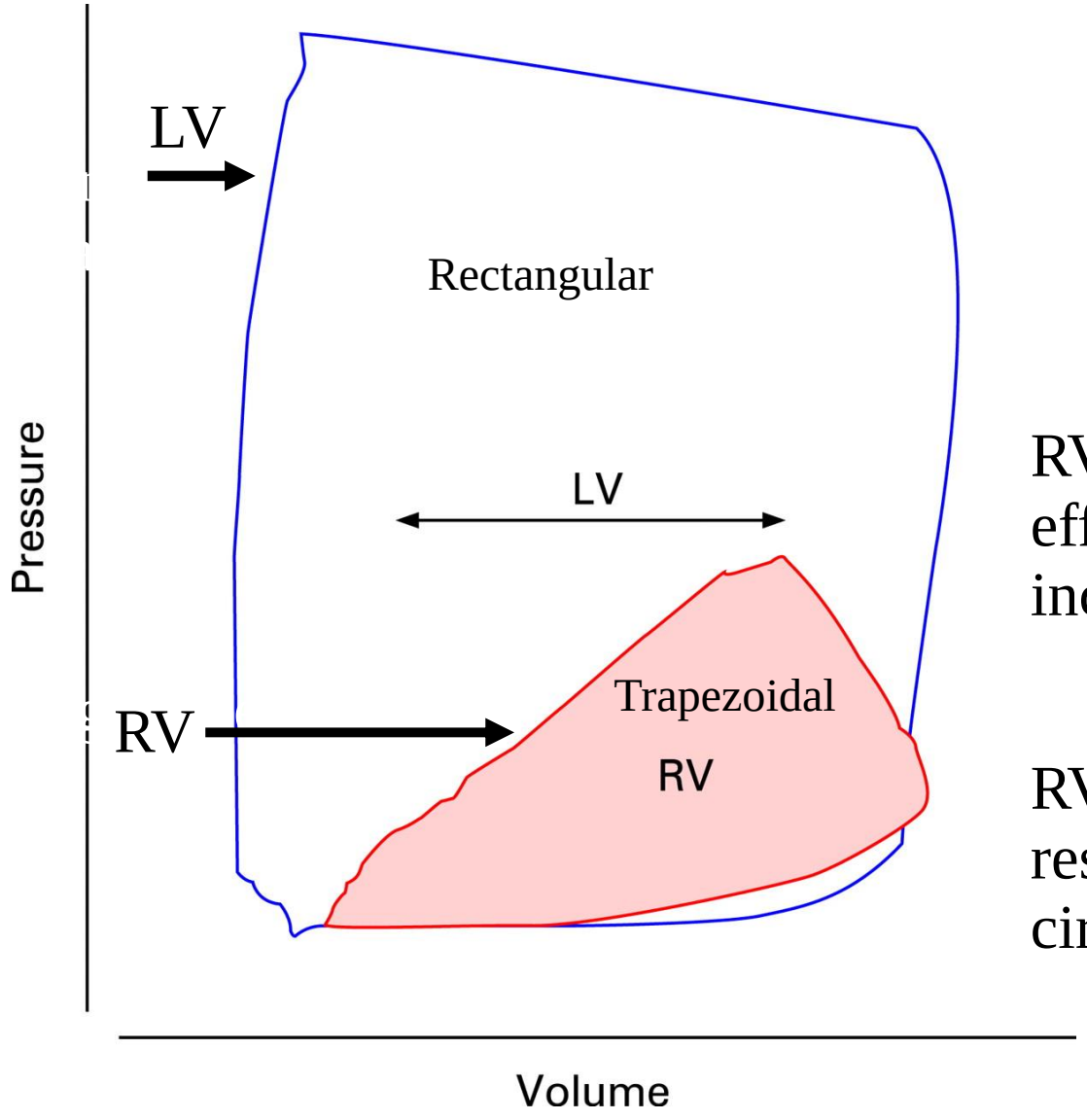
Zone II (Pab>Pivc)


Abdominal compartment behaves as:
1) a capacitor in zone III conditions or
2) a collapsible Starling resistor with little wall tone in zone II conditions
MSFP
Intrathoracic pressure (Ppl)
P_{lung}=Palv-Ppl
RA
RV
Palv
Palv
Capillaries
Palv
Palv
LV
LA
preload
Pmus



Normal volume status, no abdominal hypertension

Normal human left (LV) and right ventricular (RV) pressure–volume relationships.

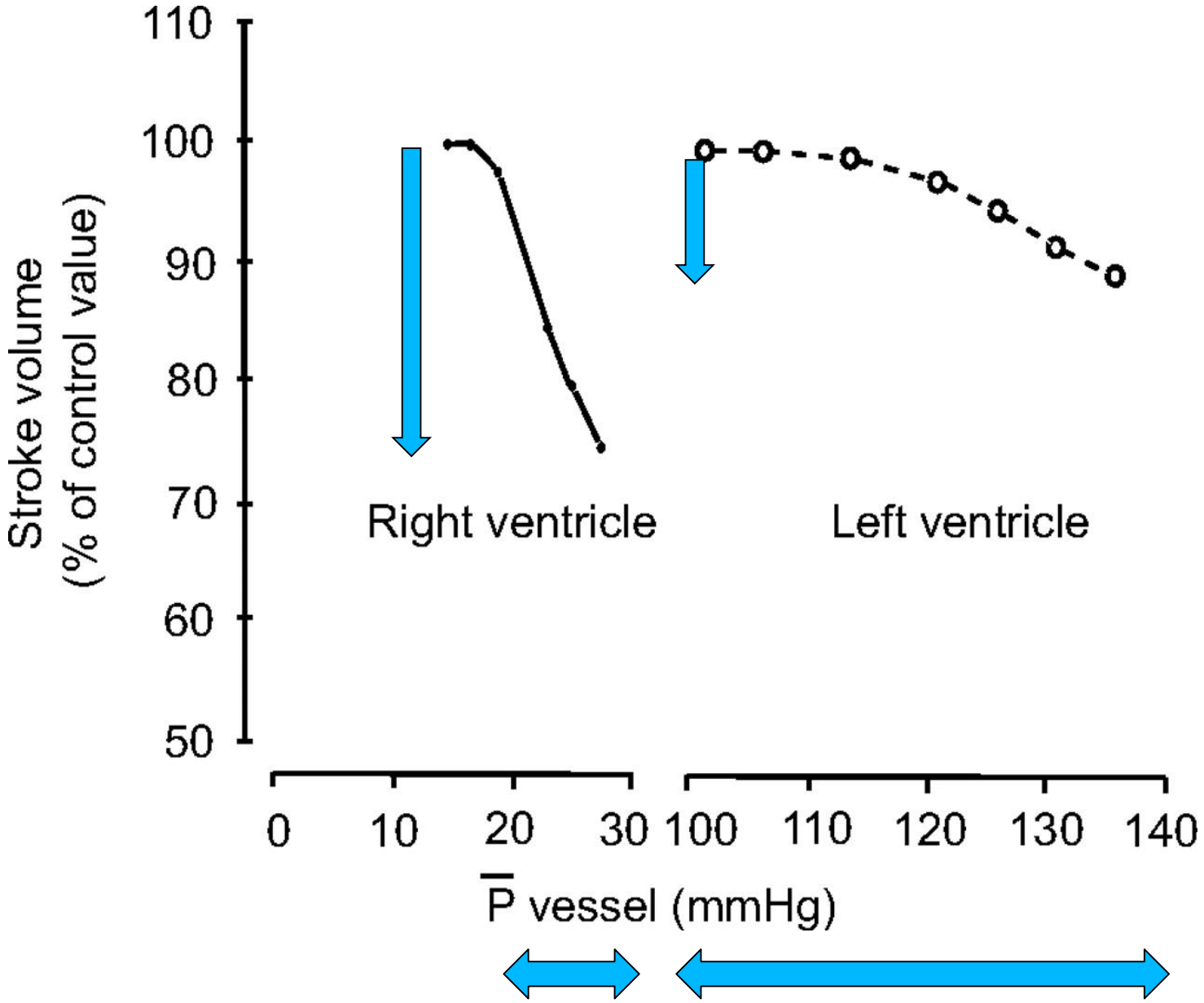


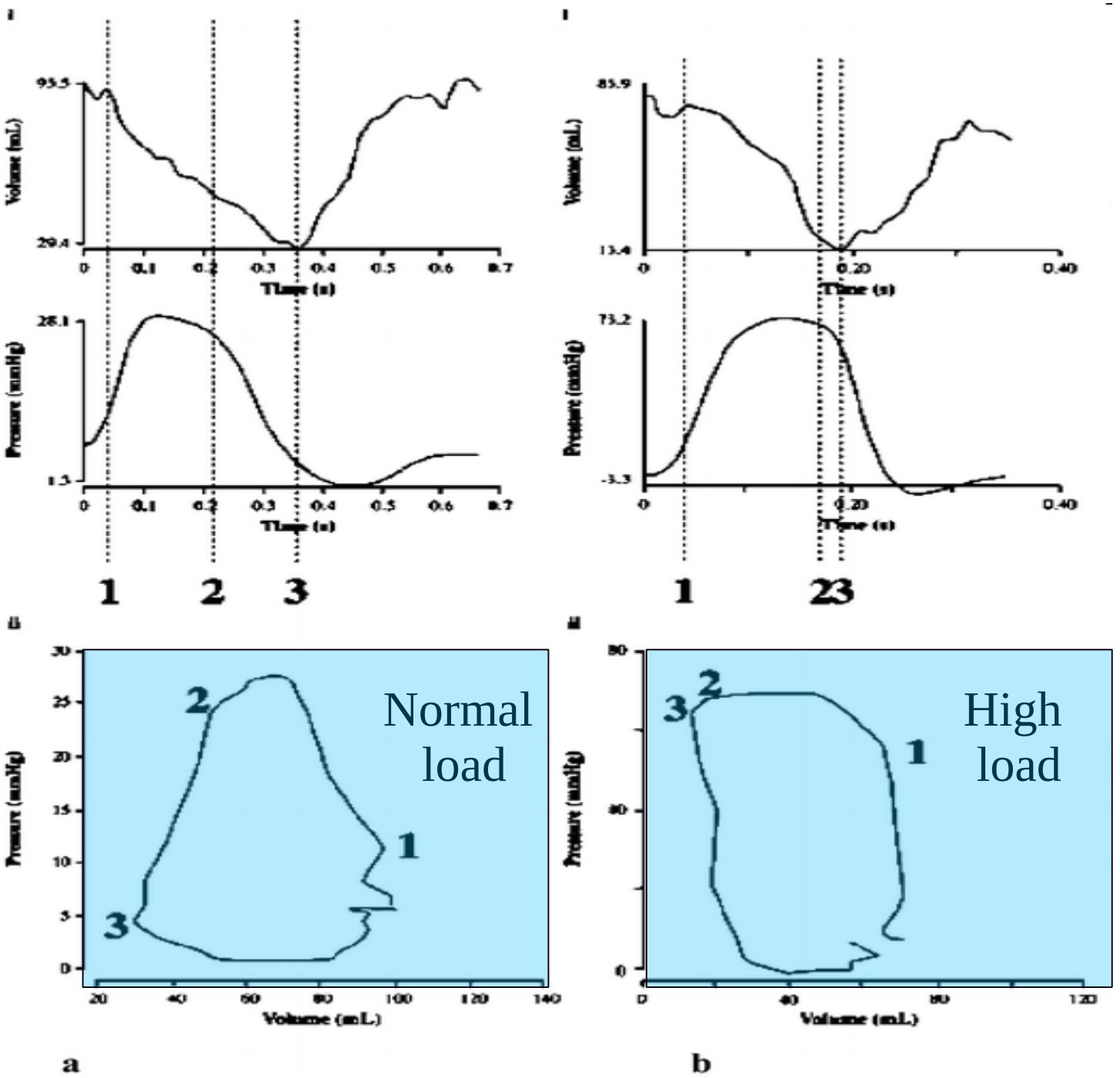
RV can not cope efficiently with sudden increases in after-load

RV ejects into a low resistance, high compliant circuit

Sheehan F , Redington A Heart 2008;94:1510-1515

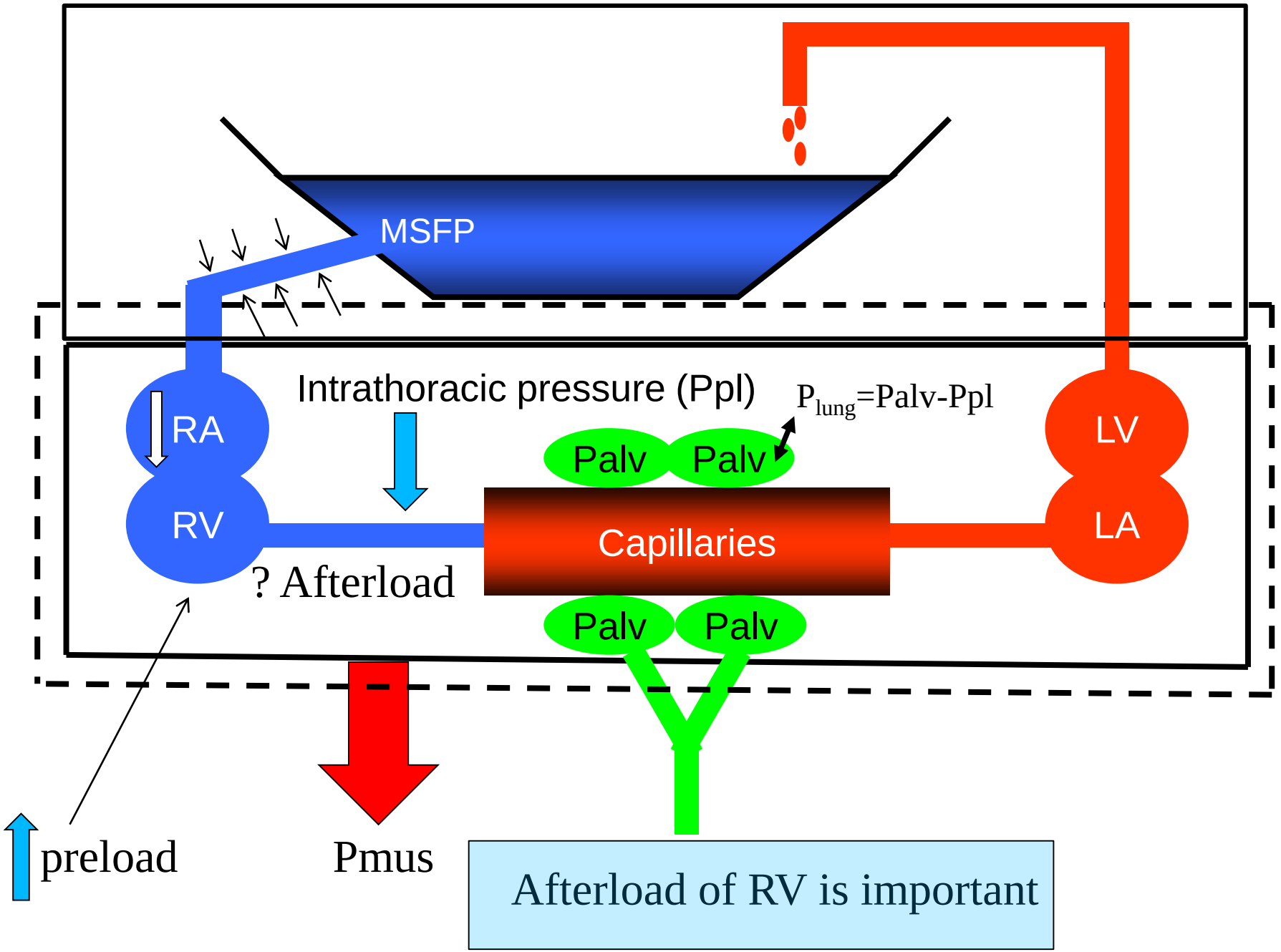
The response of the RV and LV to experimental increase in afterload.

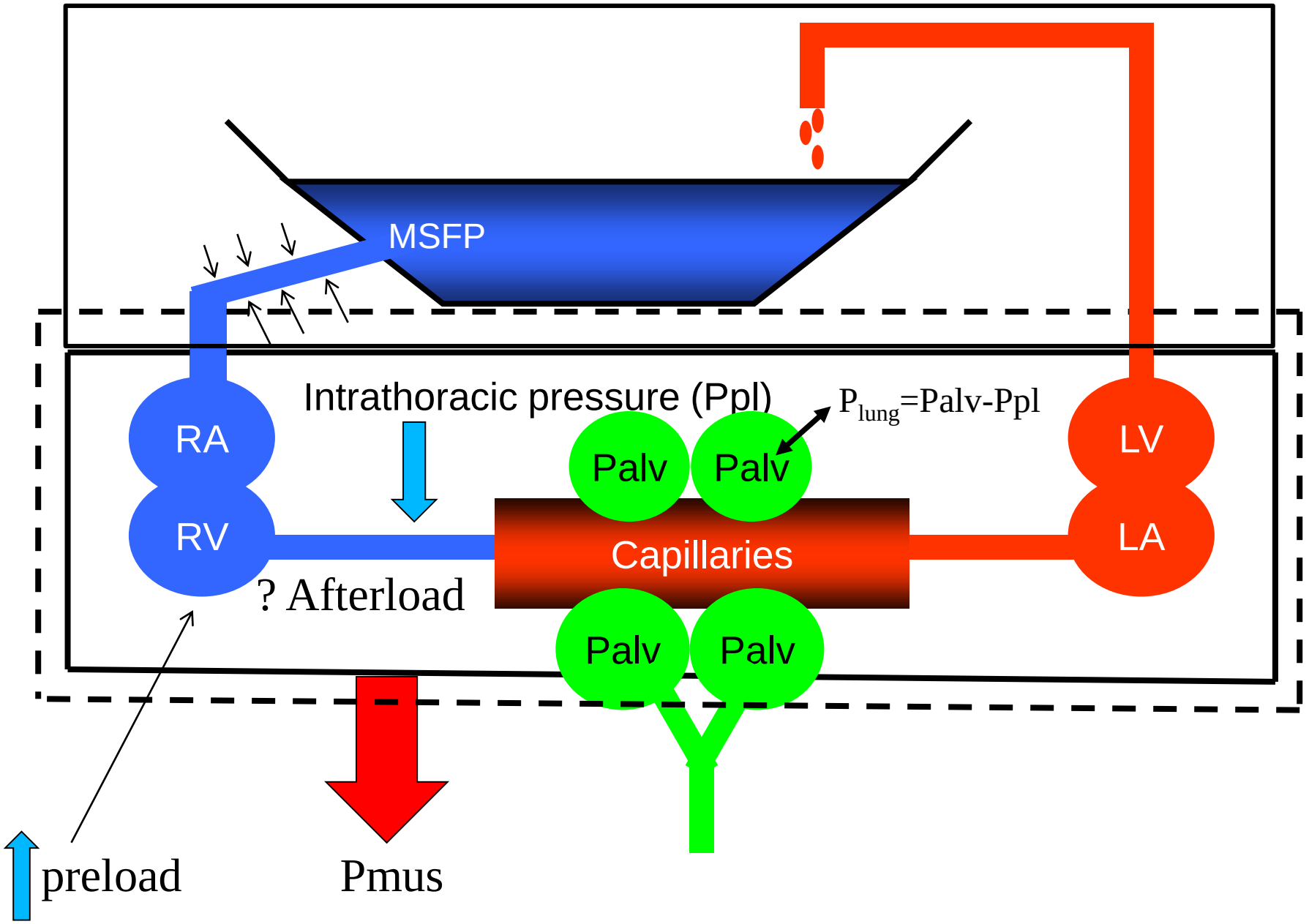




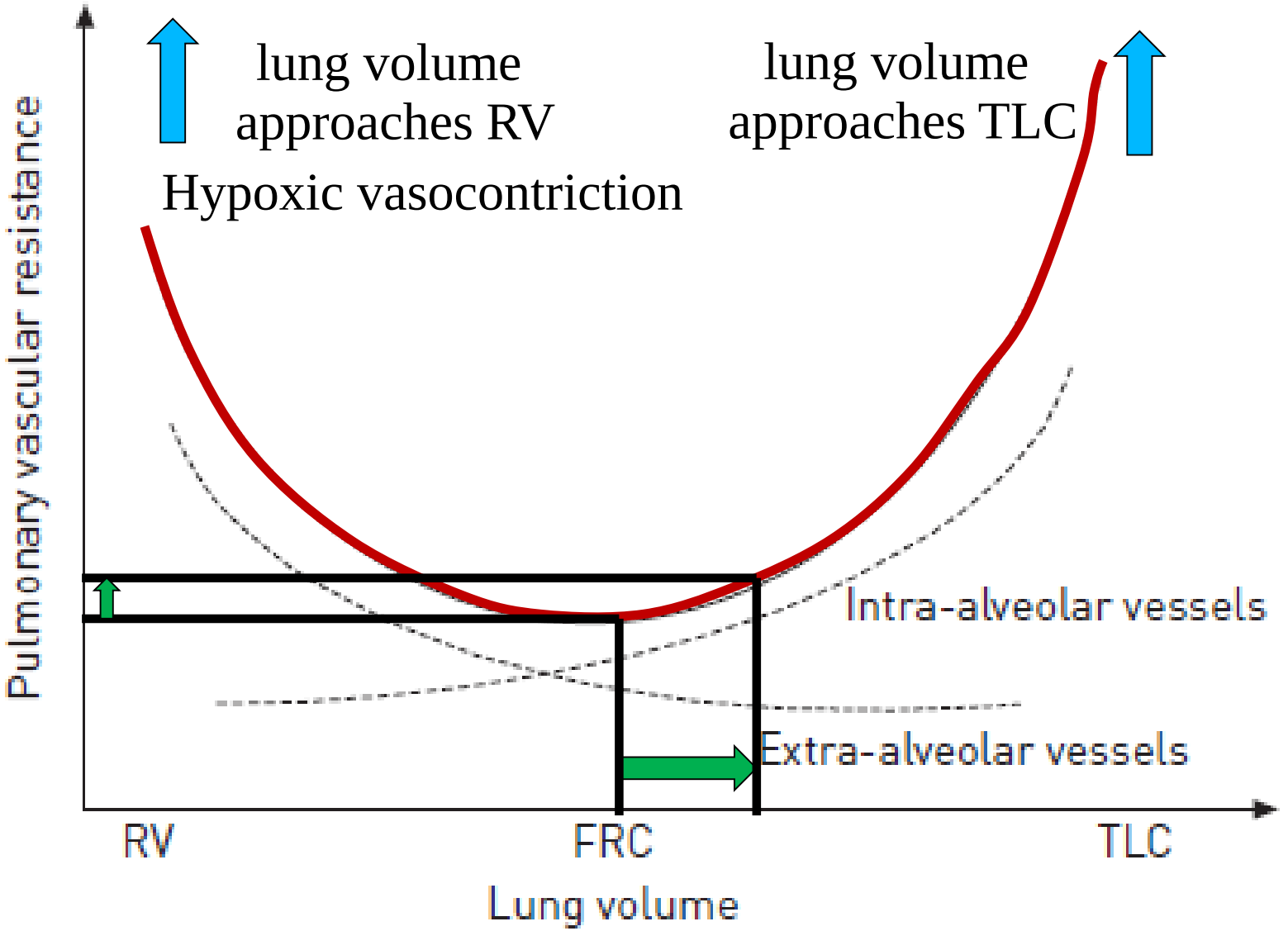
Isometric contraction and relaxation phases

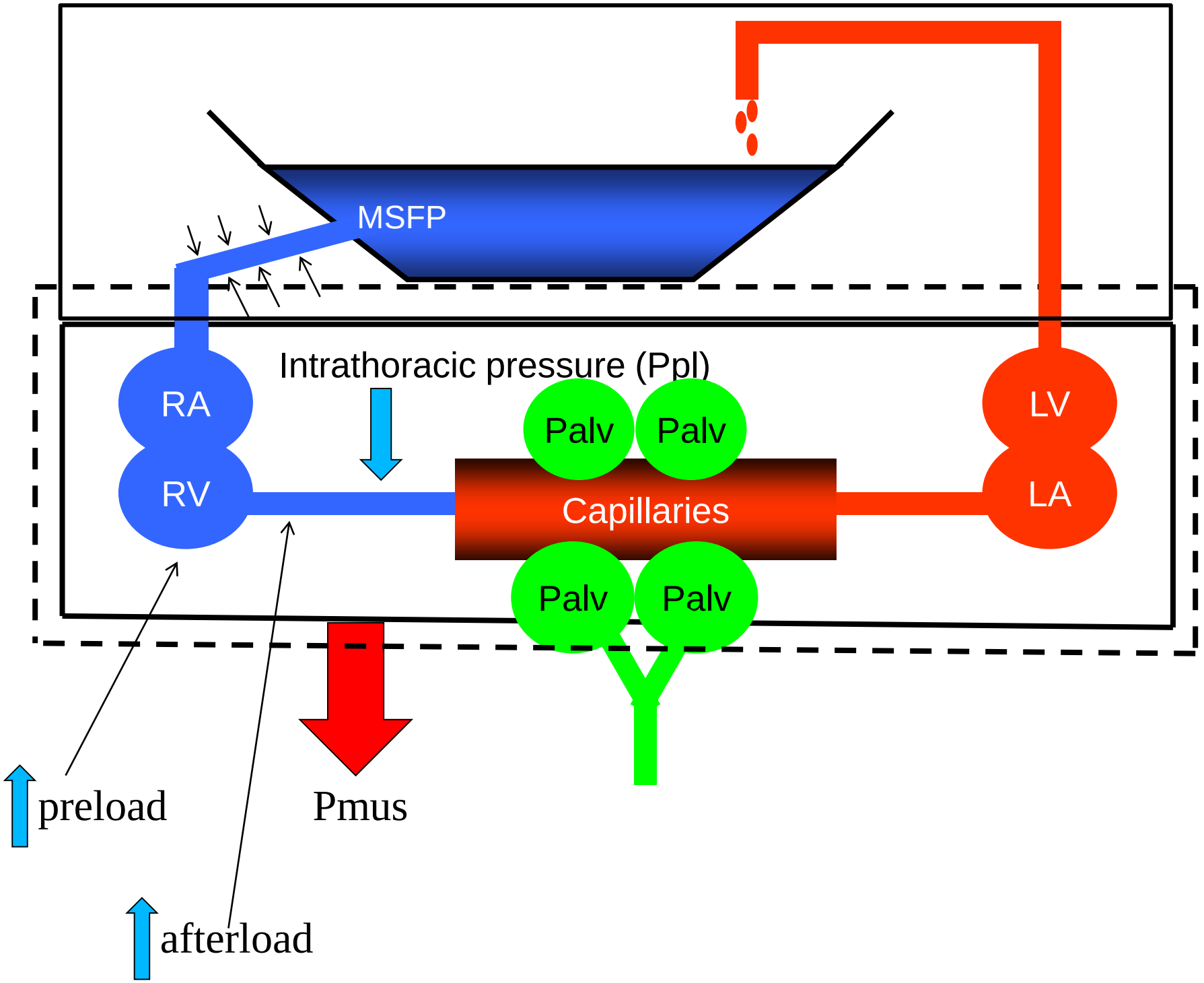
Mebazzaa et al. Intensive Care Med 2004

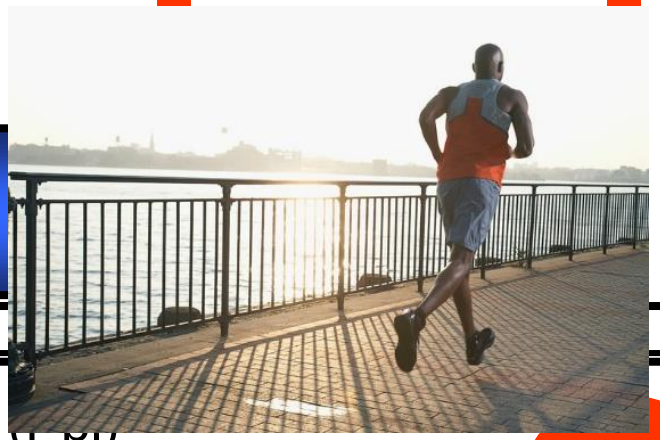

MSFP
Intrathoracic pressure (Ppl)
P_{lung}=Palv-Ppl
RA
RV
Palv
Palv
Capillaries
LV
LA
Palv
Palv
? Afterload
preload
Pmus
Afterload of RV is important


MSFP
Intrathoracic pressure (Ppl)
P_{lung}=Palv-Ppl
RA
RV
LV
LA
Palv
Palv
Capillaries
Palv
Palv
? Afterload
preload
Pmus

Afterload of the Right Ventricle




MSFP
Intrathoracic pressure (Ppl)
RA
RV
Palv
Palv
Capillaries
Palv
Palv
LV
LA
preload
Pmus
afterload



MSFP

preload

Intrathoracic pressure (Ppl)

RA

RV

Palv

Palv

Capillaries

Palv

Palv

LV

LA

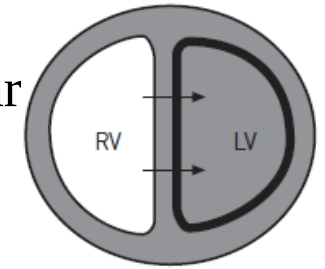
Sudden death

preload

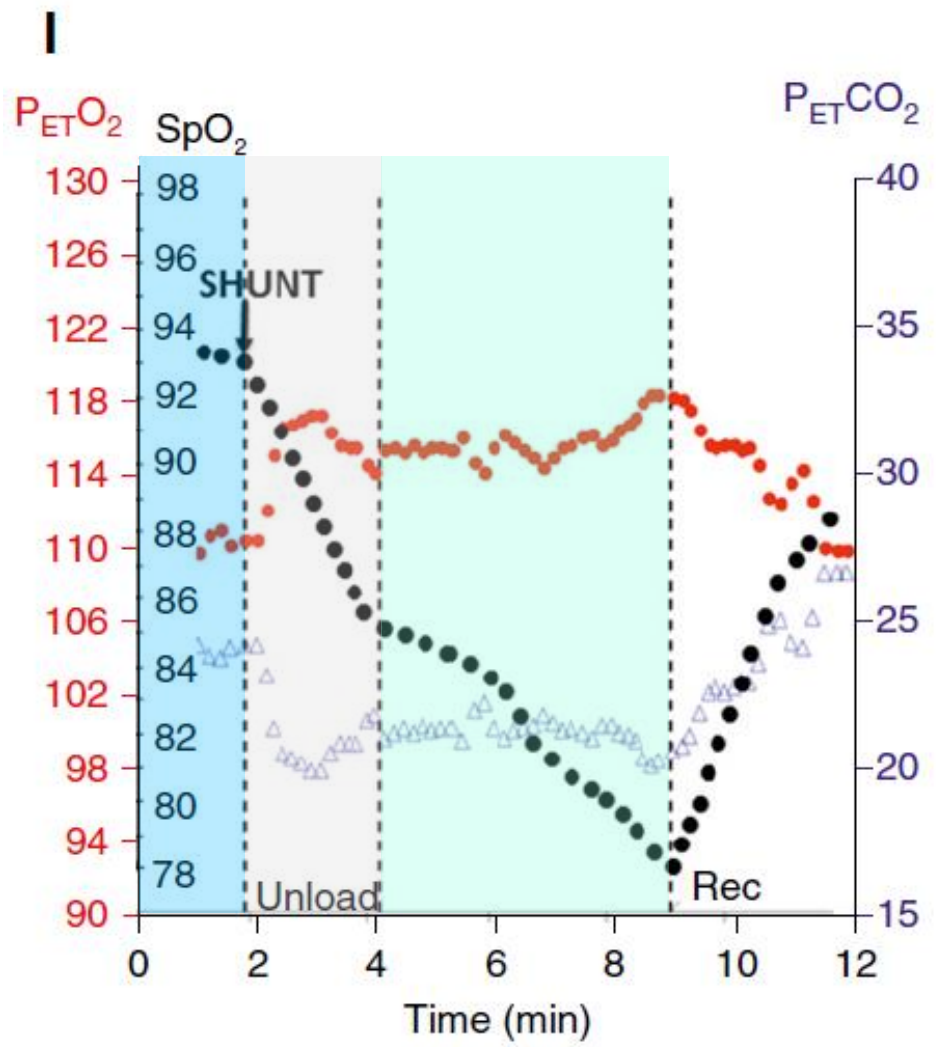
Pmus

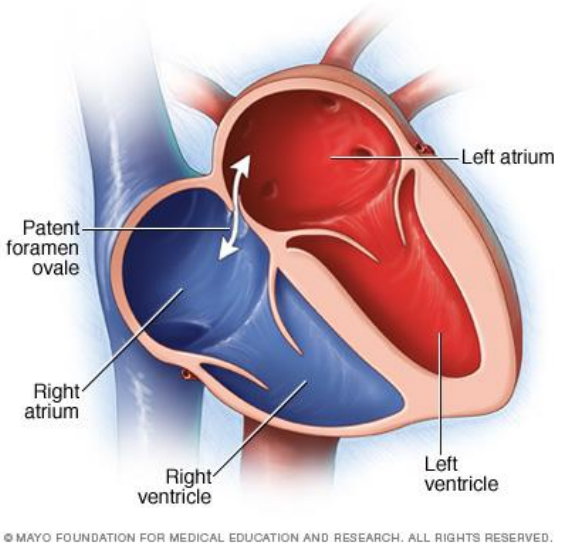
afterload

Parallel biventricular interdependence

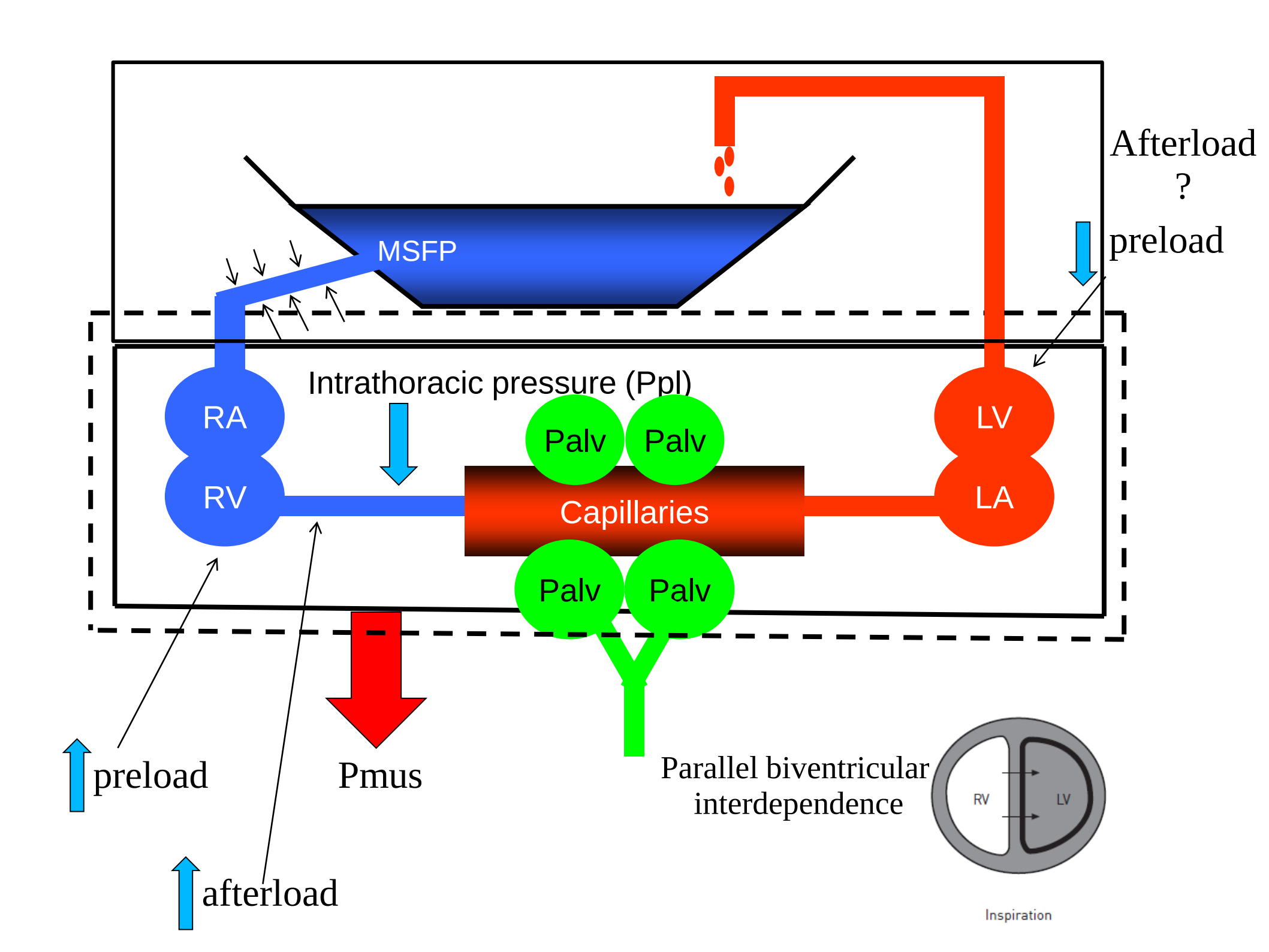


Inspiration

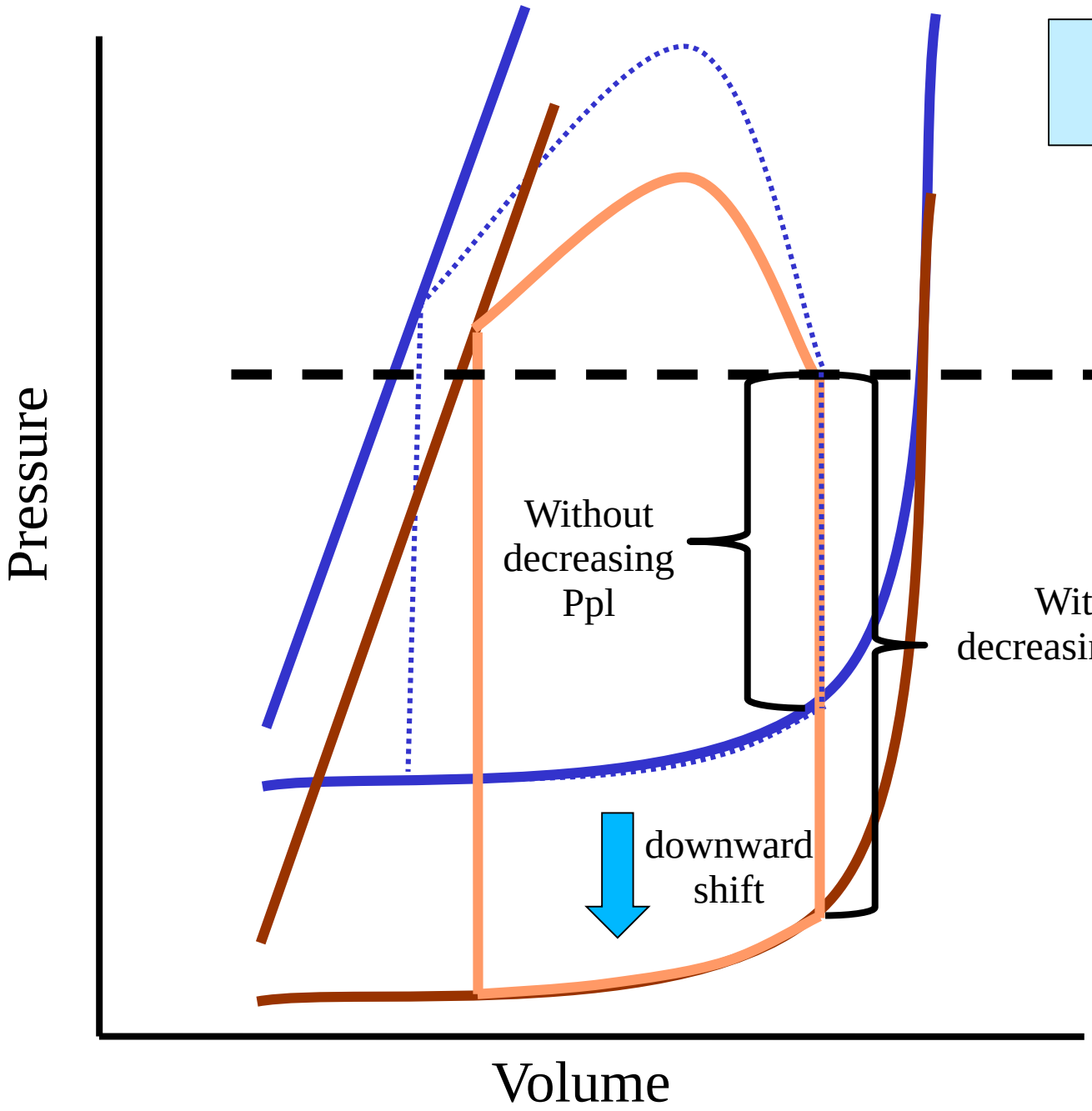




Neder et al. Ann Am Thorac Soc Vol 12, No 4, pp 604–612, Apr 2015


Afterload
?
preload
MSFP
Intrathoracic pressure (Ppl)
RA
RV
Palv
Palv
Capillaries
Palv
Palv
LV
LA
preload
Pmus
afterload
Parallel biventricular
interdependence
RV
LV
Inspiration

Effect of ↓Ppl on LV ejection

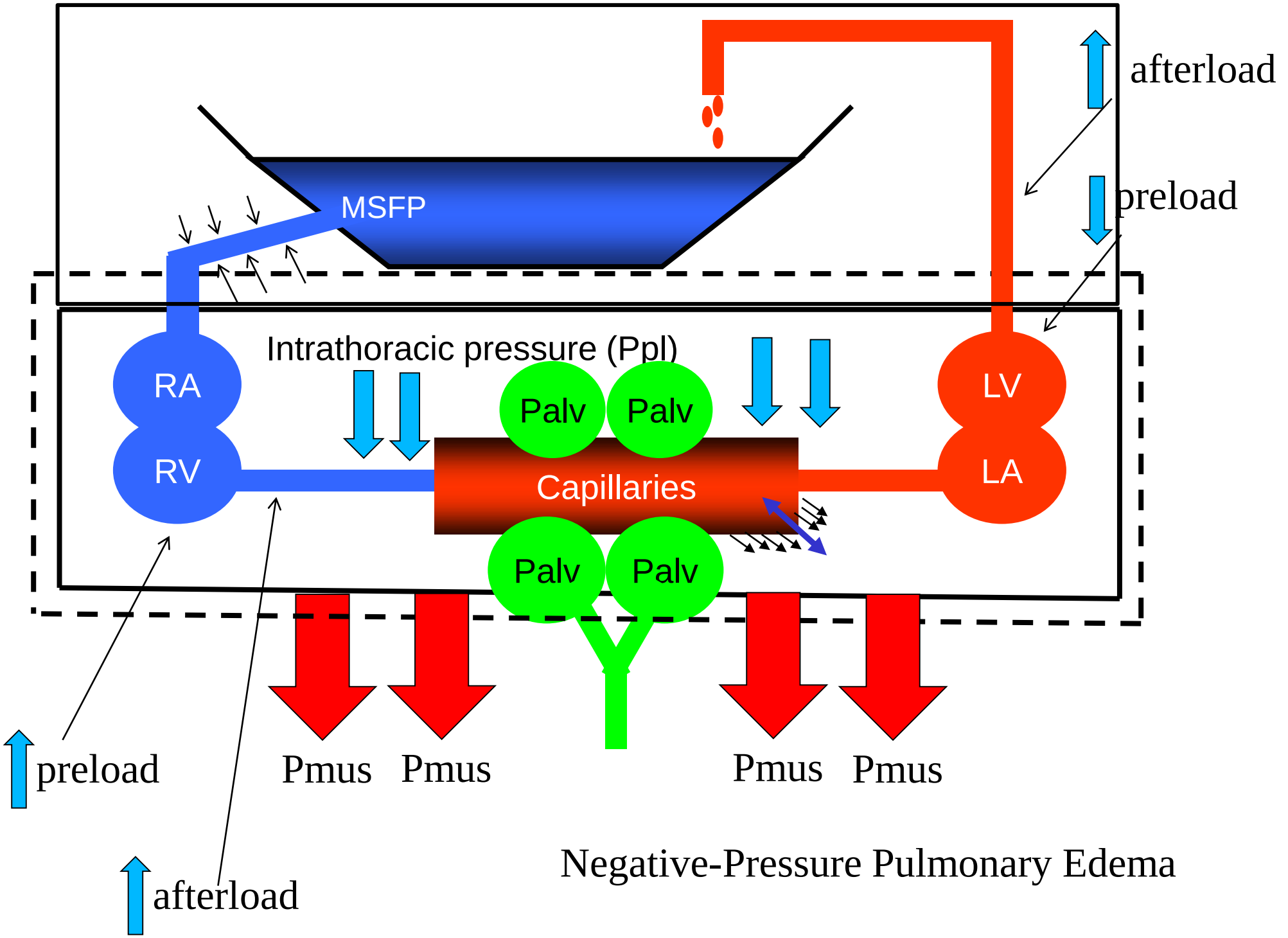


Increase in afterload

Aortic valve opening (Aortic Diastolic P)

Decrease in Psys
-shorter ejection
-decreased SV

Magder Am J Respir Crit Care Med 2004
(Supplementary Material)

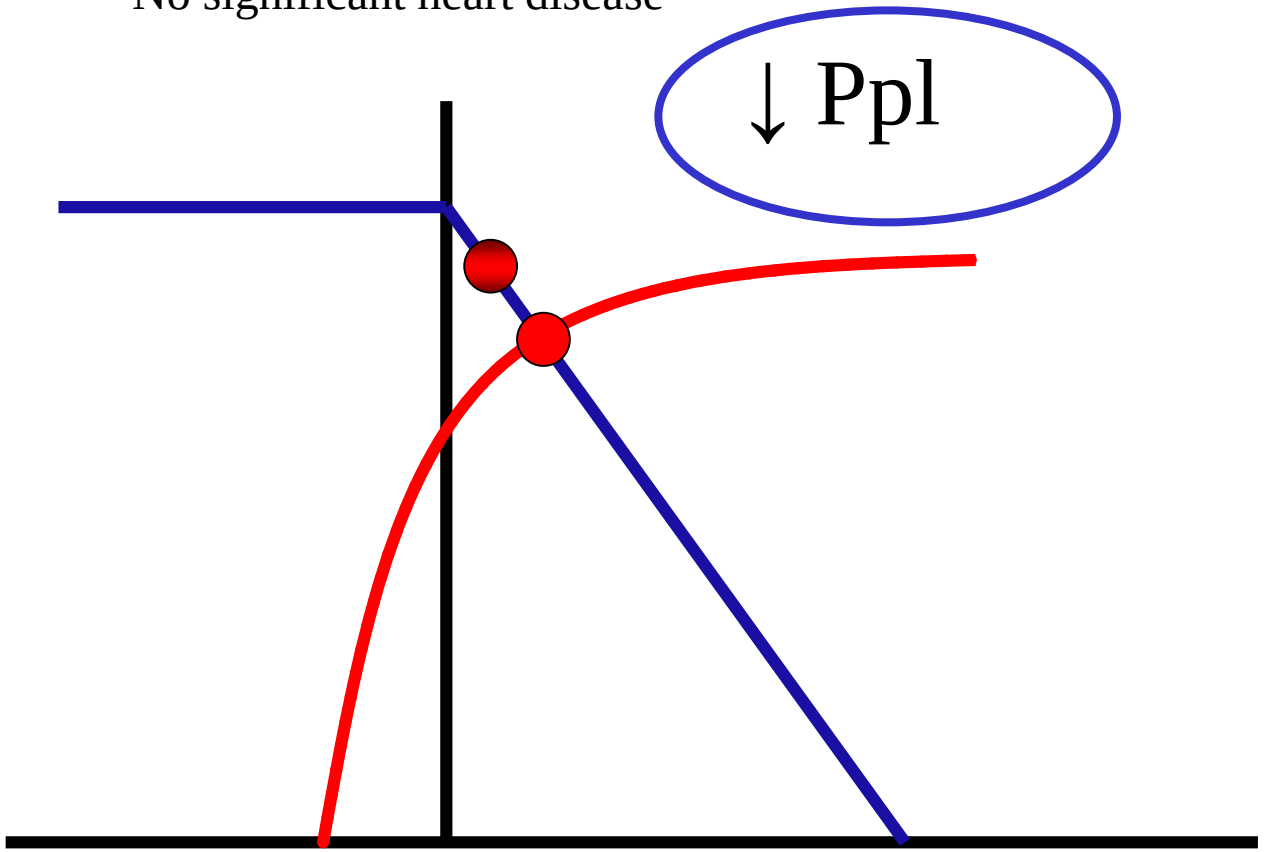


Negative-Pressure Pulmonary Edema

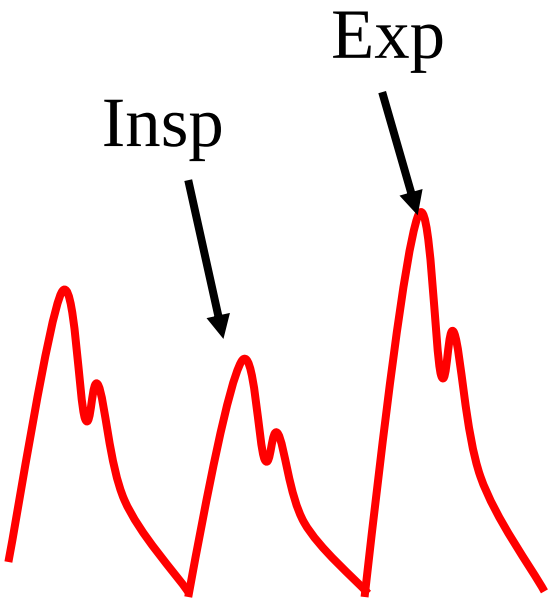
Effect of decrease in Ppl

Overall

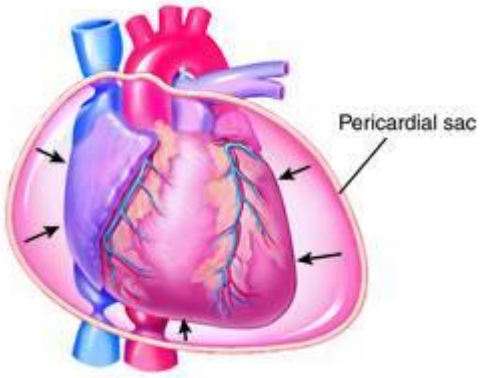
Volume status: Normal
No significant respiratory system disease
No significant heart disease



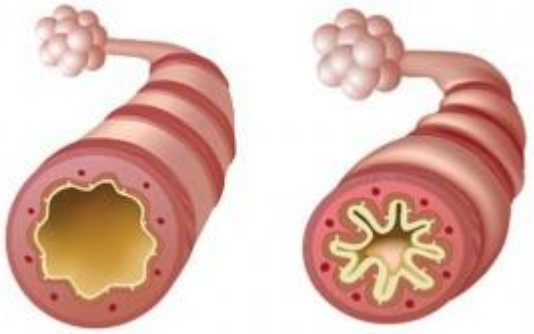
Normal <10 mmHg



Magder Am J Respir Crit Care Med 2004
(Supplementary Material)

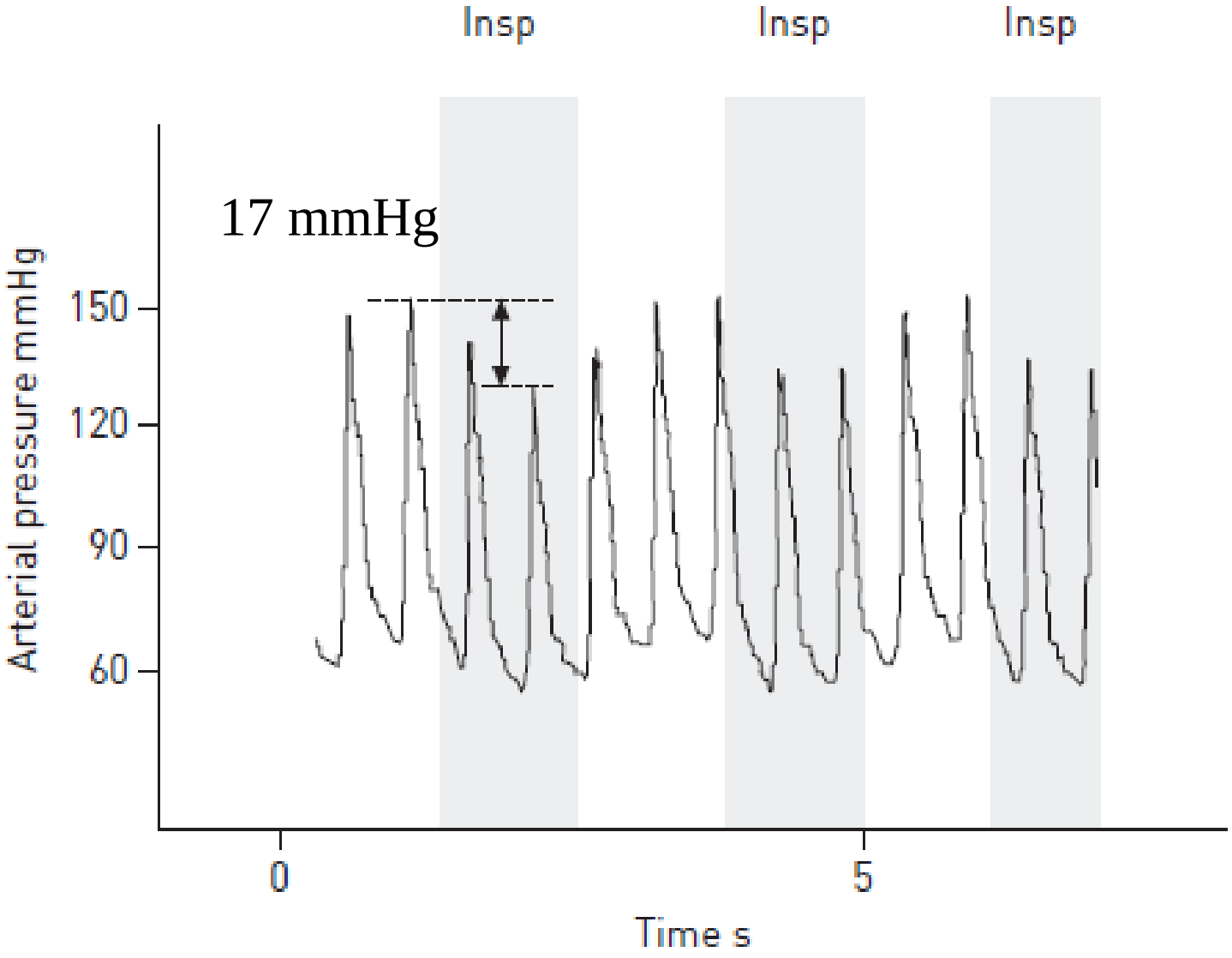


Cardiac tamponade



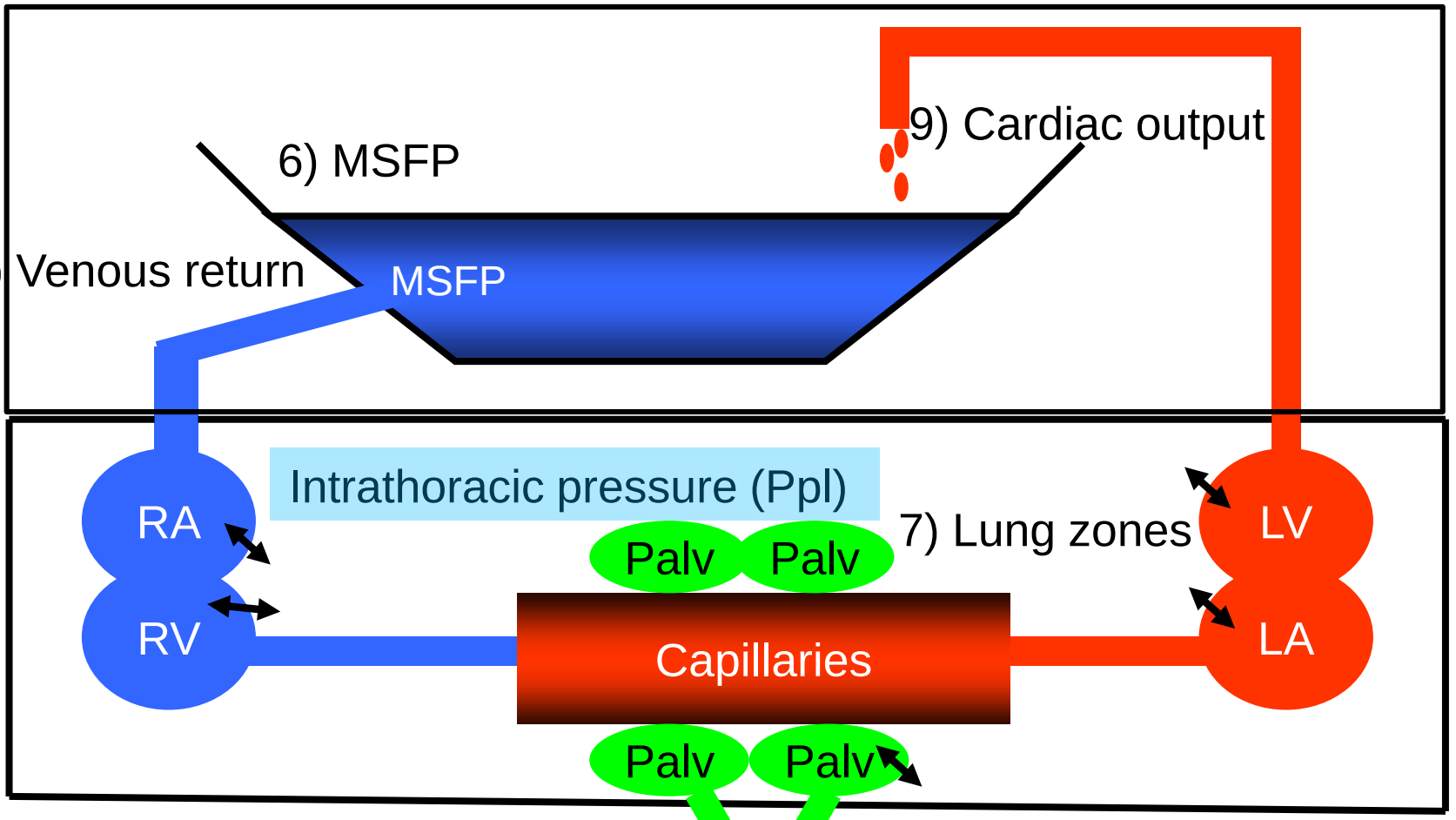
Severe asthma attack
(status asthmaticus)

Pulsus paradoxus



Modified from: Hamzaoui et al. Eur Respir J 2013; 42: 1696

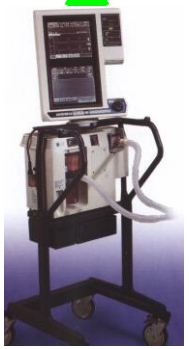
Let's place the patient on MV (passive)



Mechanical ventilation changes everything

1) Autonomic tone
2) Palv
3) Ppl

Passive

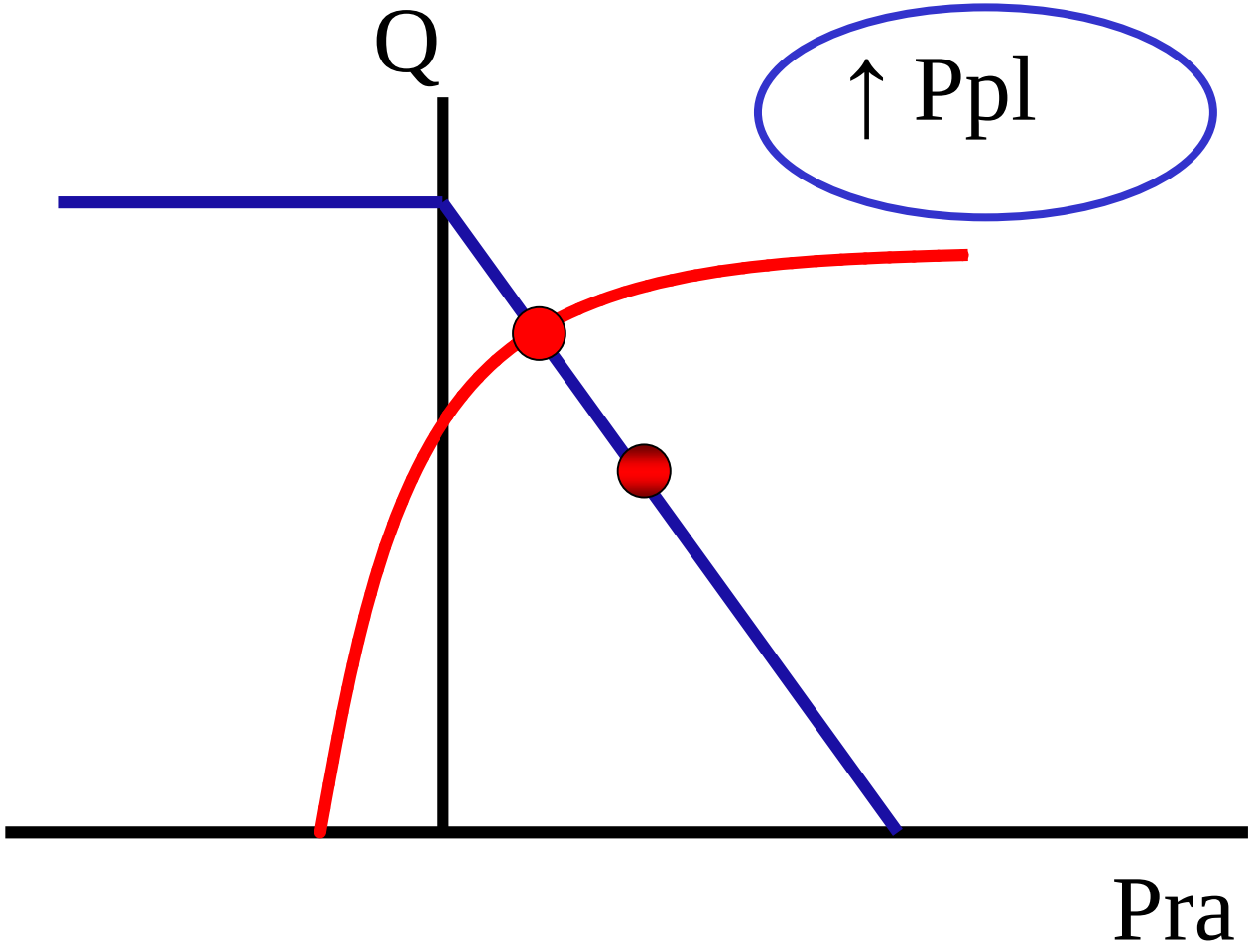


4) Trans-vascular pressure
5) Trans-pulmonary pressure

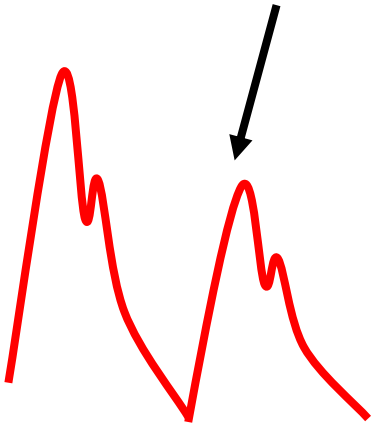
8) Lung compliance

11) Juxtacardiac pressures

Effect of increase in Ppl



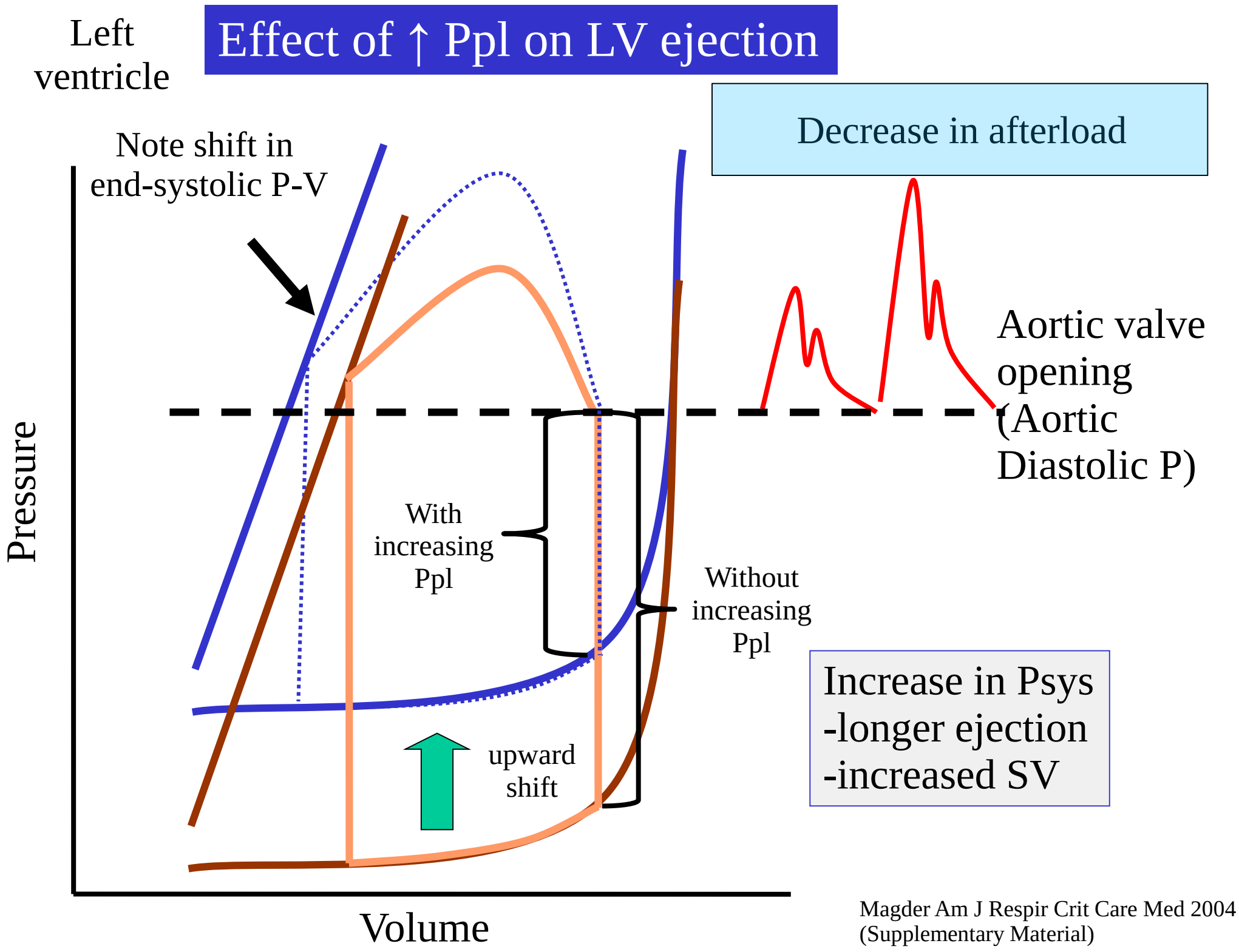
During expiration
Decrease in PP



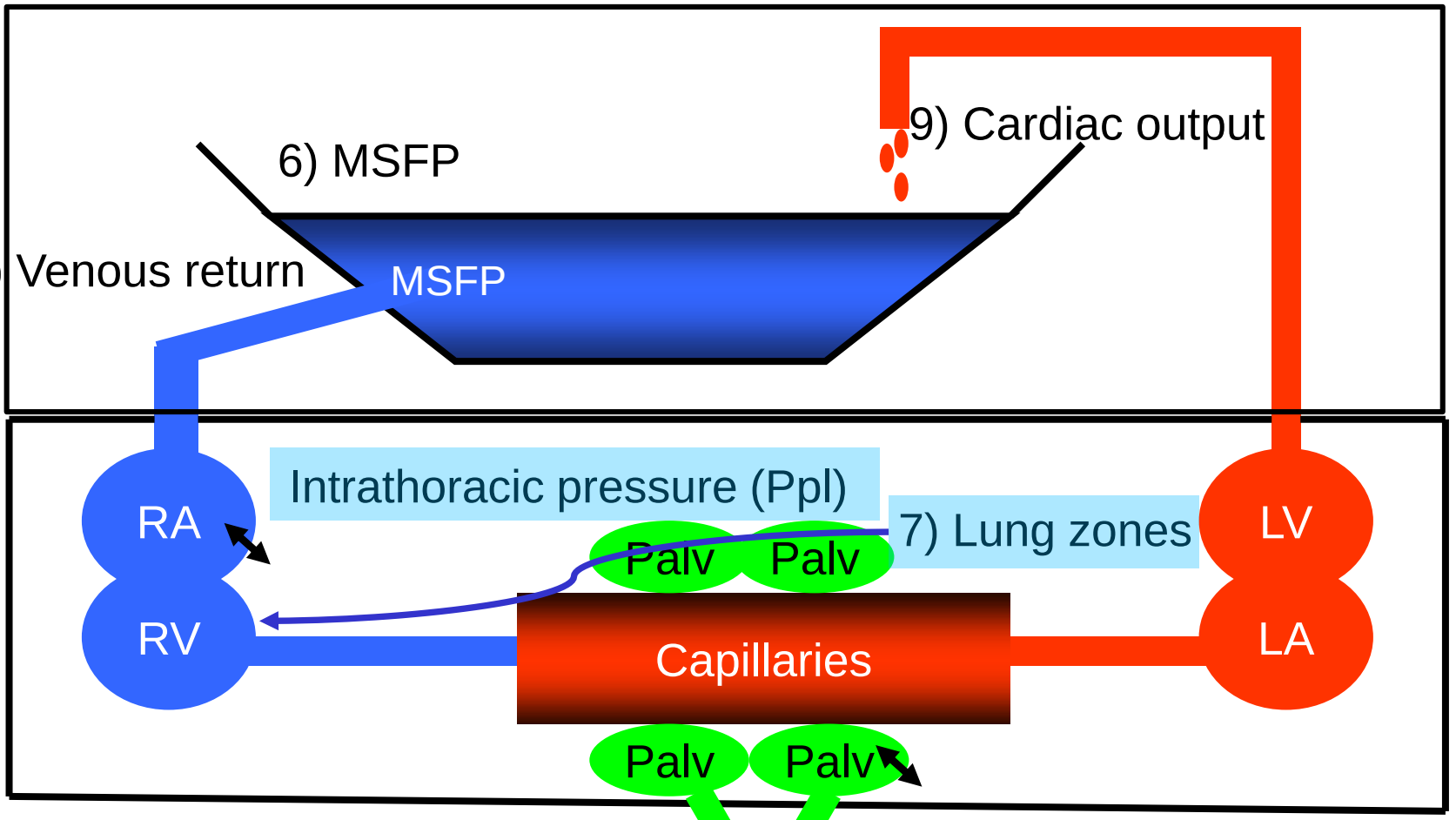
Arterial Pressure

Magder Am J Respir Crit Care Med 2004
(Supplementary Material)

Effect of ↑ Ppl on LV ejection



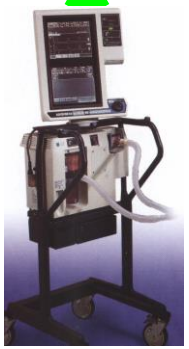
Magder Am J Respir Crit Care Med 2004
(Supplementary Material)



Mechanical ventilation changes everything

1) Autonomic tone
2) Palv
3) Ppl

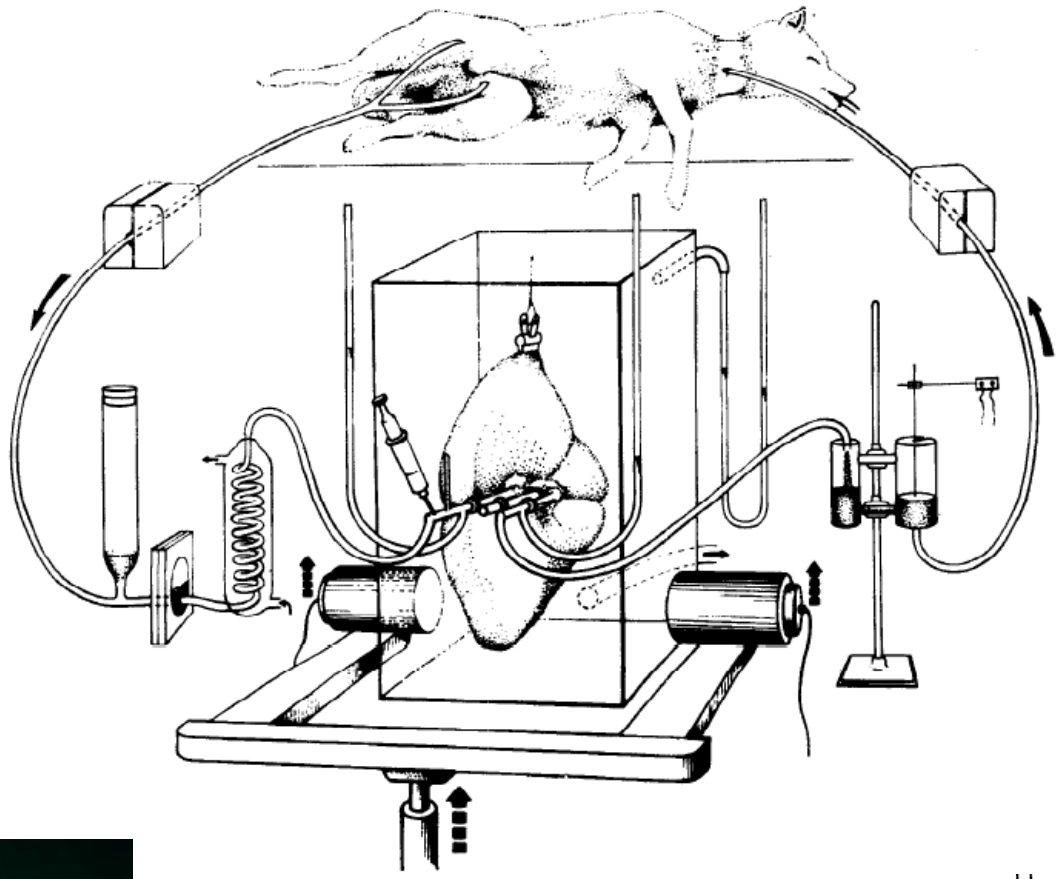
Passive



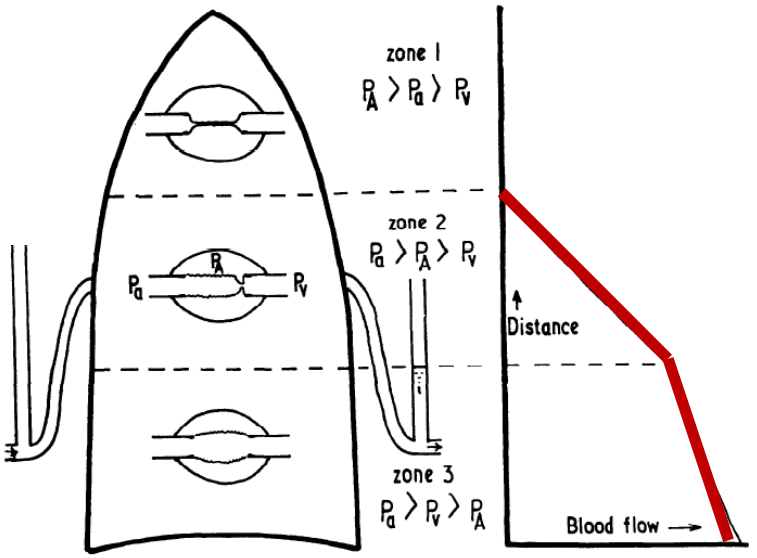
4) Trans-vascular pressure
5) Trans-pulmonary pressure

8) Lung compliance

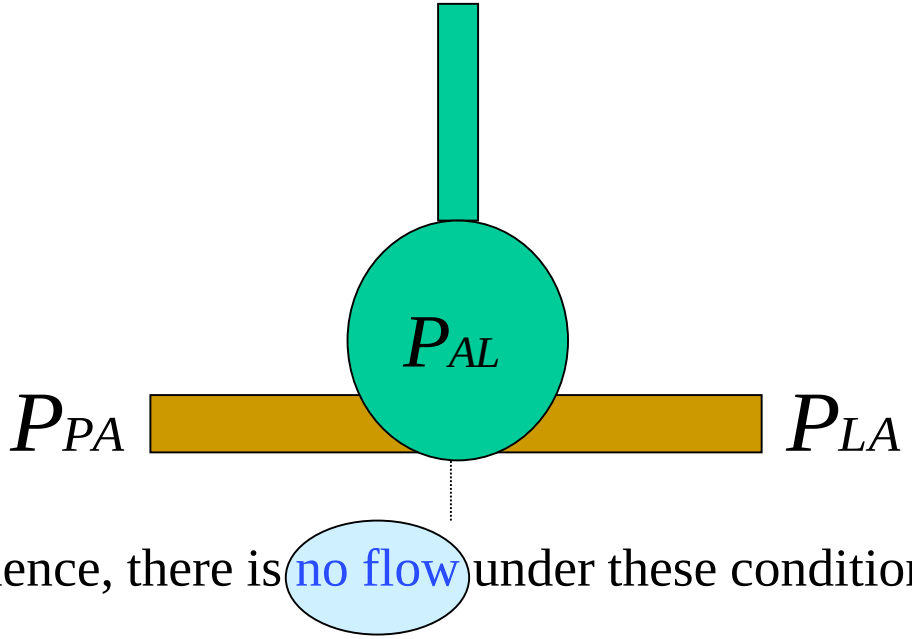
11) Juxtacardiac pressures



West et al. J Appl Physiol 1964

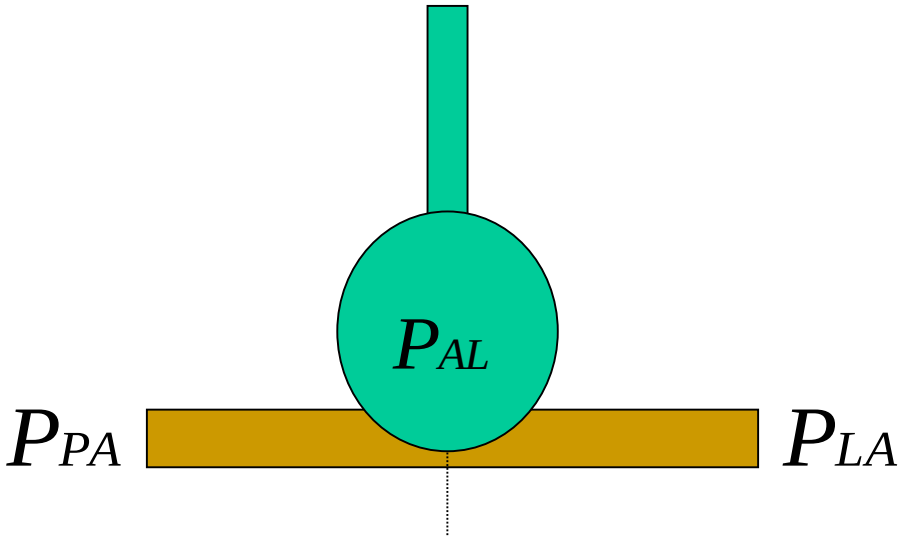


Zone I



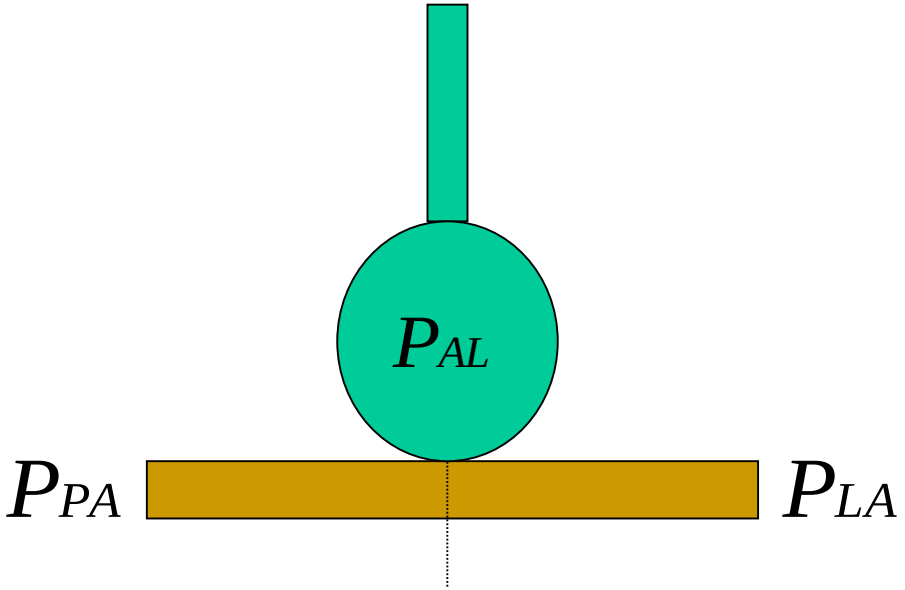
- $\mathbf{P_{AL}}$**>**$\mathbf{P_{PA}}$ and hence, there is no flow under these conditions

Zone II



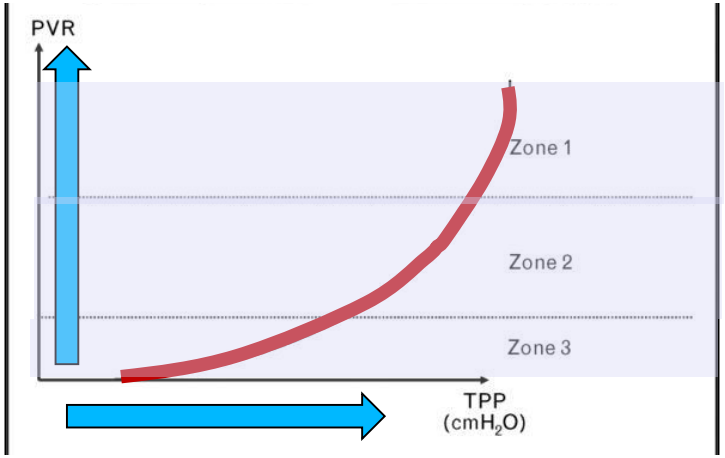
- **P_{PA}>P_{AL}>P_{LA}** and hence, flow is dependent on the pressure gradient P_{PA}-P_{AL} rather than P_{PA}-P_{LA}

Zone III



- **P_{PA}>P_{LA}>P_{AL}** and hence, flow is dependent on the pressure gradient P_{PA}-P_{LA}

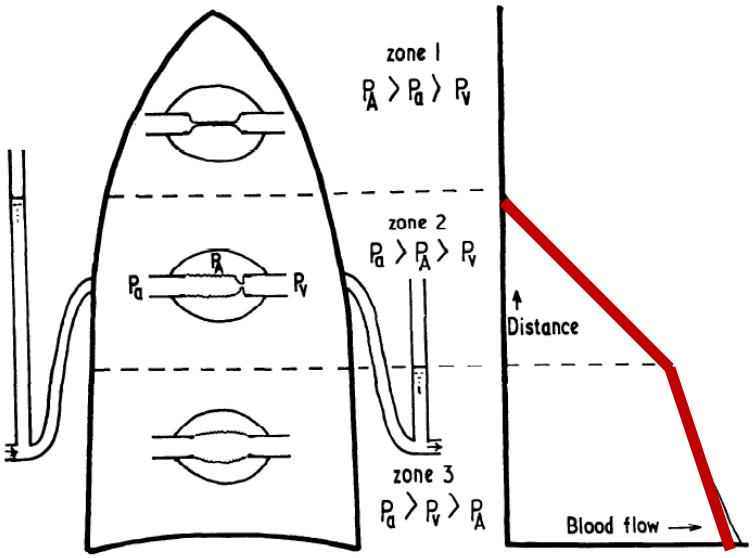
Why are lung zones important for after-load of RV?



After-load of RV

Bouferrache and Vieillard-Baron:
Current Opinion in Critical Care 2011, 17:30–35

Lung zones

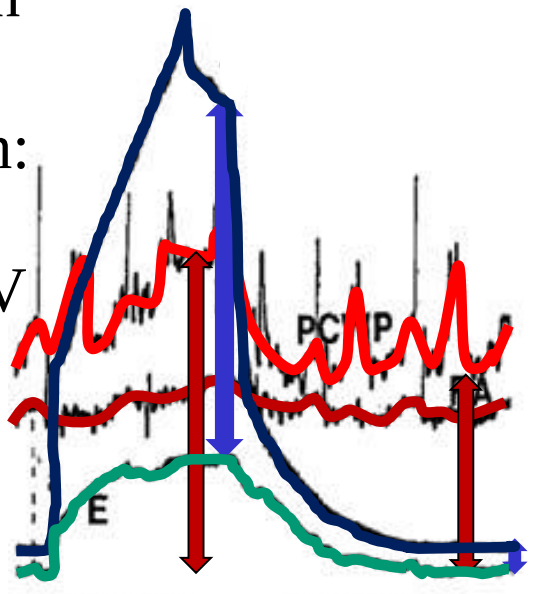


P_{lung} (Palv-Ppl) is the critical variable (and not only Palv)

Vieillard-Baron et al. J Appl Physiol 1999: 87:1644

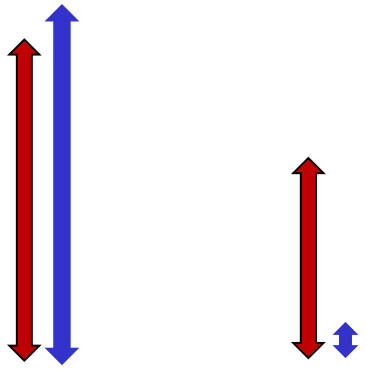
RV suffers during inspiration

During the breath: Cyclic changes in afterload of RV

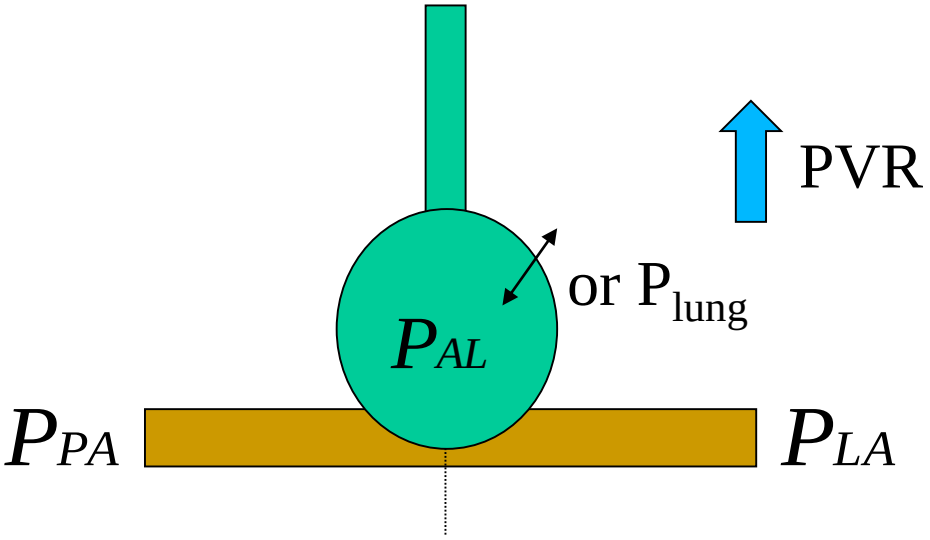


Let's change V_T

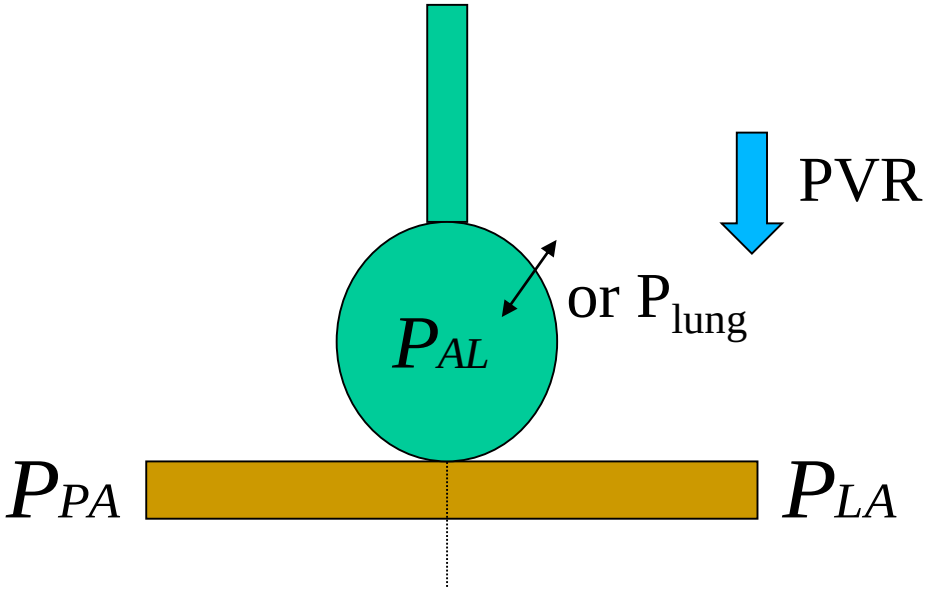
Change in V_T changes P_{lung}



End inspiration: Zone II



End expiration: Zone III



Jardin et al. Intensive care Med 2003;29:1426

Static change in afterload of RV?

Dynamic changes in afterload of RV increases with V_T

300 mL

425 mL

950 mL

RV

PA

Paw

4mmHg

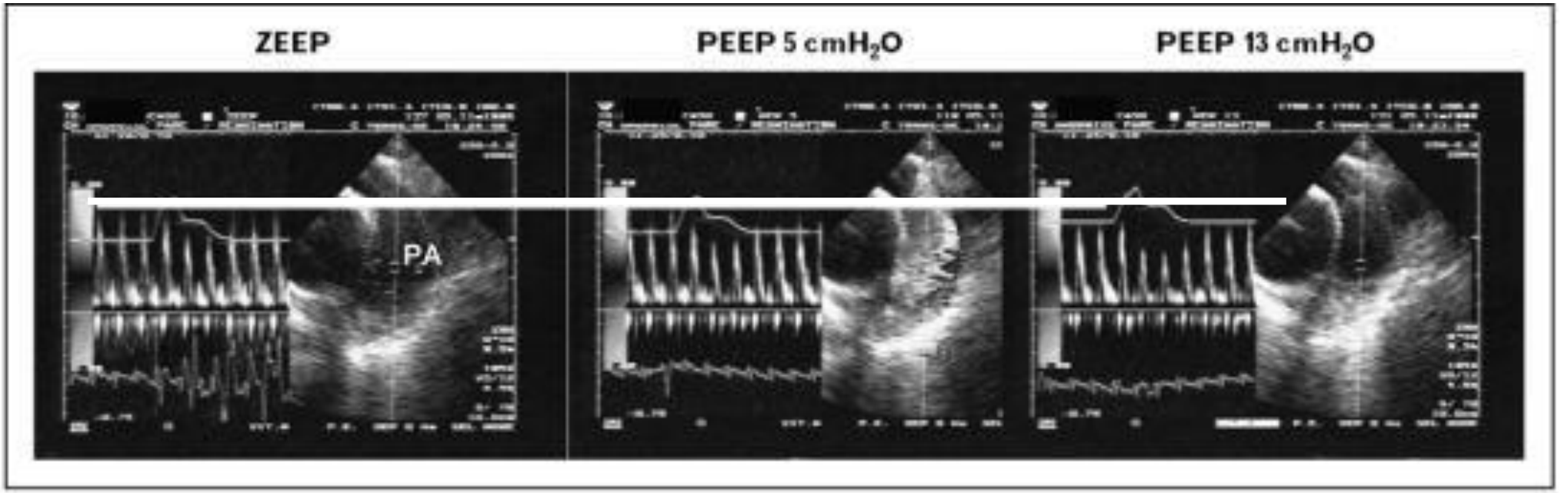
V_T: 300 425 625 825 950

RV needs more and more pressure to open the door to pulmonary circulation at end inspiration

Jardin et al. Intensive Care Med 2003;29:1426

Increasing PEEP caused a progressive decrease in RV ejection flow during expiration

Bouferrache and Vieillard-Baron:
Current Opinion in Critical Care 2011

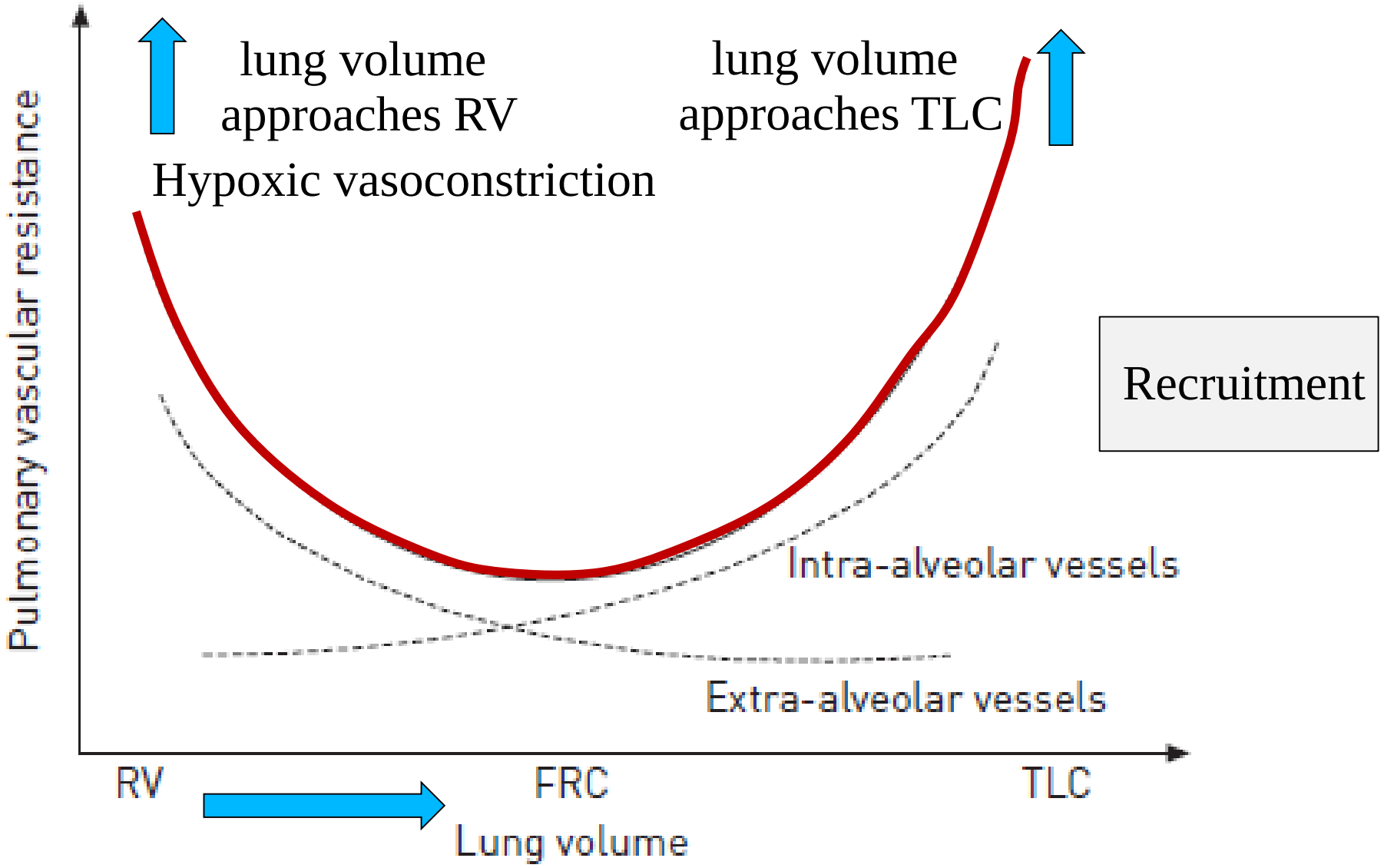


Static increase in transpulmonary pressure (PEEP application)
Static increase in afterload of Right ventricle

HFVO
Quasi-static increase in Palv

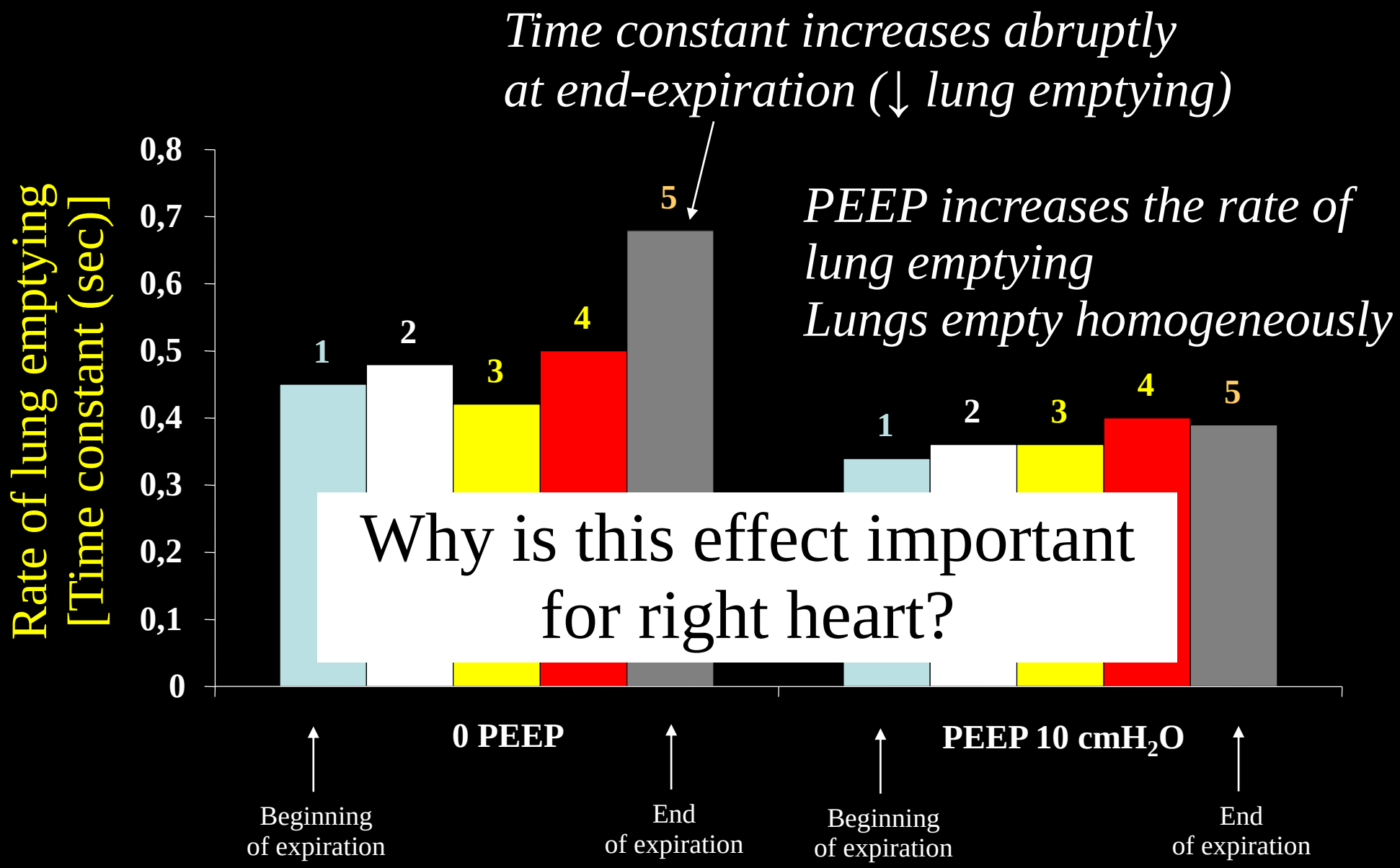
May PEEP have (direct) beneficial effect on Right Ventricle?

Afterload Right ventricle

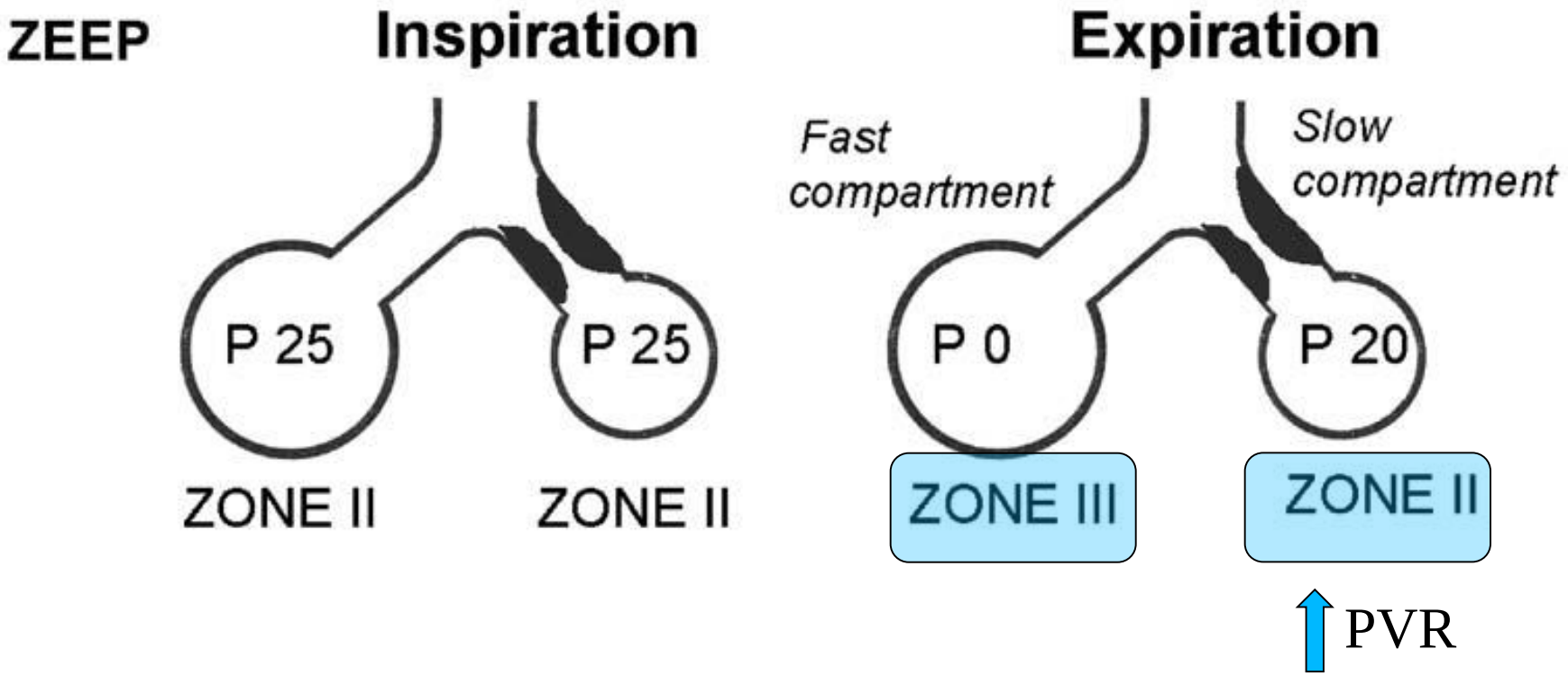


Mekontso-Dessap et al.
Intensive Care Med 2009

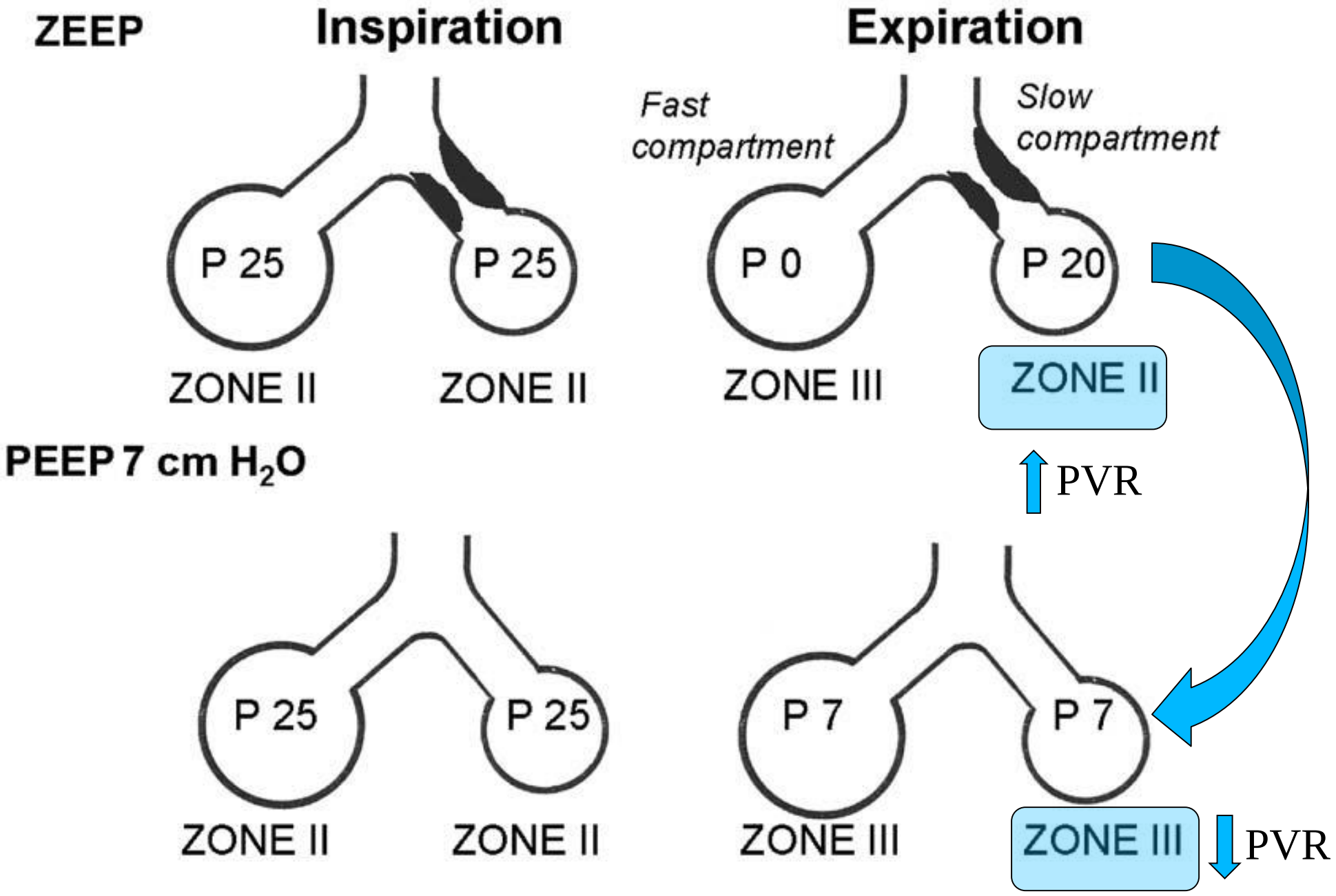
Rate of lung emptying of respiratory system in ARDS patients with and without PEEP (beginning to end of expiration)



Kondili et al. Eur J Respir Dis 2002;19:811

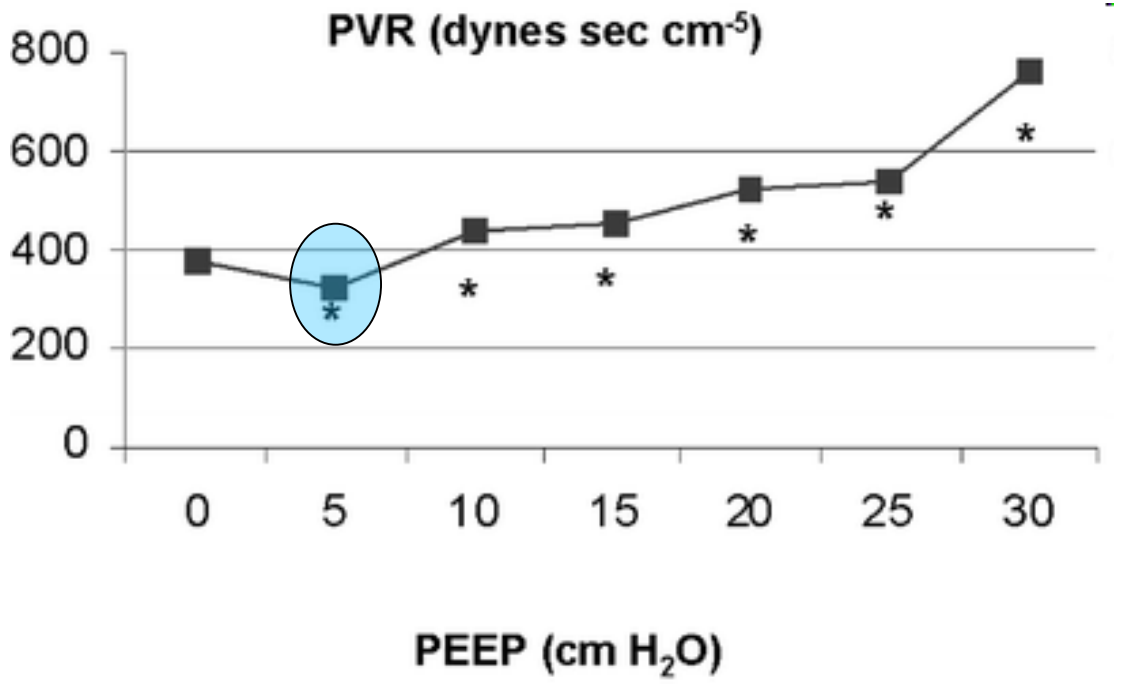


Vieillard-Baron A, Jardin F. Eur Respir J Suppl. 2003 Aug;42:43s-47s

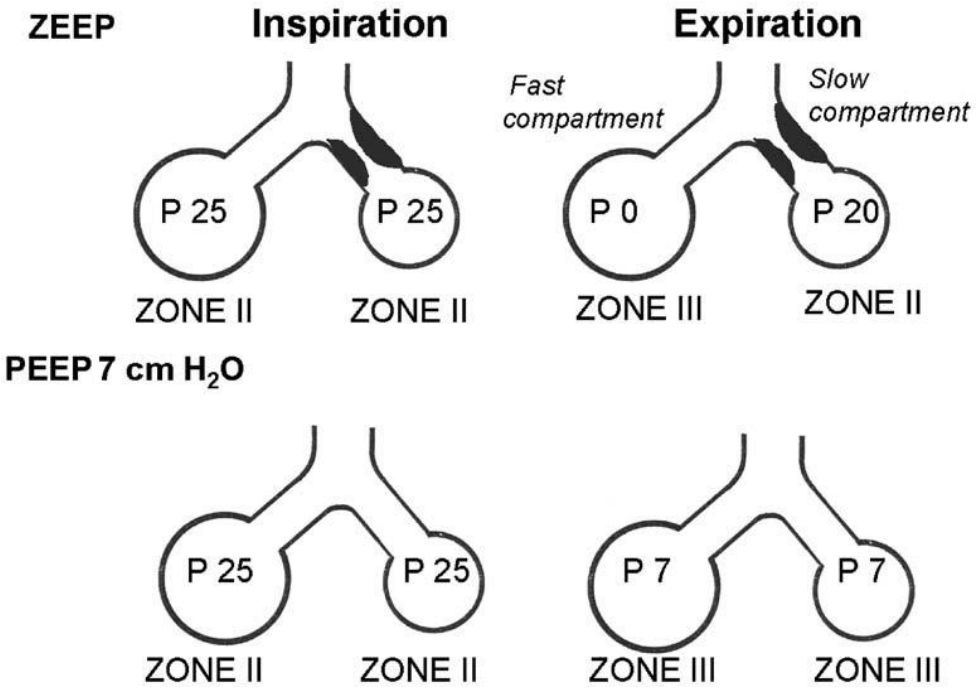


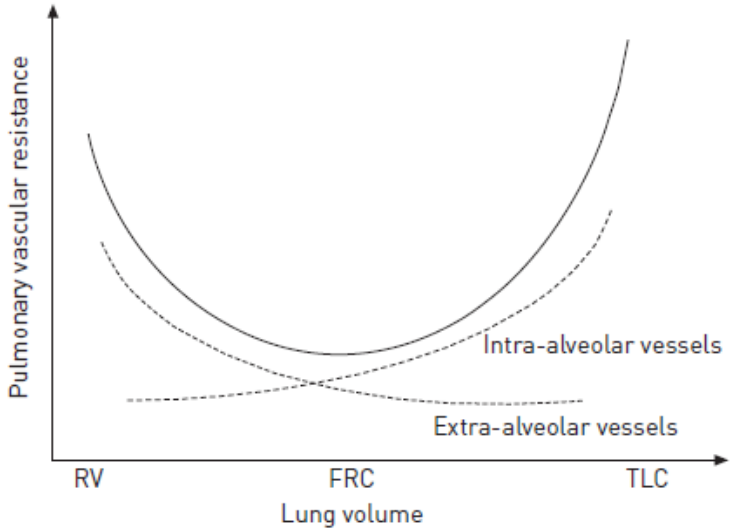
Vieillard-Baron A, Jardin F. Eur Respir J Suppl. 2003 Aug;42:43s-47s

PEEP
may decrease the afterload
of RV

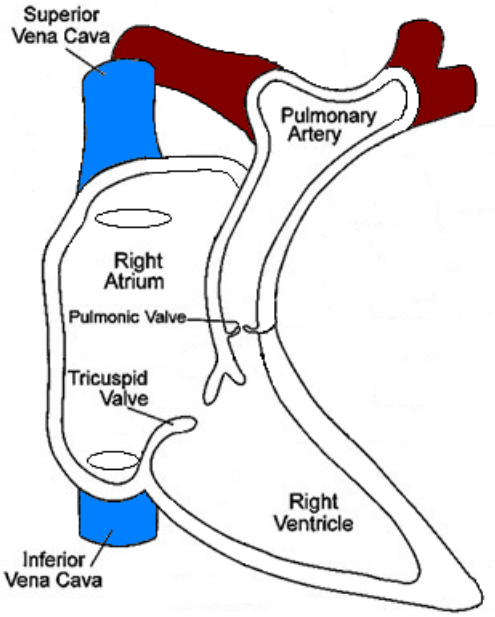


Jardin et al. Intensive Care Med 2003;29:1426

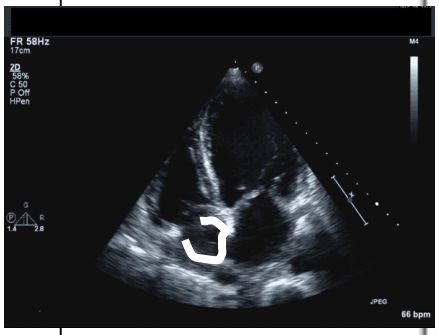


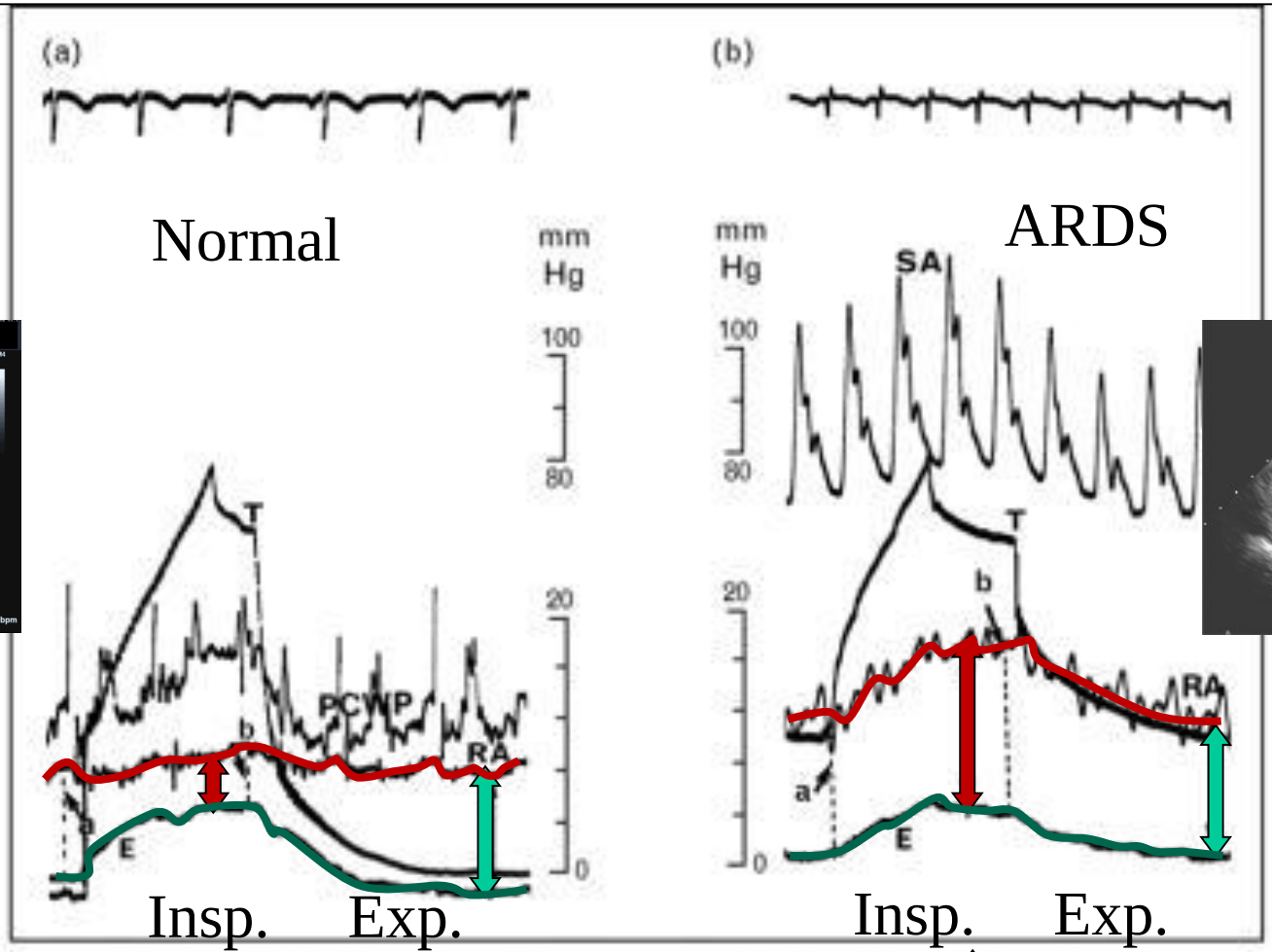


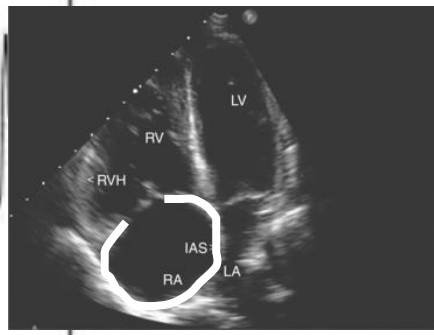
Respiratory system mechanics – Right heart interaction during mechanical ventilation



WHY?





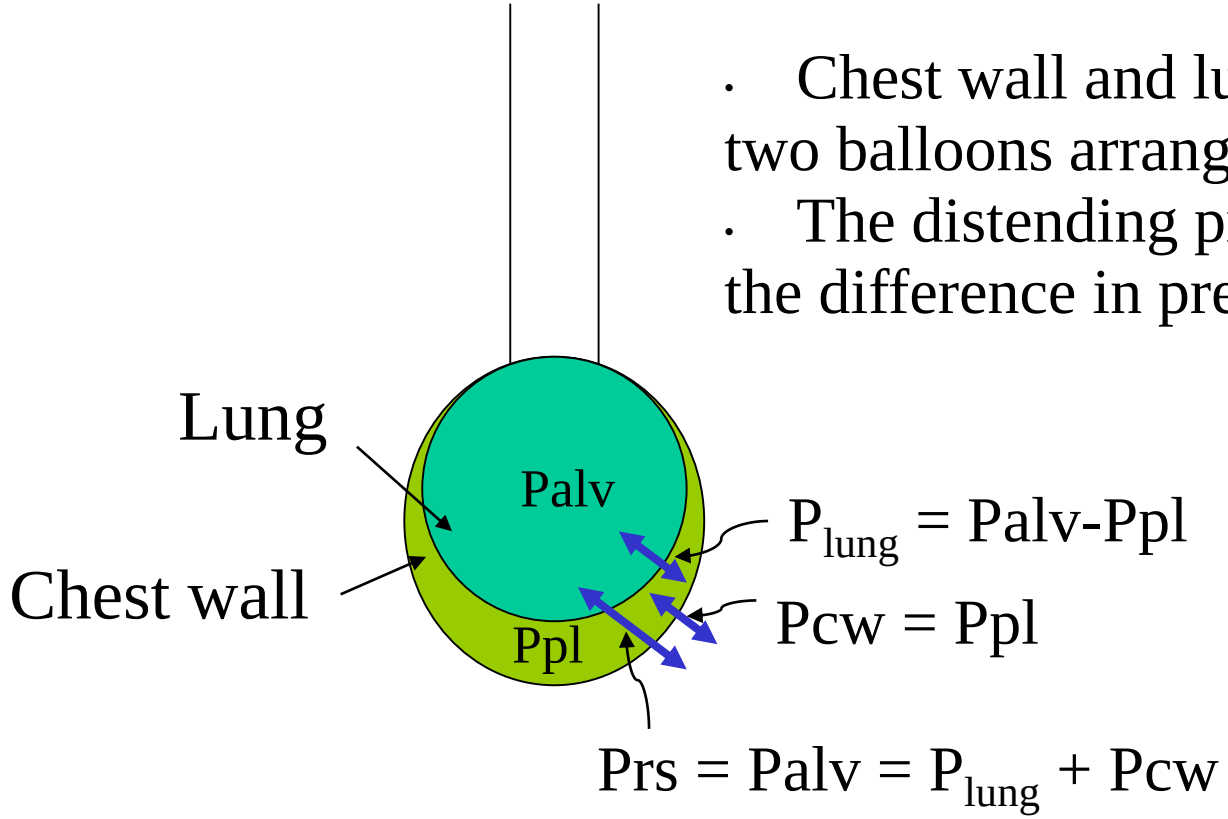


Pressure across the RA

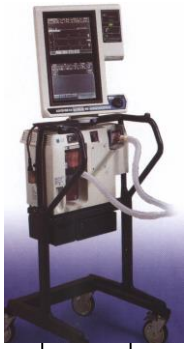
Preload effect (during inspiration)

Afterload effect (during inspiration)

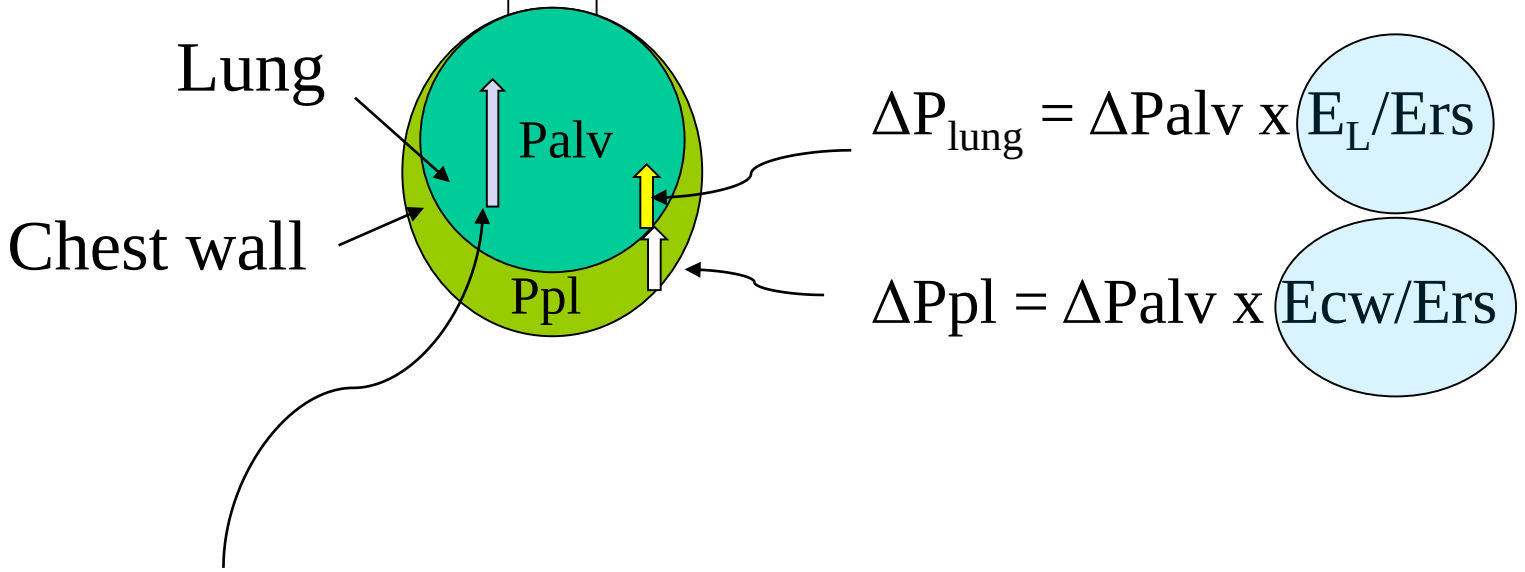
Modified from: Bouferrache and Vieillard-Baron
Current Opinion in Critical Care 2011, 17:30–35



- Chest wall and lung may be considered as two balloons arranged in series
- The distending pressure of each balloon is the difference in pressure across its wall

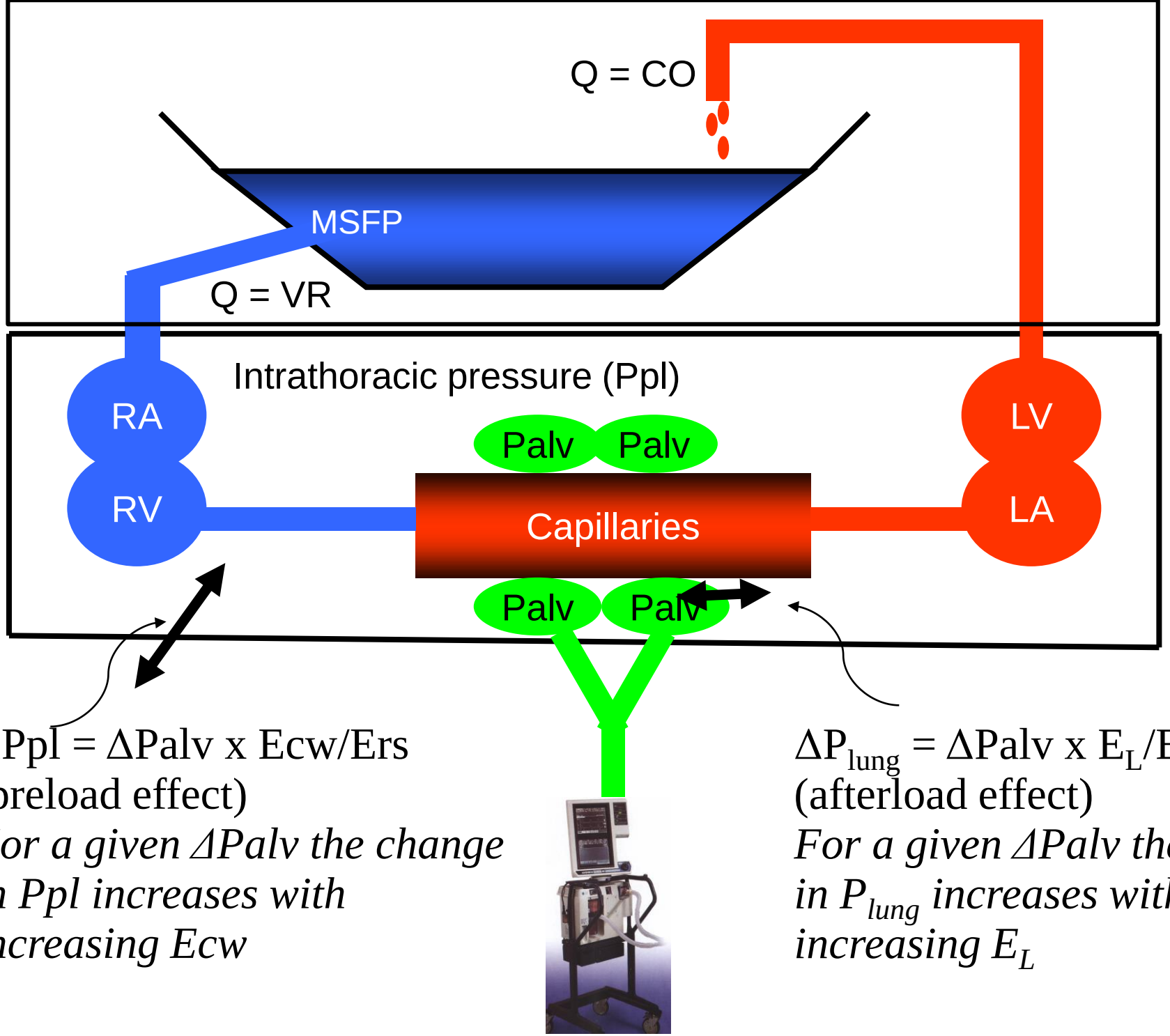


- Chest wall and lung may be considered as two balloons arranged in series
- The distending pressure of each balloon is the difference in pressure across its wall



$\Delta Palv$ is dissipated to inflate the lungs and chest wall

$\Delta Palv = \Delta P_{lung} + \Delta Ppl$



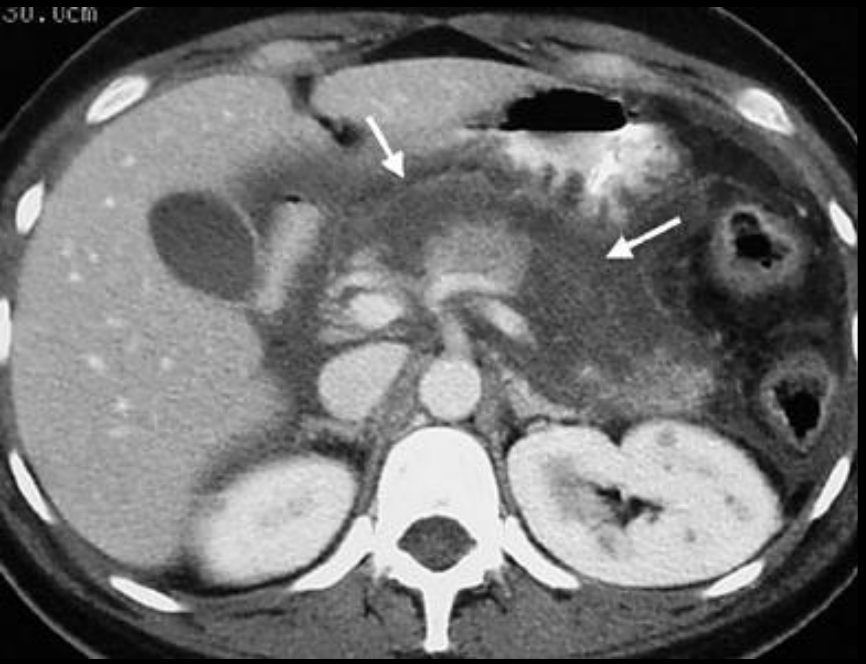
$\Delta Ppl = \Delta Palv \times Ecw/Ers$
(preload effect)
For a given ΔPalv the change in Ppl increases with increasing Ecw

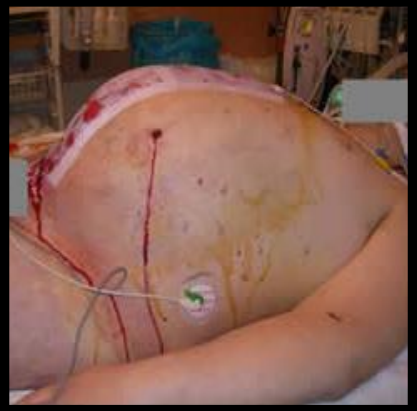
$\Delta P_{lung} = \Delta Palv \times E_L/Ers$
(afterload effect)
For a given ΔPalv the change in P_{lung} increases with increasing E_L

V_T 6 ml/kg (0.42 ml), PEEP 15 cmH_2O

End inspiratory plateau pressure 30 cmH_2O

Ers = (30-15)/0.42 = 36 cmH_2O/L

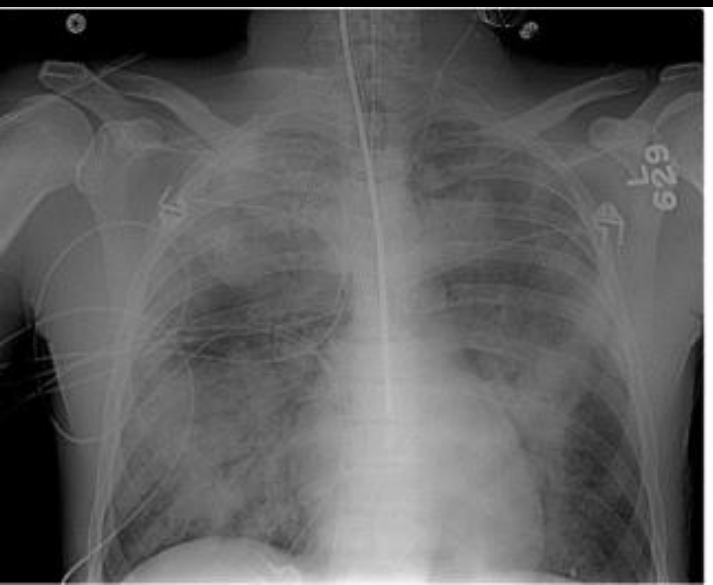


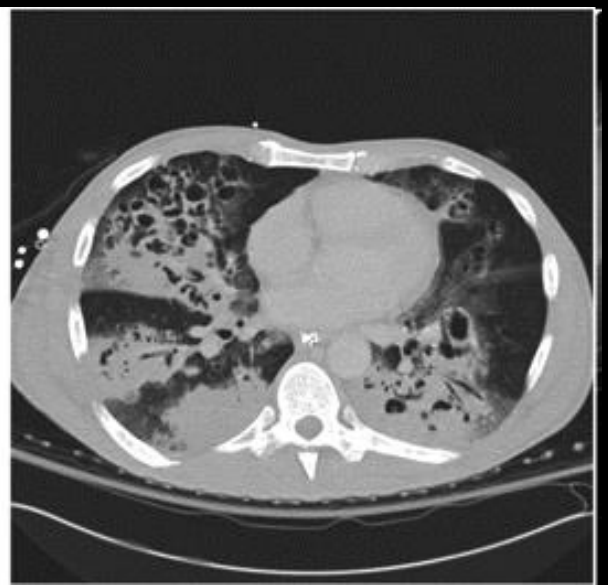


Patient A:
acute pancreatits
Ecw = 21cmH_2O/L

ΔP_{lung} =6 cmH_2O
ΔPpl = 9 cmH_2O

Predominant preload effect





Patient B:
pneumonia
Ecw = 6 cmH_2O/L

ΔP_{lung} = 13 cmH_2O
ΔPpl = 3 cmH_2O

Predominant afterload effect

ΔPes

ΔPlung

Prone position

Jozwiak et al. AJRCCM 2013

Vieillard-Baron et al. Chest. 2007

Recruitment

$ECCO_2$ removal

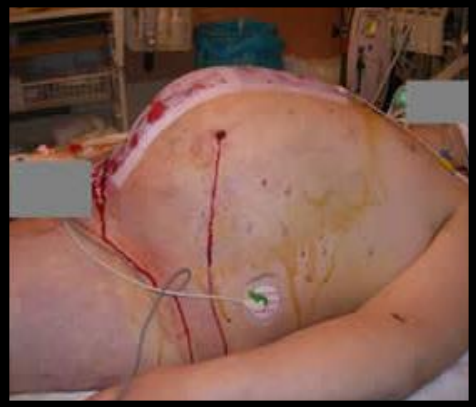
Lower driving P

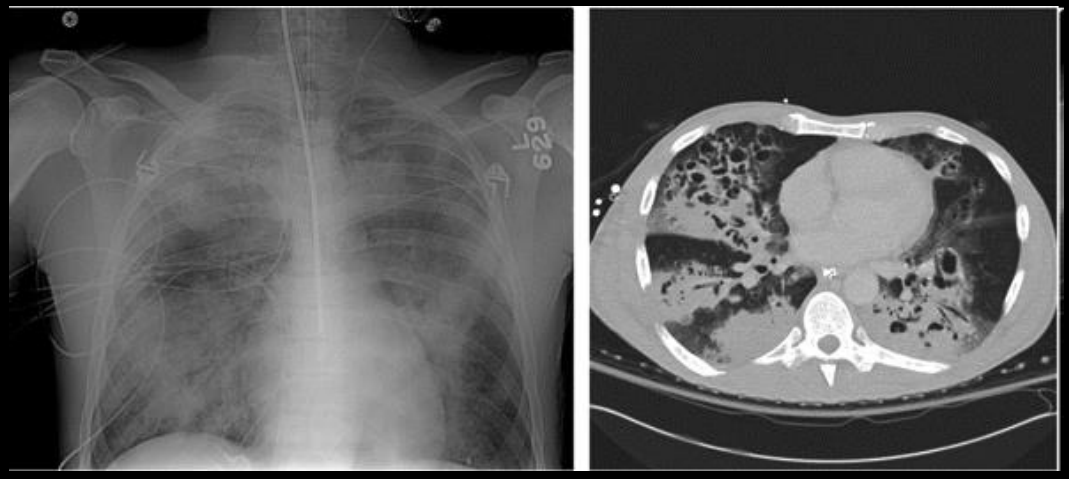
Lower V_T

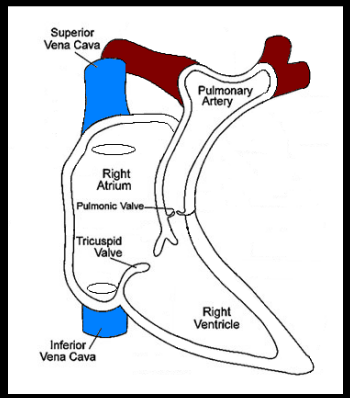
Vieillard-Baron et al.
Intensive Care Med 2013

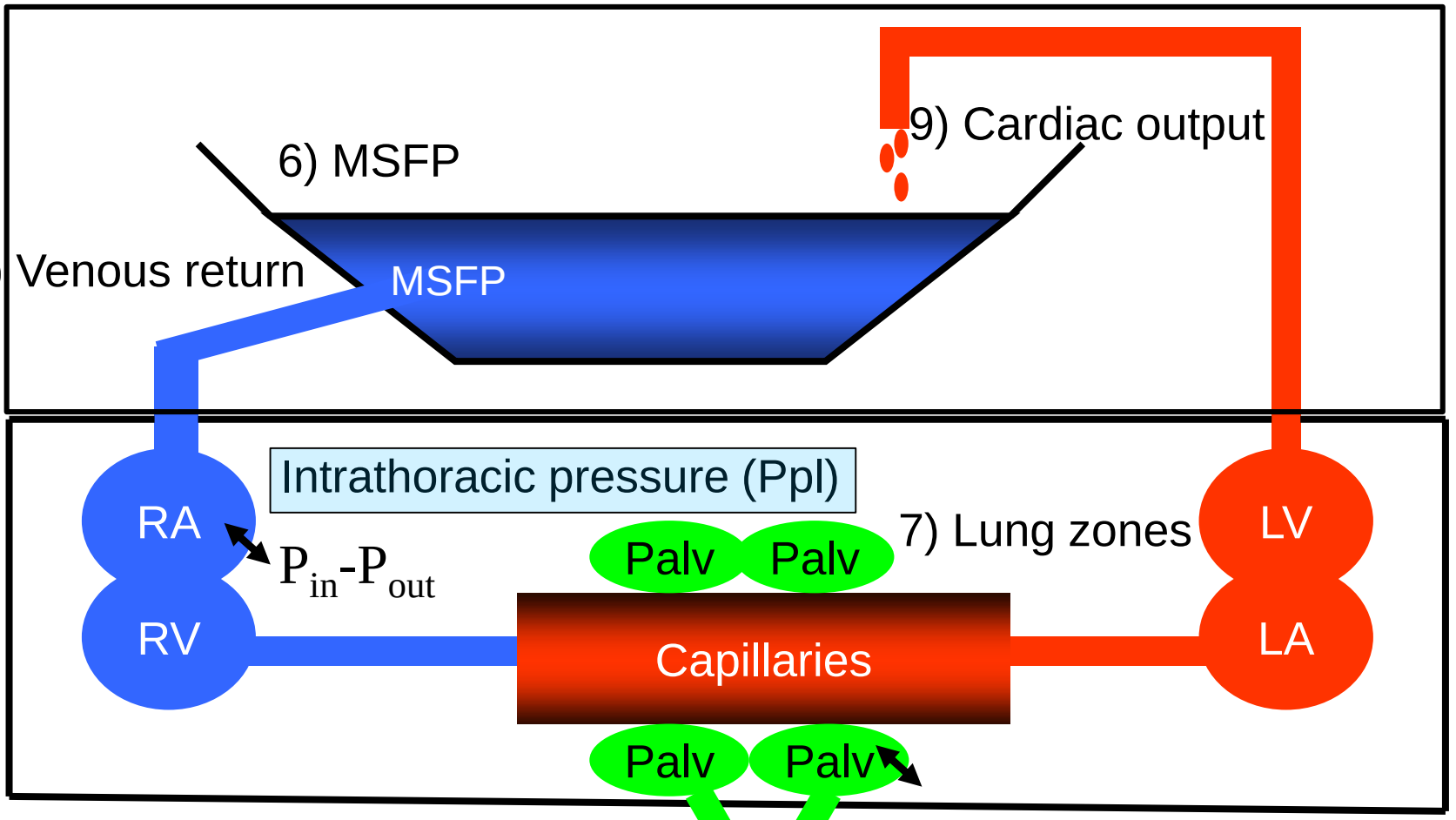
Pre-load effect

After-load effect





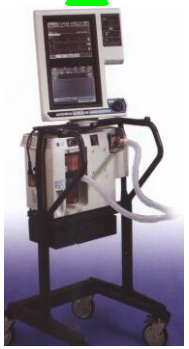




Mechanical ventilation changes everything

1) Autonomic tone
2) Palv
3) Ppl

Passive



4) Trans-vascular pressure

5) Trans-pulmonary pressure

8) Lung compliance

11) Juxtacardiac pressures

CONCISE CLINICAL REVIEW

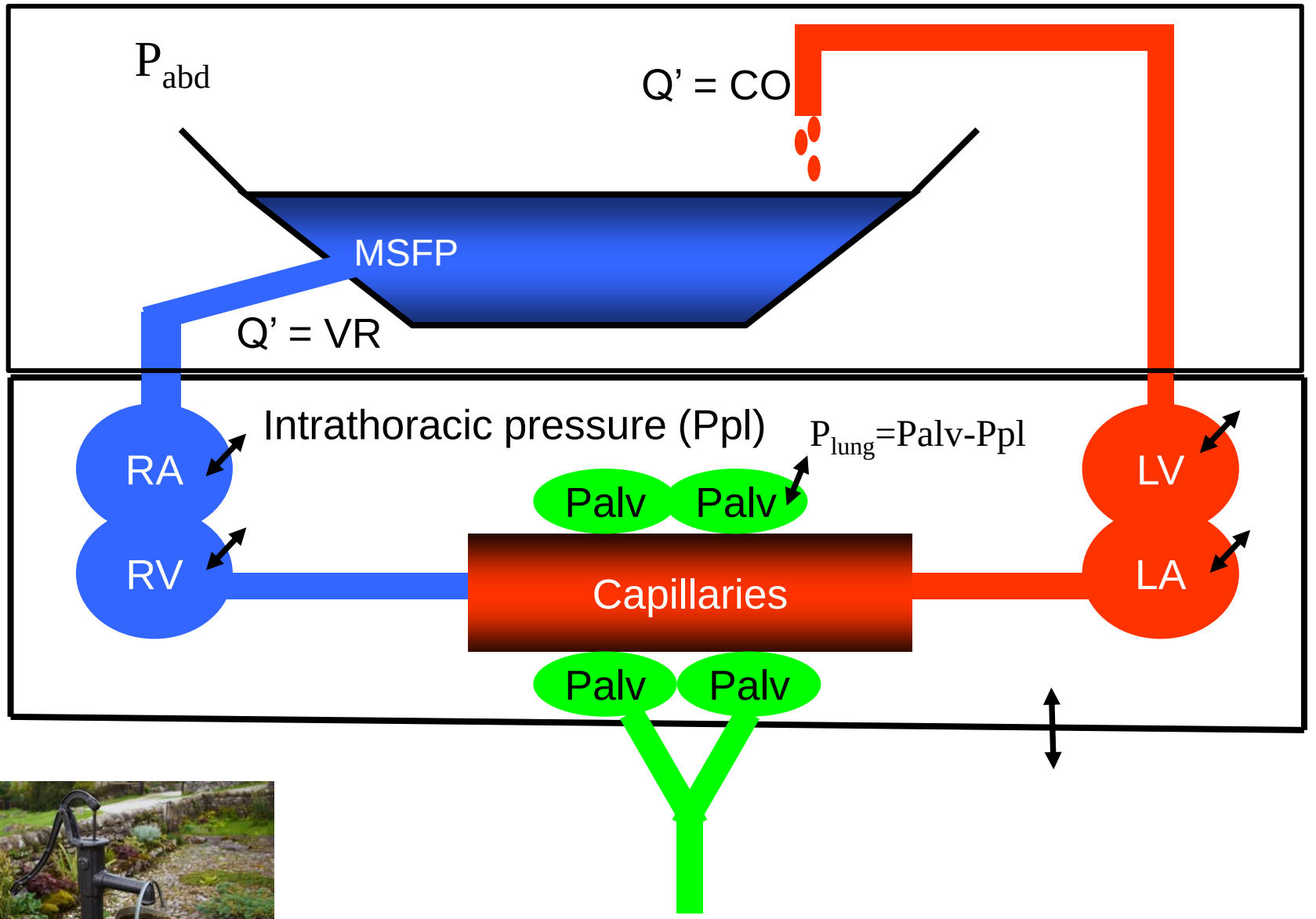
The Application of Esophageal Pressure Measurement in Patients with Respiratory Failure

Evangelia Akoumianaki[1], Salvatore M. Maggiore[2], Franco Valenza[3], Giacomo Bellani[4], Amal Jubran[5], Stephen H. Loring[6], Paolo Pelosi[7], Daniel Talmor[6], Salvatore Grasso[8], Davide Chiumello[9], Claude Guérin[10], Nicolo Patroniti[4], V. Marco Ranieri[11], Luciano Gattinoni[12], Stefano Nava[13], Pietro-Paolo Terragni[11], Antonio Pesenti[4], Martin Tobin[5], Jordi Mancebo[14], and Laurent Brochard[15]

Vieillard-Baron et al. Intensive Care Med 2016; 42:739

For a given CVP

Trans-vascular pressure
- Volume status
- Ppl
  - Patient effort (Pmus)
  - Chest wall elastance

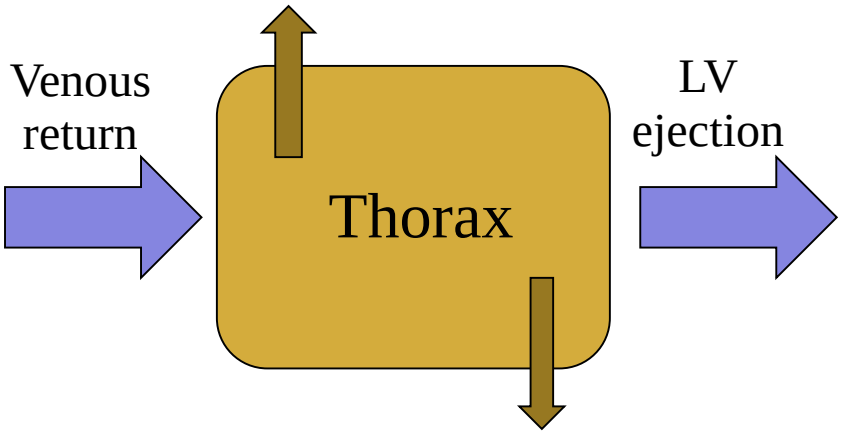


Venous return (VR) = Cardiac output (CO)

Heart-lung interaction

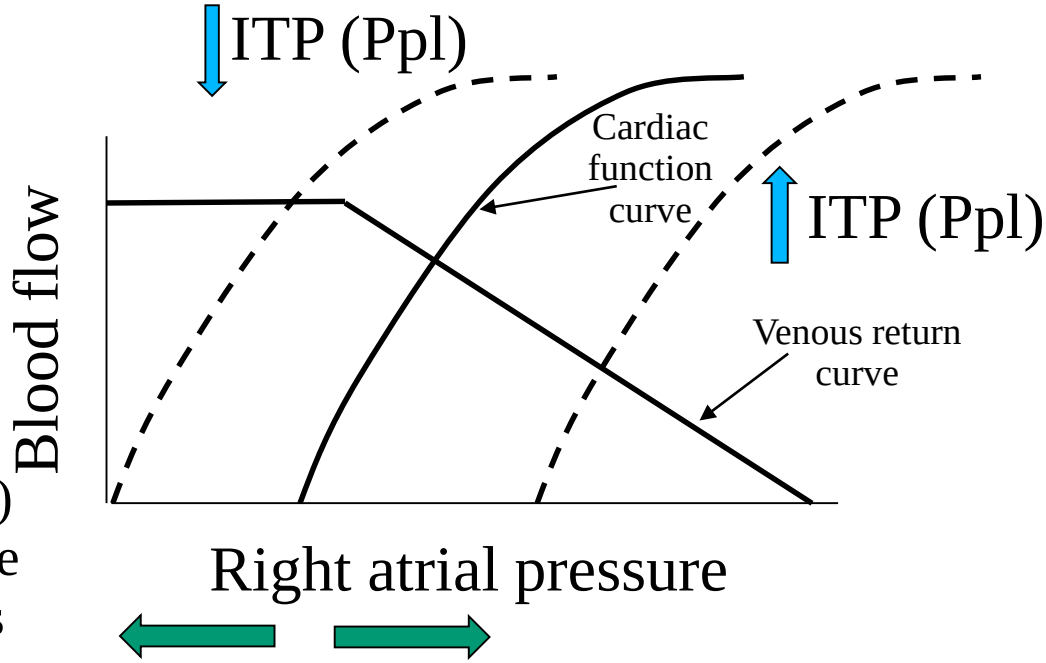
is not

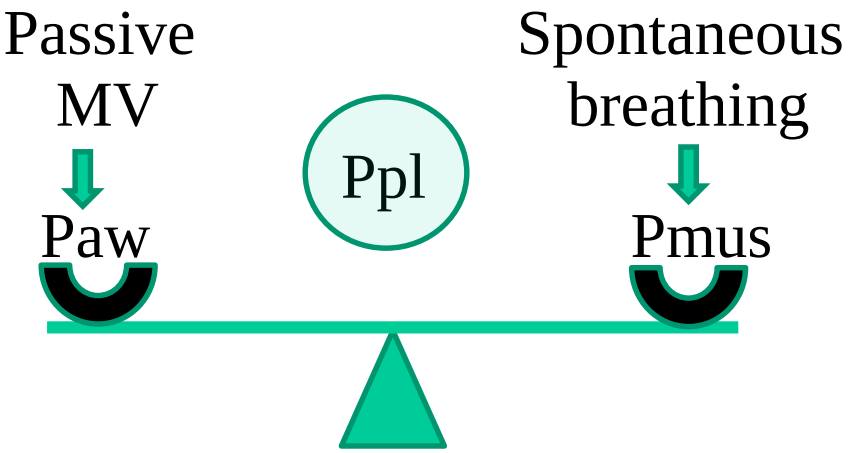
Black White



Increasing ITP (Ppl) decreases the pressure gradients for venous return and LV ejection

Decreasing ITP (Ppl) increases the pressure gradients for venous return and LV ejection





Assisted modes of MV

Adapted from:
Gomez and Pinsky. Principles and Practice of Mechanical Ventilation
(ed. Tobin) 2013; pp.821-849