# Hemodynamic effects of prone positioning

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# Conflicts of interest

Member of the Medical Advisory Board of **Maquet/Getinge**

ORIGINAL

# Clinical and organizational factors associated with mortality during the peak of first COVID-19 wave: the global UNITE-COVID study

Massimiliano Greco[1,2], Thomas De Corte[3,4], Ari Ercole[5,6], Massimo Antonelli[7,8], Elie Azoulay[9,10], Giuseppe Citerio[11,12], Andy Conway Morris[13,14,15], Gennaro De Pascale[7,8], Frantisek Duska[16,17], Paul Elbers[18], Sharon Einav[19,20], Lui Forni[21], Laura Galarza[22], Armand R. J. Girbes[23], Giacomo Grasselli[24,25], Vitaly Gusarov[26], Alasdair Jubb[27,28,29], Jozef Kesecioglu[30], Andrea Lavinio[31], Maria Cruz Martin Delgado[32,33], Johannes Mellinghoff[34], Sheila Nainan Myatra[35], Marlies Ostermann[36], Mariangela Pellegrini[37,38], Pedro Povoa[39,40,41], Stefan J. Schaller[42,43], Jean-Louis Teboul[44], Adrian Wong[45], Jan J. De Waele[3,4*] and Maurizio Cecconi[1,2] on behalf of the ESICM UNITE-COVID investigators

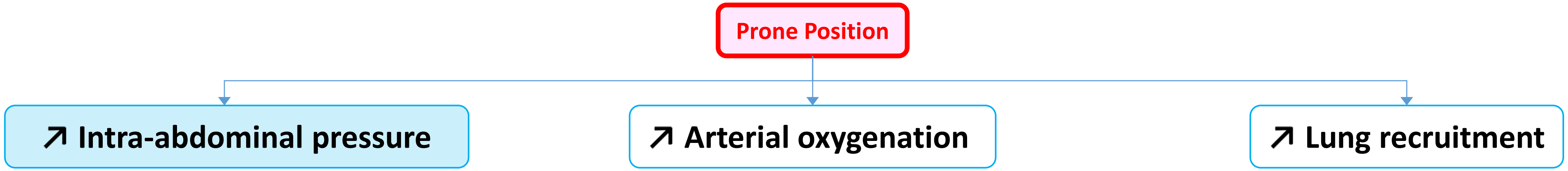
*Intensive Care Med* (2022) 48:690–705

## Table 2 Supportive care received during ICU stay

| Characteristic | All patients ($N=4994$)[1] | Patients intubated at admission ($N=2325$)[1] A | Patients intubated during ICU stay ($N=1677$)[1] B |
|---|---|---|---|
| Duration of IMV | 16 [10–27] (3984) | 18 [11–27] (2251) | 15 [8–26] (1609) |
| Prone position | 61.7% (4717) | 65.2% (2276) | 67.4% (1646) |

Prone Position

- ↗ Intra-abdominal pressure
- ↗ Arterial oxygenation
- ↗ Lung recruitment


Prone Position
↗ Intra-abdominal pressure
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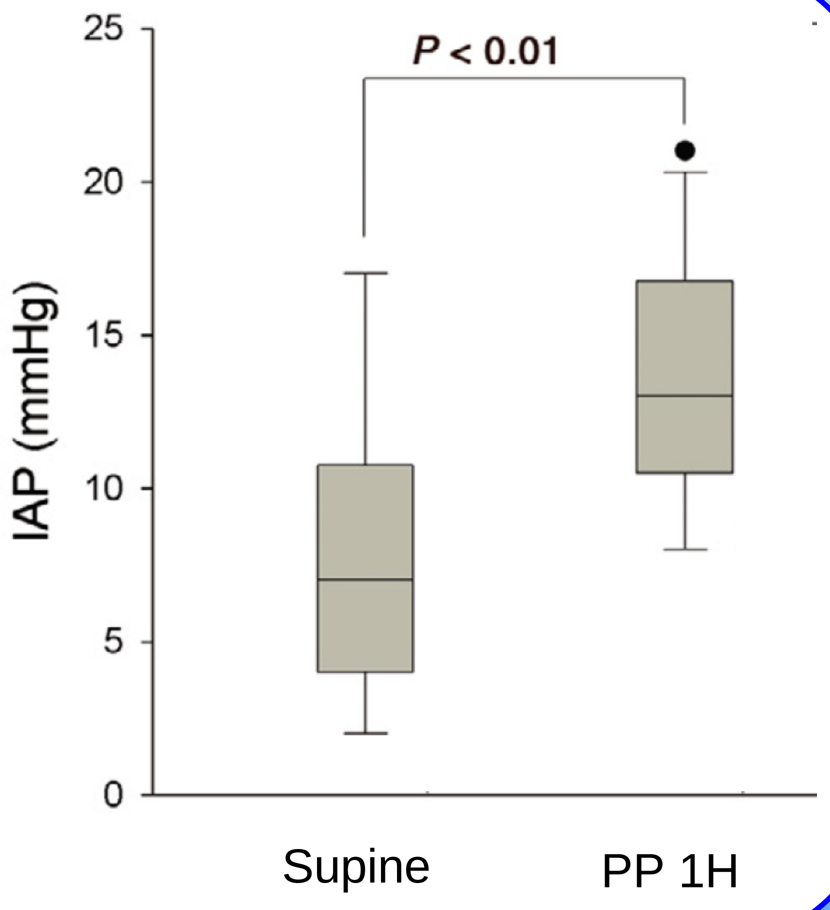
↗ Lung recruitment

**Influence of support on intra-abdominal pressure, hepatic kinetics of indocyanine green and extravascular lung water during prone positioning in patients with ARDS: a randomized crossover study**

Pierre Michelet, Antoine Roch, Marc Gainnier, Jean-Marie Sainty, Jean-Pierre Auffray and Laurent Papazian

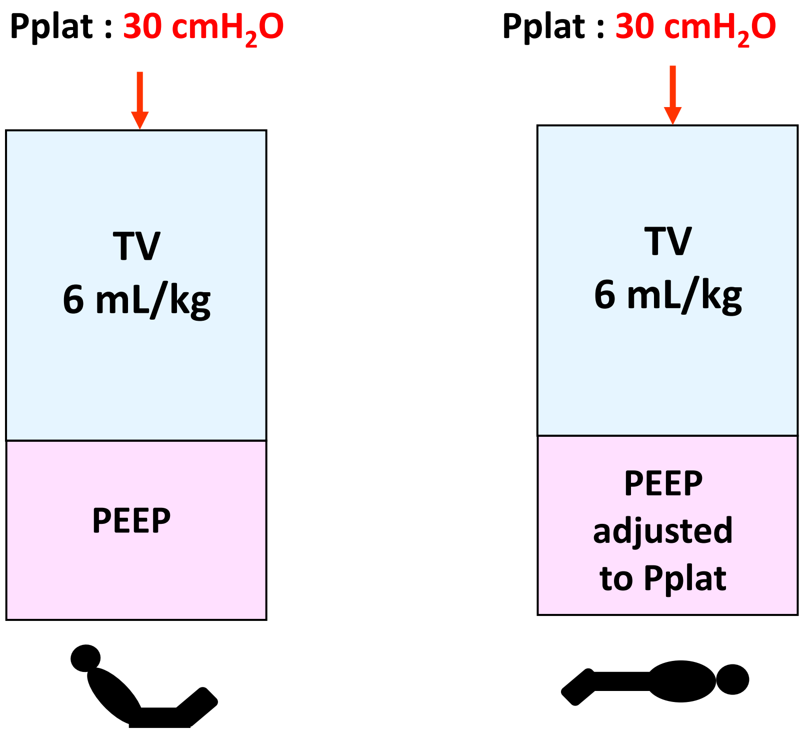
*Critical Care* 2005, **9**:R251-R257



# Beneficial Hemodynamic Effects of Prone Positioning in Patients with Acute Respiratory Distress Syndrome

Mathieu Jozwiak[1,2], Jean-Louis Teboul[1,2], Nadia Anguel[1,2], Romain Persichini[1,2], Serena Silva[1,2], Denis Chemla[2,3], Christian Richard[1,2], and Xavier Monnet[1,2]

Am J Respir Crit Care Med Vol 188, Iss. 12, pp 1428–1433, Dec 15, 2013



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Am J Respir Crit Care Med Vol 188, Iss. 12, pp 1428–1433, Dec 15, 2013

| Respiratory variables | supine | prone |
|---|---|---|
| **Tidal Volume** (mL/kg) | **6.4** [6.1-7.0] | **6.4** [6.1-7.0] |
| **PEEP** ($cmH_2O$) | **13** [11-15] | **14** [12-15] |
| **Intrinsic PEEP** ($cmH_2O$) | **1** [0-2] | **2** [0-3] |
| **Plateau pressure** ($cmH_2O$) | **30** [0-0] | **30** [0-0] |
| **Respiratory rate** (c/min) | **35** [30-35] | **35** [30-35] |
| **Resp system compliance** ($mL/cmH_2O$) | **23** [21-26] | **26** [22-31] * |
| **$PaO_2$ / $FiO_2$** (mL/kg) | **134** [113-154] | **186** [142-232] * |
| **$PaCO_2$** (mmHg) | **34** [30-40] | **32** [27-39] |
| **Intra-abdominal pressure** (mmHg) | **14** [12-17] | **17** [16-20] * |

## Effects of Prone Positioning on Venous Return in Patients With Acute Respiratory Distress Syndrome

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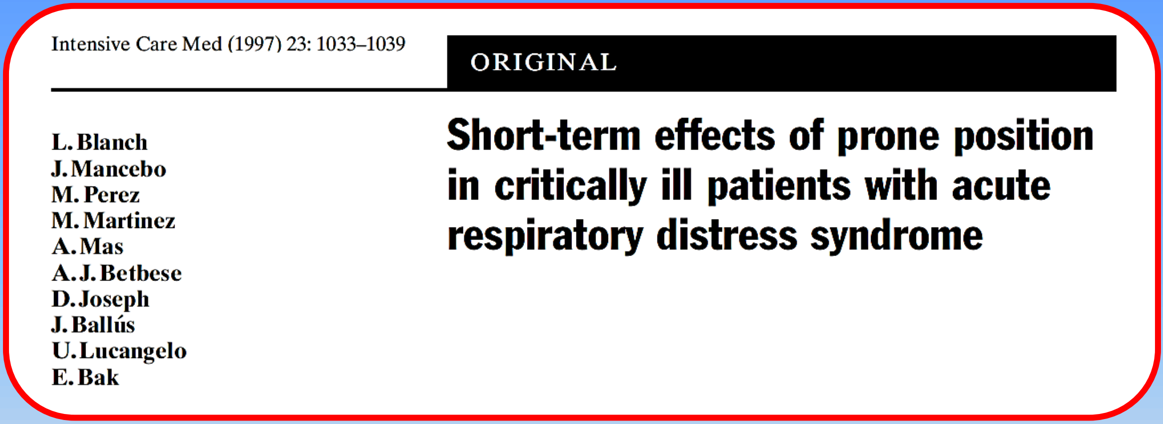
Crit Care Med 2021; 49:781-789

### Respiratory and Hemodynamic Effects of Prone Positioning According to Change in Cardiac Index With Prone Positioning

| Variables | Significant Increase in CI ≥ 15% ($n = 7$) | | No Significant Increase in CI ($n = 15$) | |
|---|---|---|---|---|
| | Semirecumbent Position | Prone Position | Semirecumbent Position | Prone Position |
| IAP, mm Hg | 10 (9–15) | 15 (14–17)[a] | 13 (9–16) | 18 (14–22)[a] |

**Prone Position**

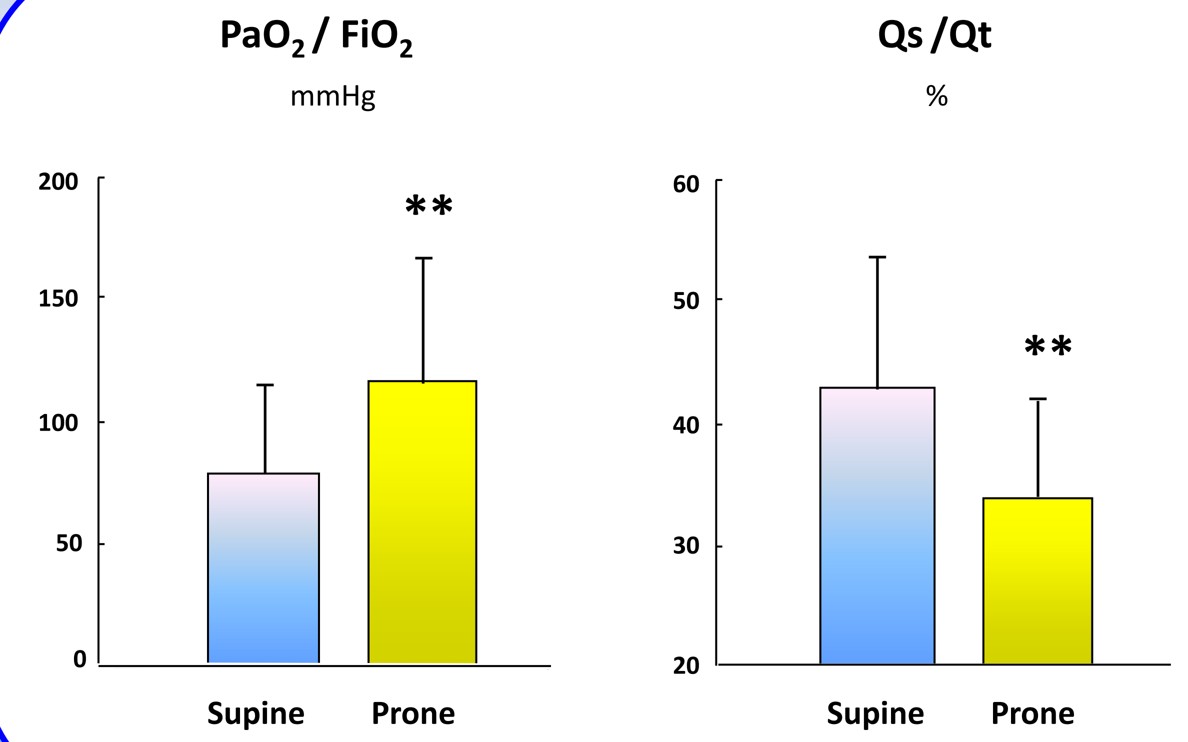
- ↗ Intra-abdominal pressure
- ↗ Arterial oxygenation
- ↗ Lung recruitment


Intensive Care Med (1997) 23: 1033–1039

ORIGINAL

L. Blanch
J. Mancebo
M. Perez
M. Martinez
A. Mas
A. J. Betbese
D. Joseph
J. Ballús
U. Lucangelo
E. Bak

# Short-term effects of prone position in critically ill patients with acute respiratory distress syndrome



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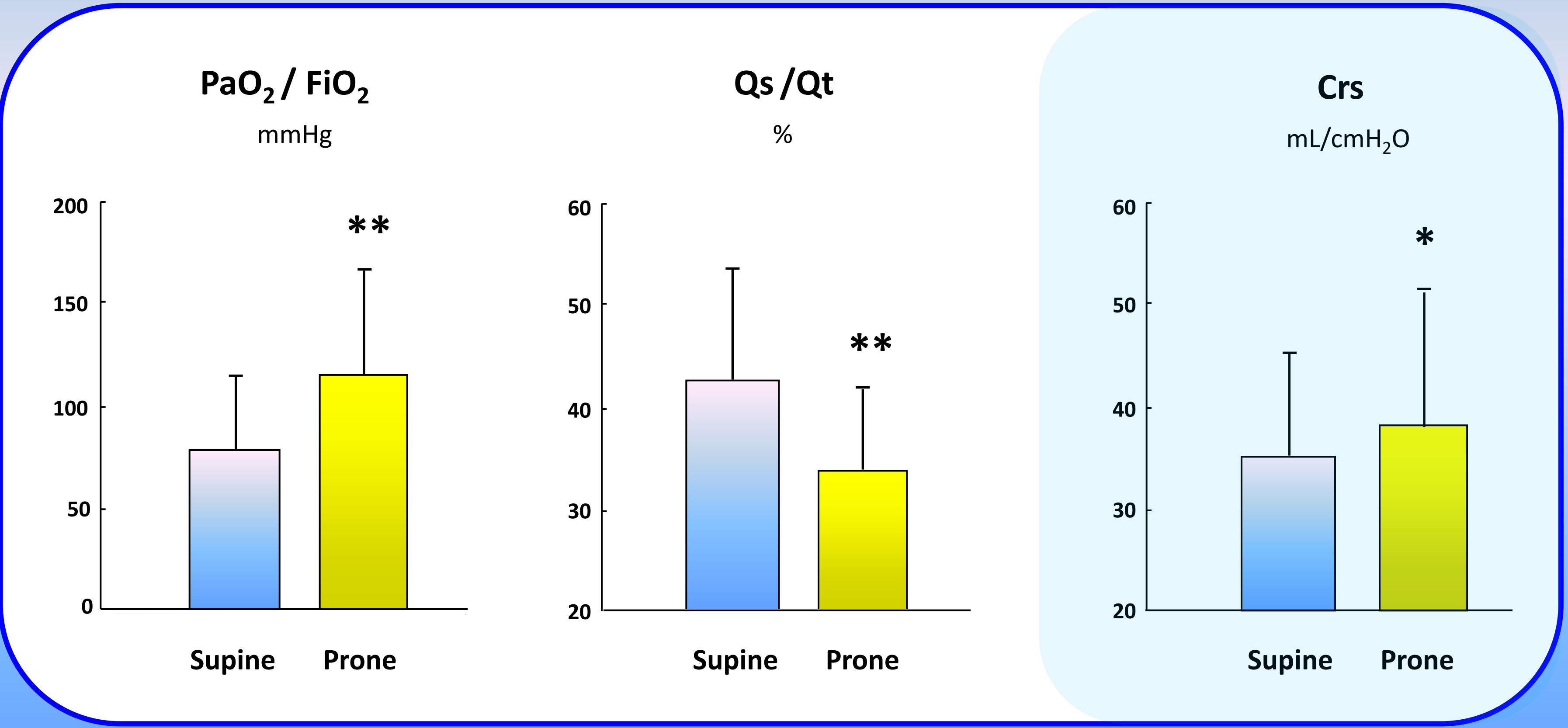
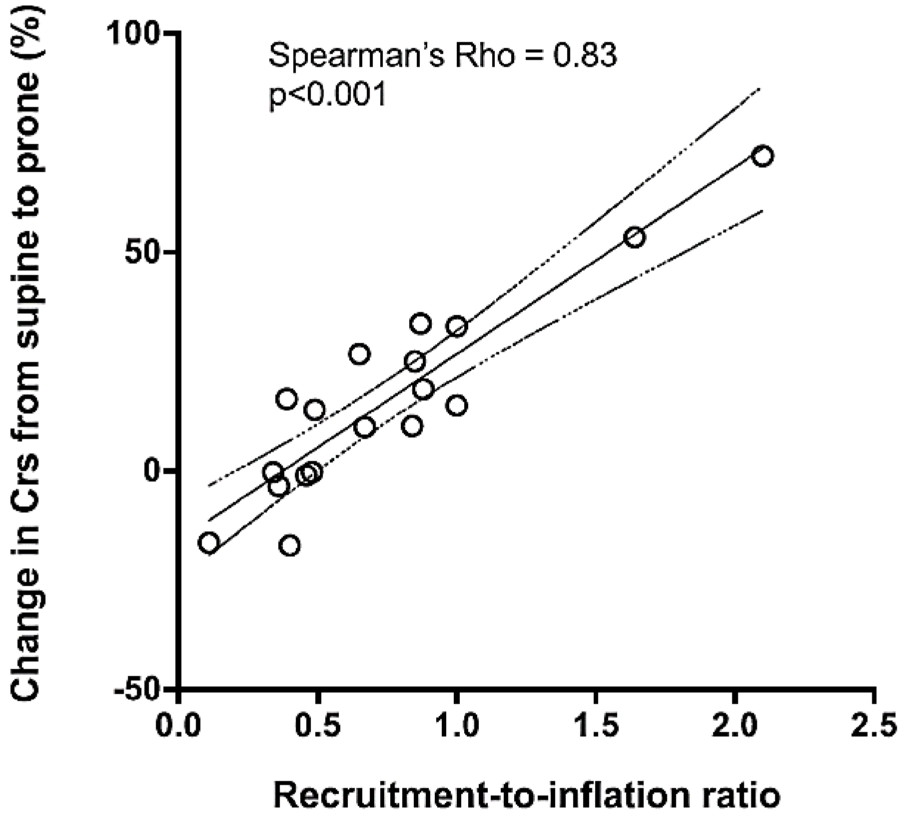


# Differential effects of prone position in COVID-19-related ARDS in low and high recruiters

Martin Cour[1,2*], David Bussy[1,2], Neven Stevic[1,2], Laurent Argaud[1,2] and Claude Guérin[1,2]

*Intensive Care Med (2021) 47:1044–1046*



**Prone Position**

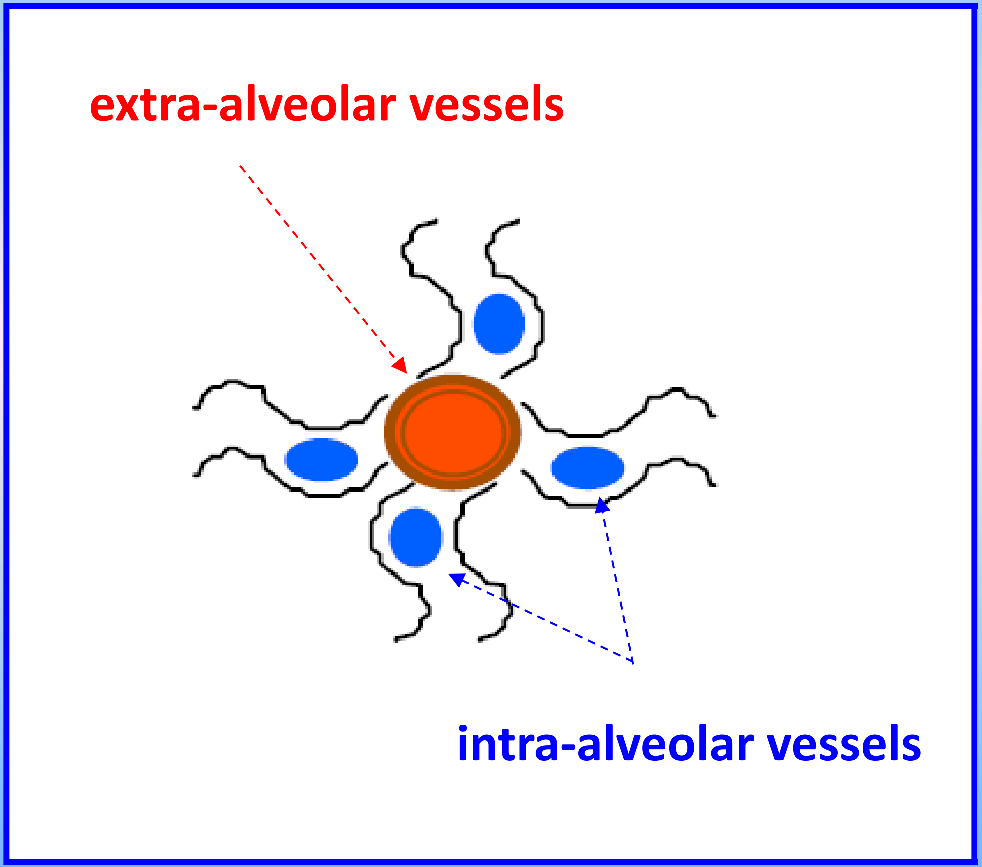
- ↗ Intra-abdominal pressure
- ↗ Arterial oxygenation
- ↗ Lung recruitment

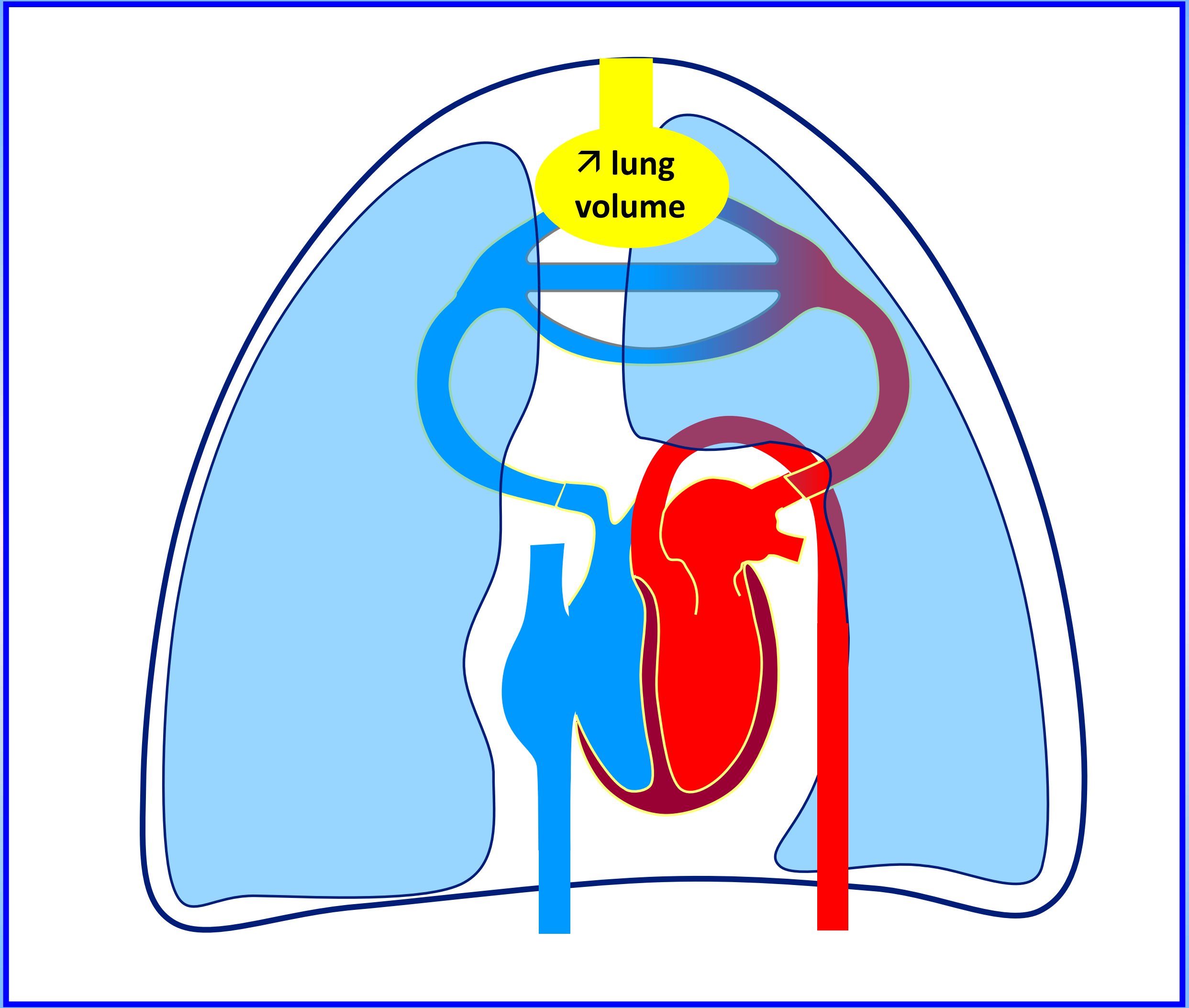
**Hemodynamic** consequences?

**Prone Position**

- ↗ Intra-abdominal pressure
- ↗ Arterial oxygenation
- ↗ Lung recruitment

**Hemodynamic** consequences?

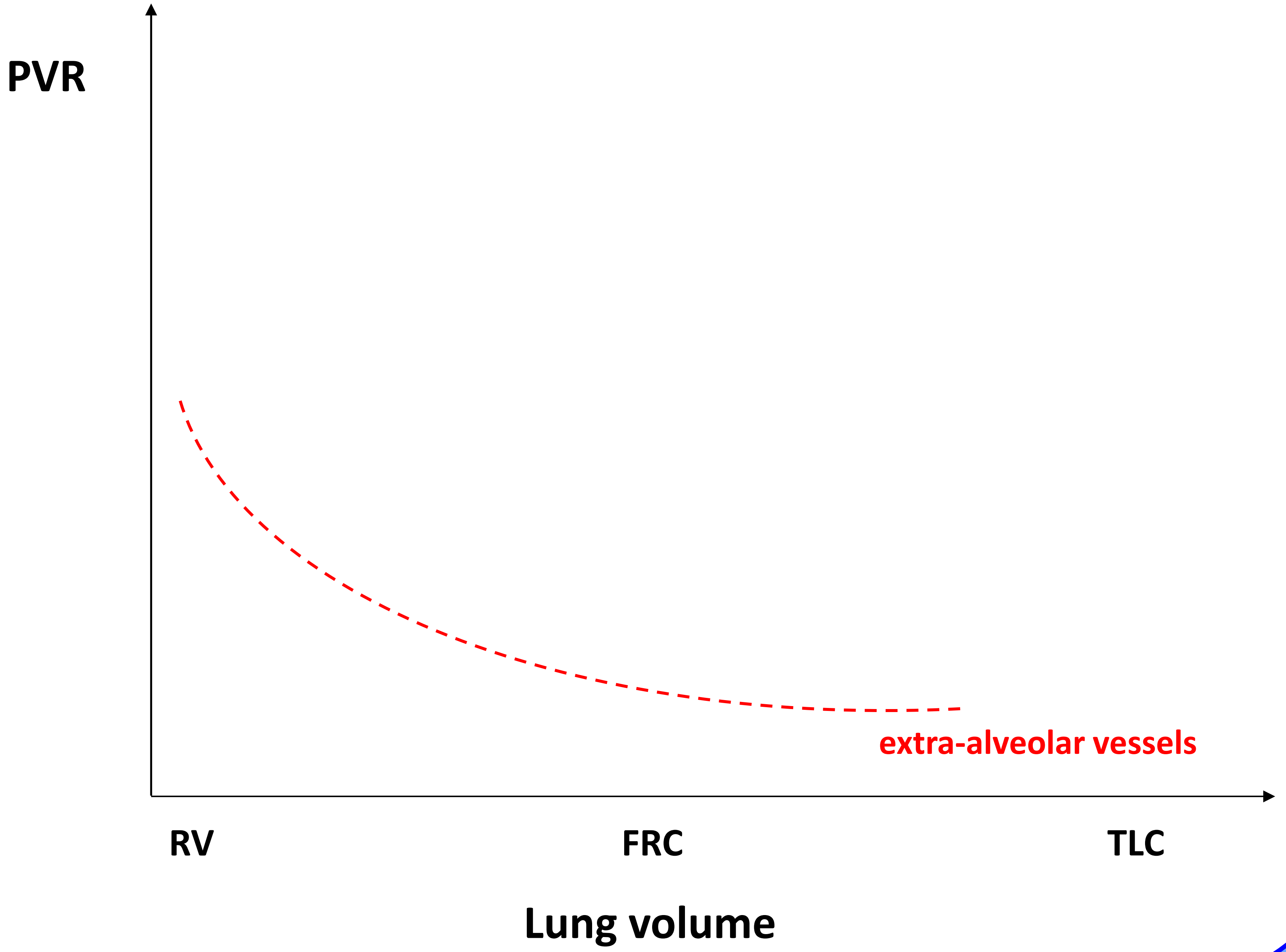

extra-alveolar vessels
intra-alveolar vessels

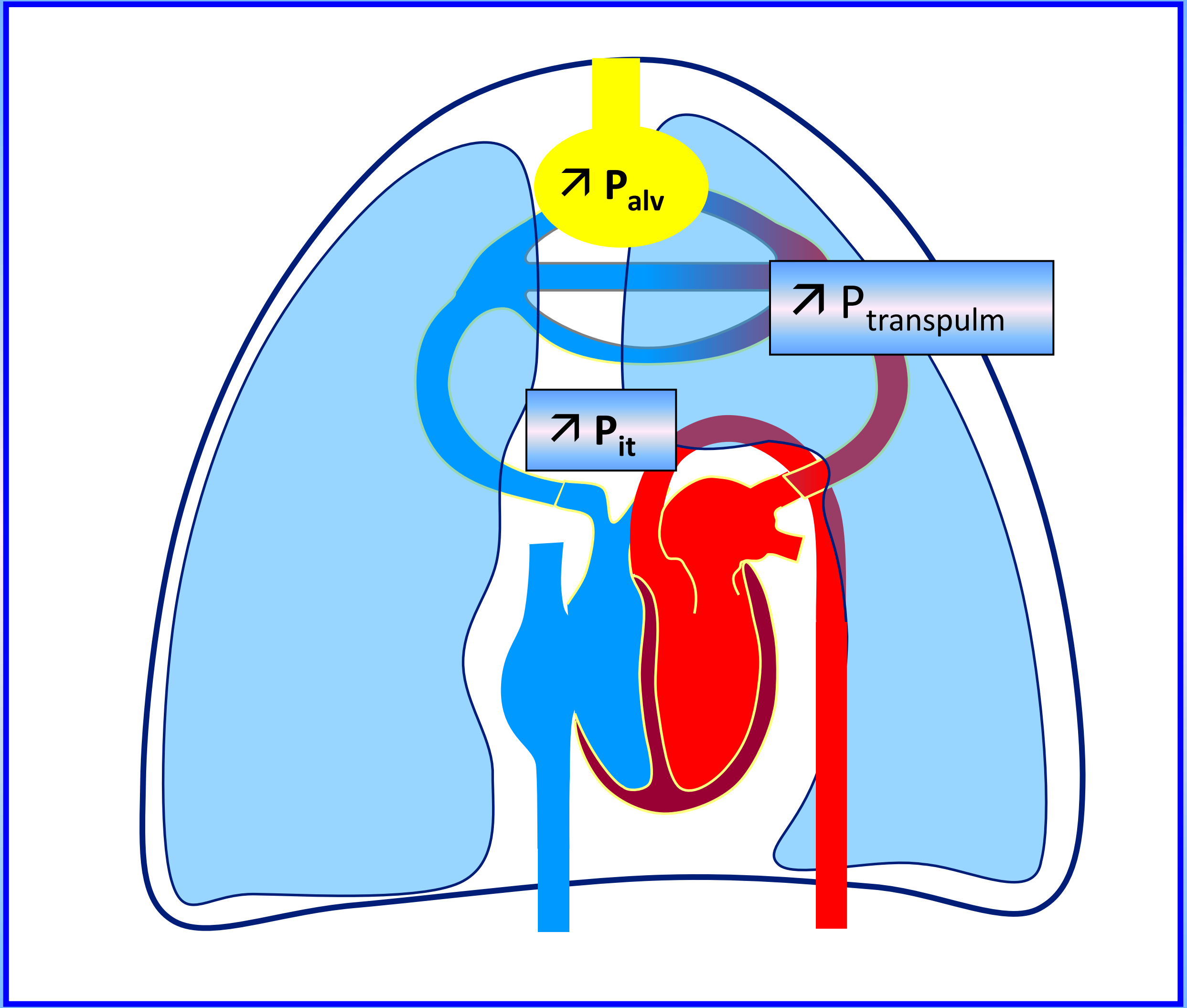



## ↗ Lung volume

**decreases** the **resistance**

of the **extra-alveolar vessels**


PVR
extra-alveolar vessels
RV
FRC
TLC
Lung volume




↗ **Lung volume**

decreases **the** resistance of

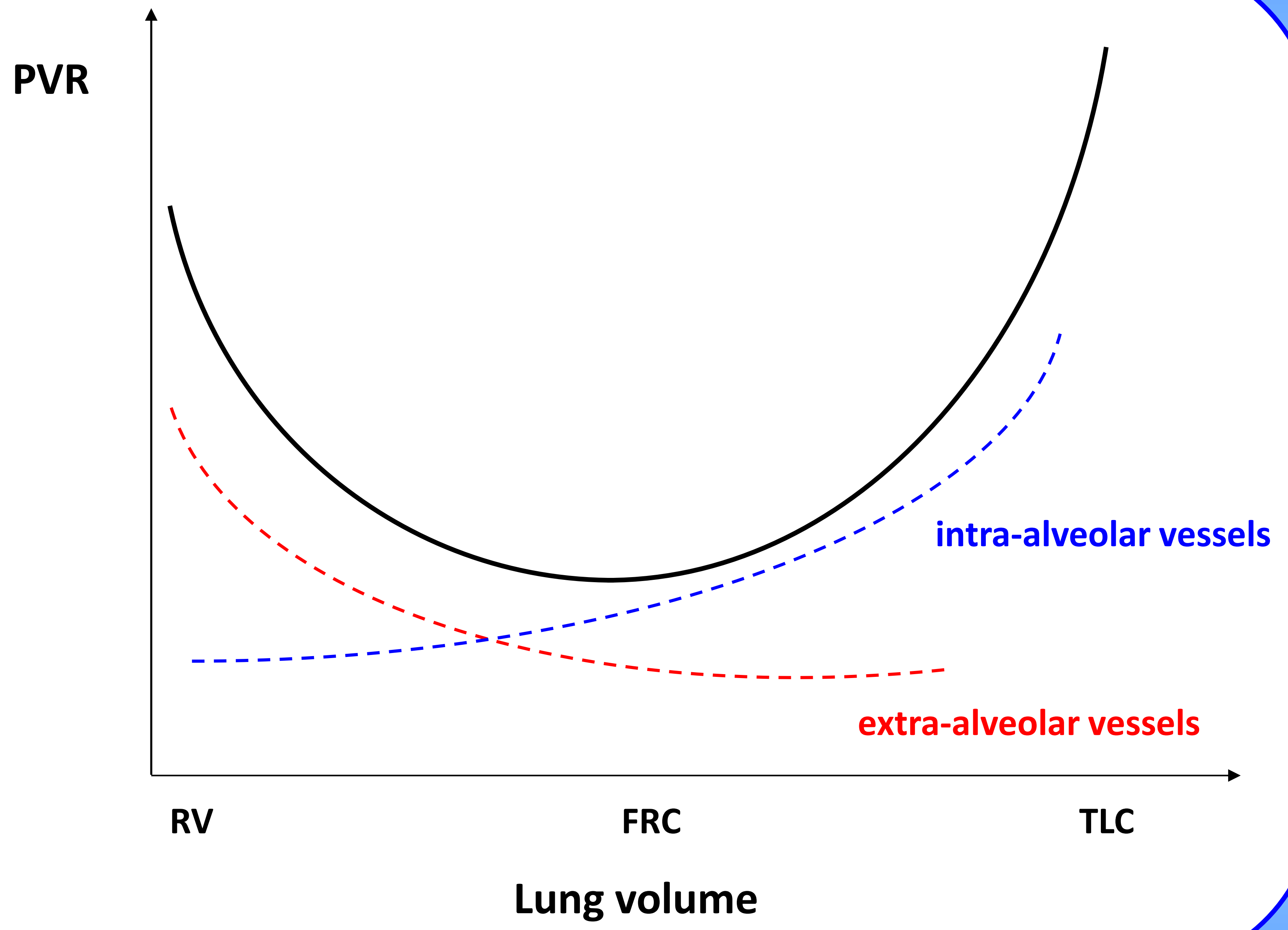
the **extra-alveolar vessels**

**↗ Transpulmonary pressure**

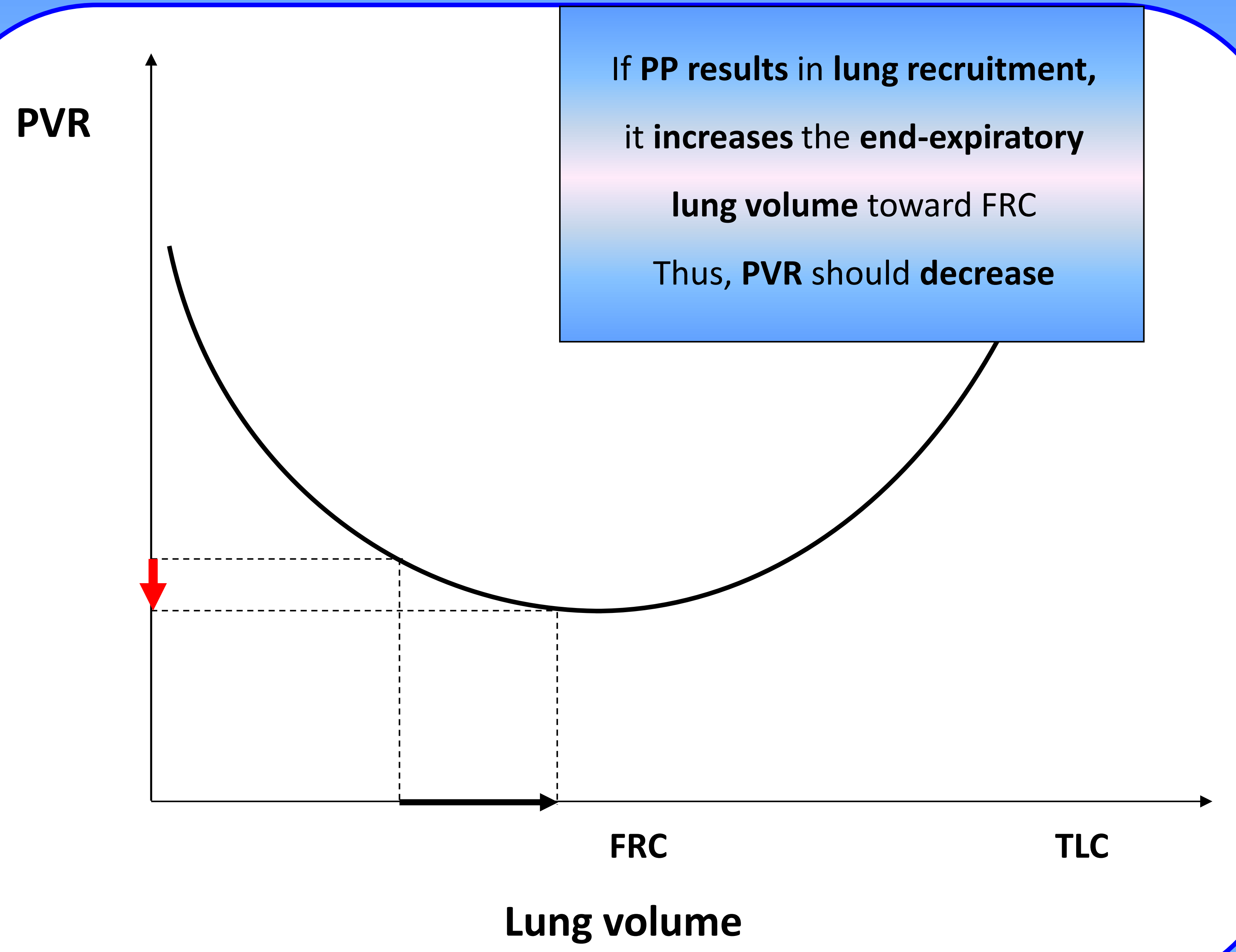
**= $P_{alv}$ - $P_{it}$**

**Increases** the **resistance** of

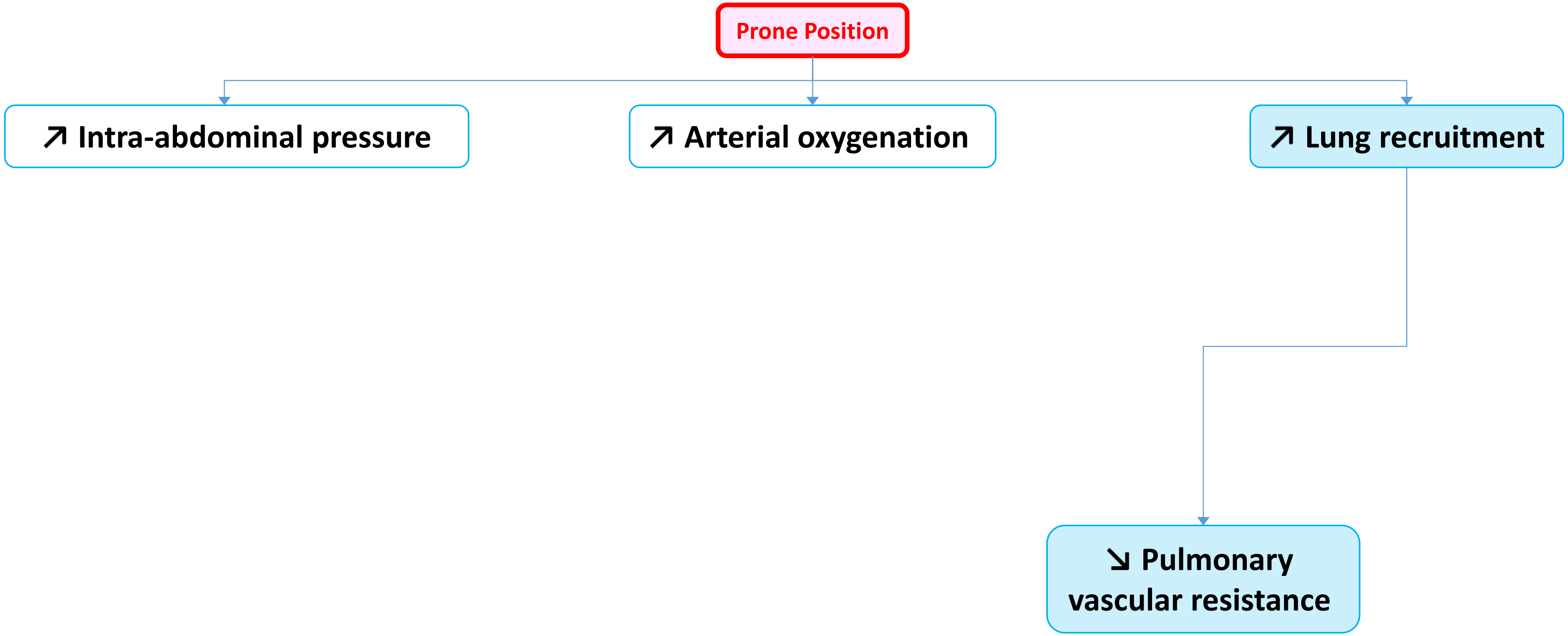
the **intra-alveolar vessels**

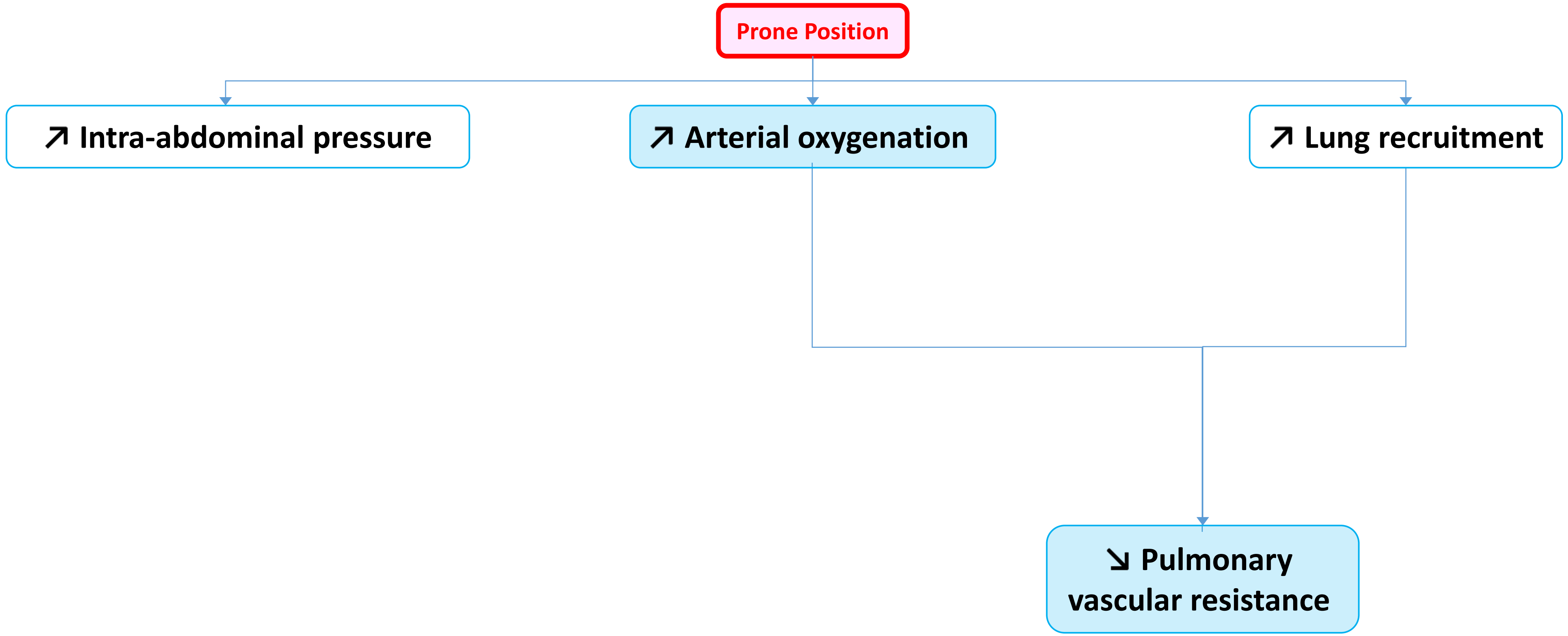


PVR
intra-alveolar vessels
extra-alveolar vessels
RV
FRC
TLC
Lung volume



PVR
If **PP results** in **lung recruitment,**
it **increases** the **end-expiratory**
**lung volume** toward FRC
Thus, **PVR** should **decrease**
FRC
TLC
Lung volume


Prone Position
↗ Intra-abdominal pressure
↗ Arterial oxygenation
↗ Lung recruitment
↘ Pulmonary vascular resistance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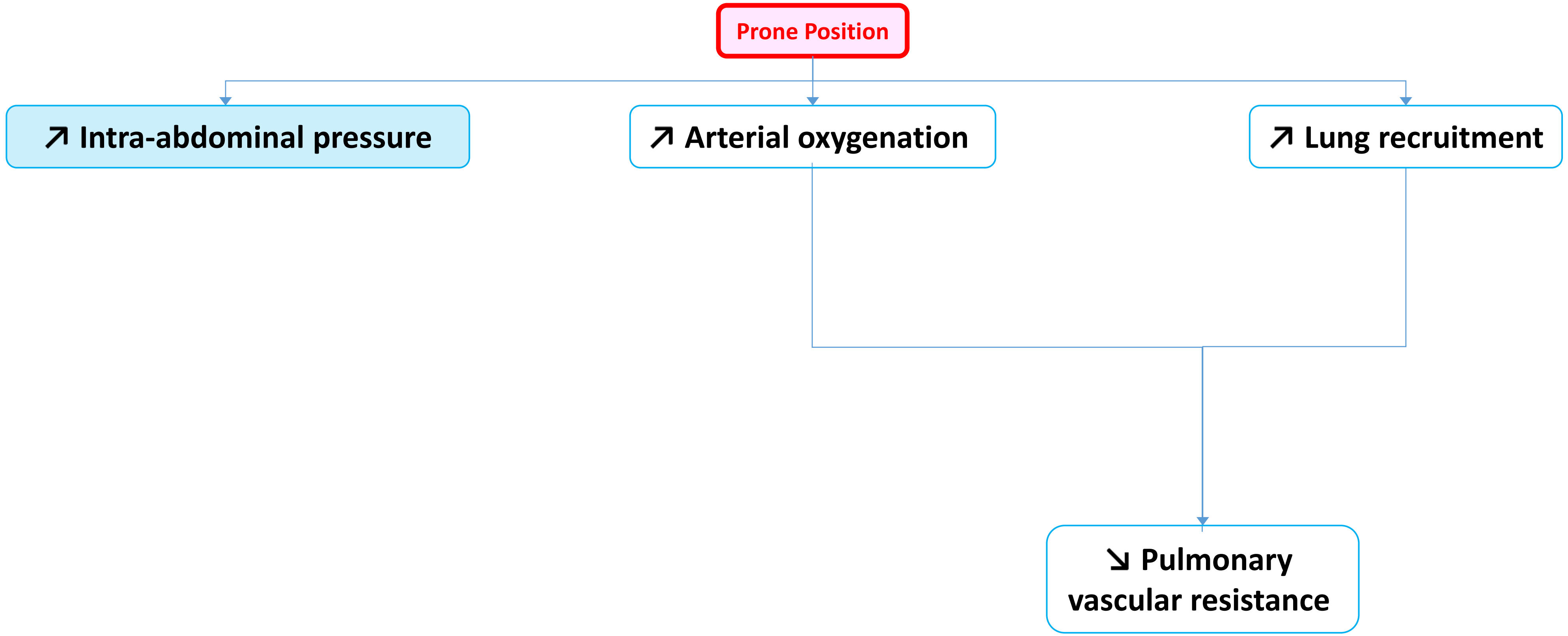
Prone Position
↗ Intra-abdominal pressure
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↗ Lung recruitment
↘ Pulmonary vascular resistance

Intensive Care Med (2013) 39:1487–1488

EDITORIAL

Jean-Louis Teboul

# Mean systemic pressure: we can now estimate it, but for what?

**Venous return = (Pms – RAP) / Resistance to venous return**

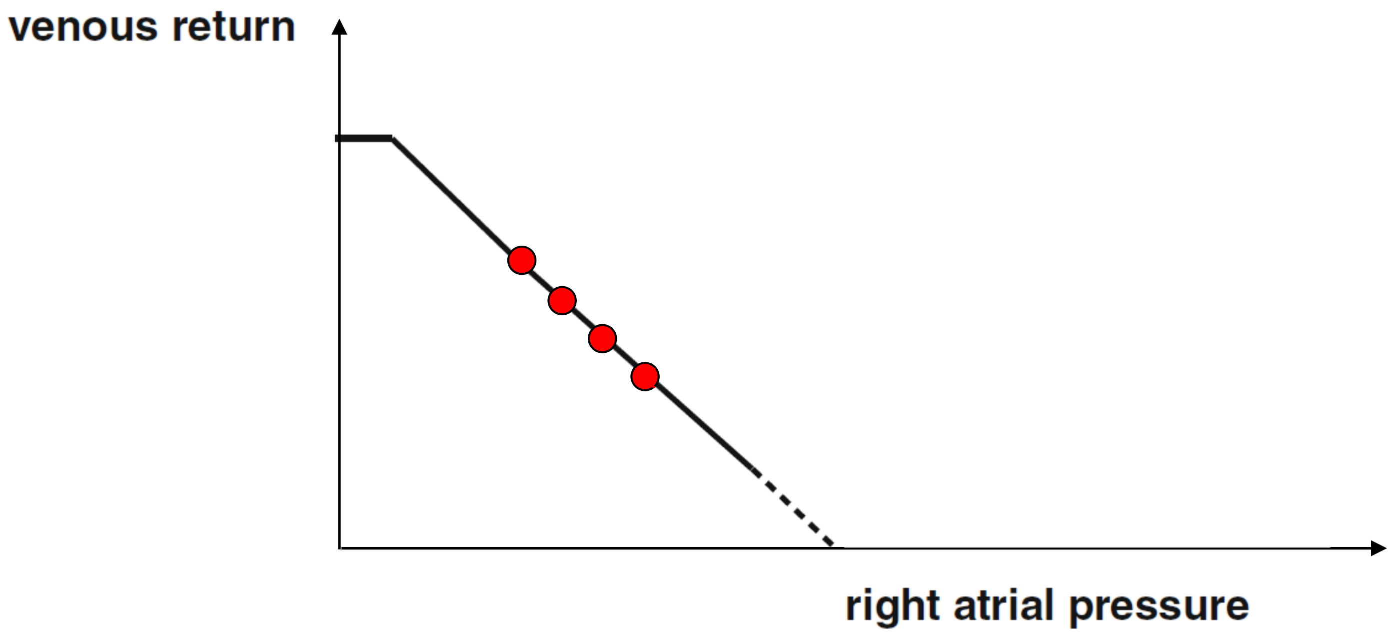
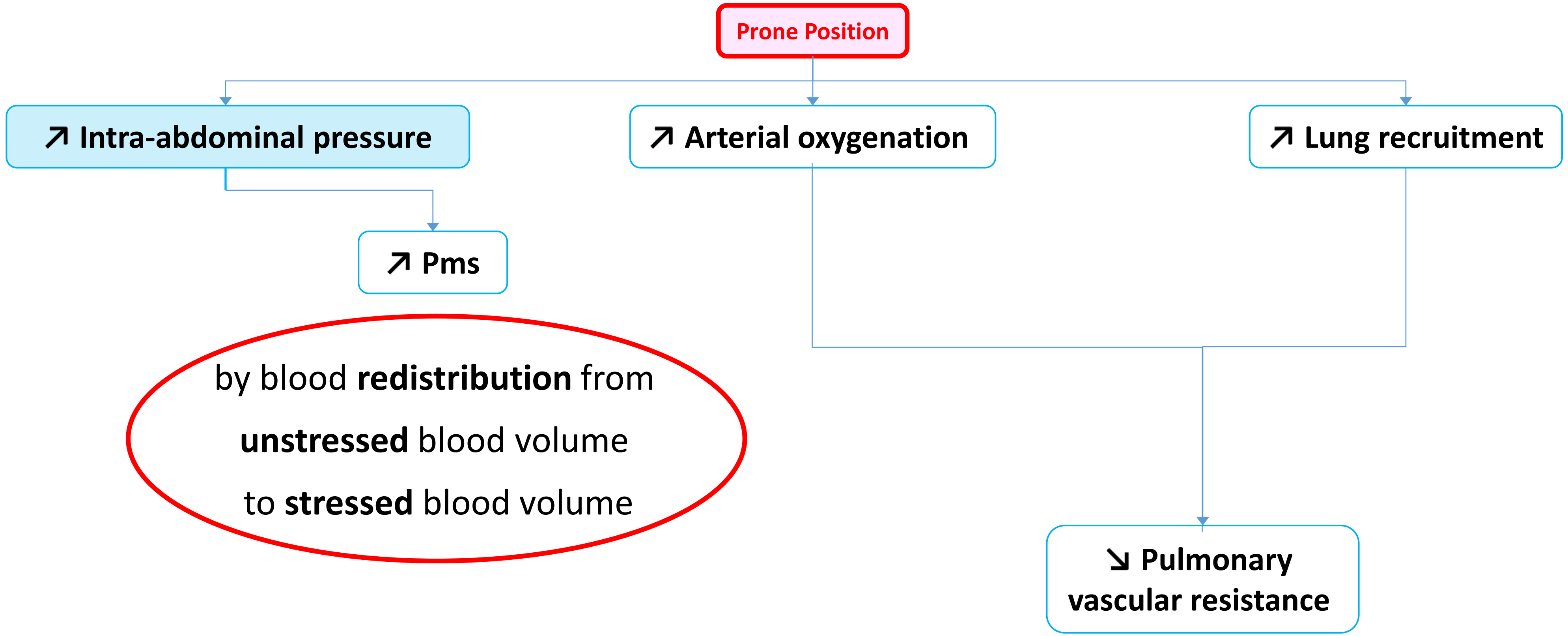



**Fig. 1** Relationship between right atrial pressure and venous return according to Guyton's model.


Prone Position
↗ Intra-abdominal pressure
↗ Arterial oxygenation
↗ Lung recruitment
↗ Pms
by blood **redistribution** from
**unstressed** blood volume
to **stressed** blood volume
↘ Pulmonary vascular resistance

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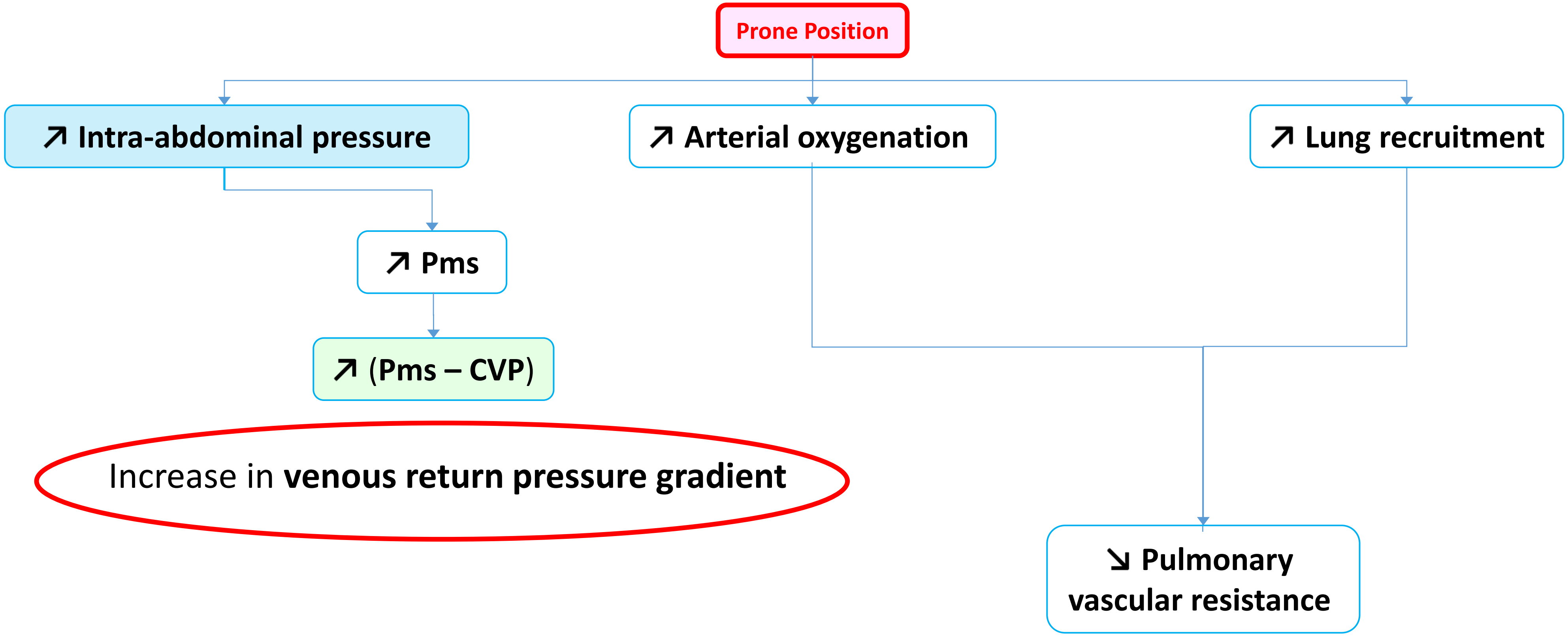
|---|---|---|---|---|
| | Semirecumbent Position | Prone Position | Semirecumbent Position | Prone Position |
| Pms, mm Hg | 16 (15–21) | 34 (28–39)[a] | 29 (24–37)[b] | 42 (33–54)[a] |


Prone Position
↗ Intra-abdominal pressure
↗ Arterial oxygenation
↗ Lung recruitment
↗ Pms
↗ (Pms – CVP)
Increase in **venous return pressure gradient**
↘ Pulmonary vascular resistance

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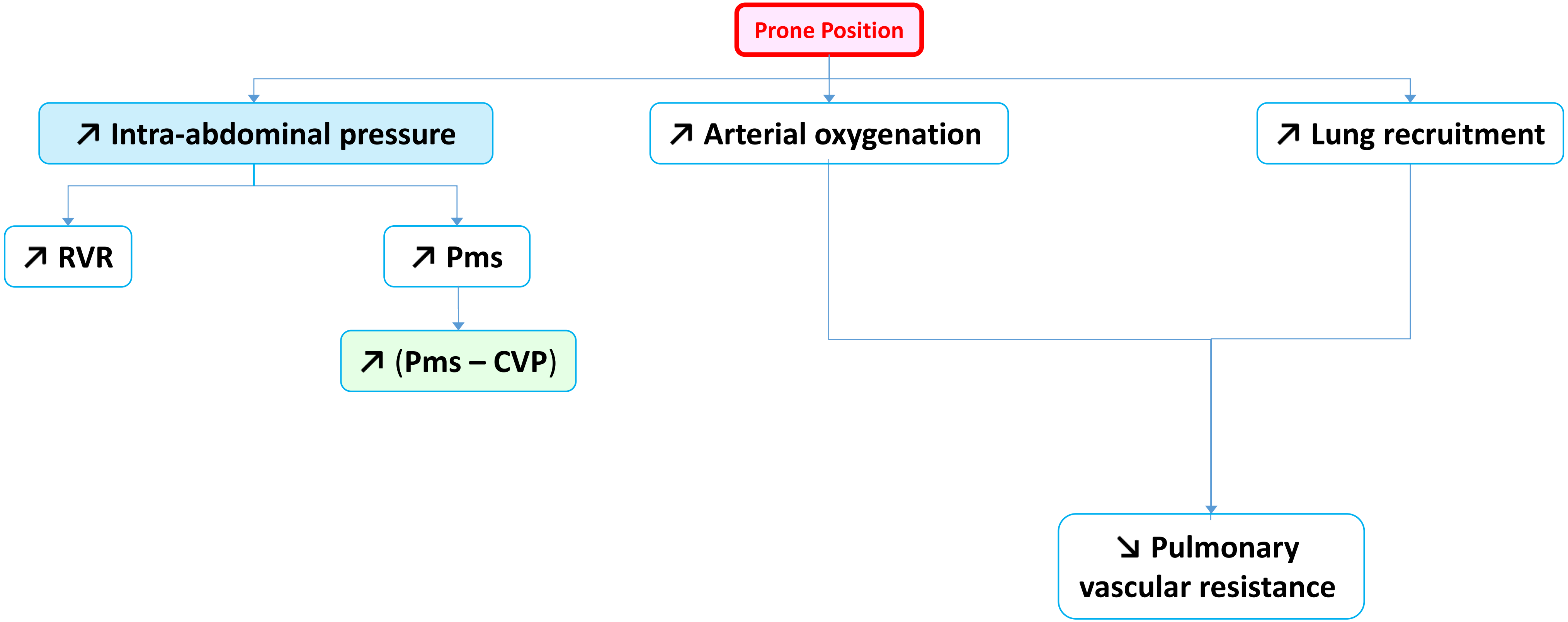
| Pms – CVP, mm Hg | 8 (6–12) | 19 (17–23)[a] | 18 (14–24)[b] | 26 (19–33)[a] |



Prone Position
↗ Intra-abdominal pressure
↗ Arterial oxygenation
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↗ RVR
↗ Pms
↗ (Pms – CVP)
↘ Pulmonary vascular resistance

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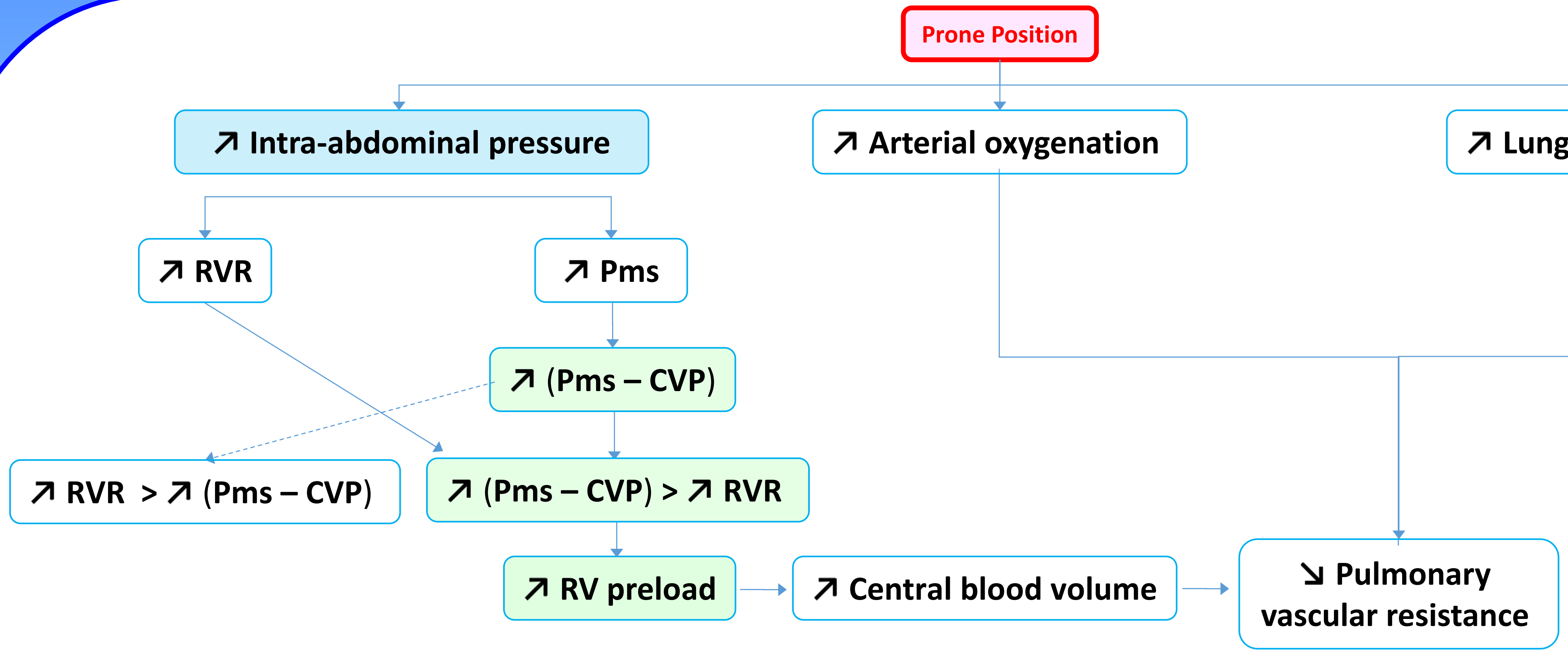
| Pms – CVP, mm Hg | 8 (6–12) | 19 (17–23)[a] | 18 (14–24)[b] | 26 (19–33)[a] |
| Rvr, mm Hg/min/L | 1.7 (1.5–1.9) | 3.0 (2.6–3.7)[a] | 2.3 (1.6–3.8) | 3.4 (2.5–4.8)[a] |


Prone Position
↗ Intra-abdominal pressure
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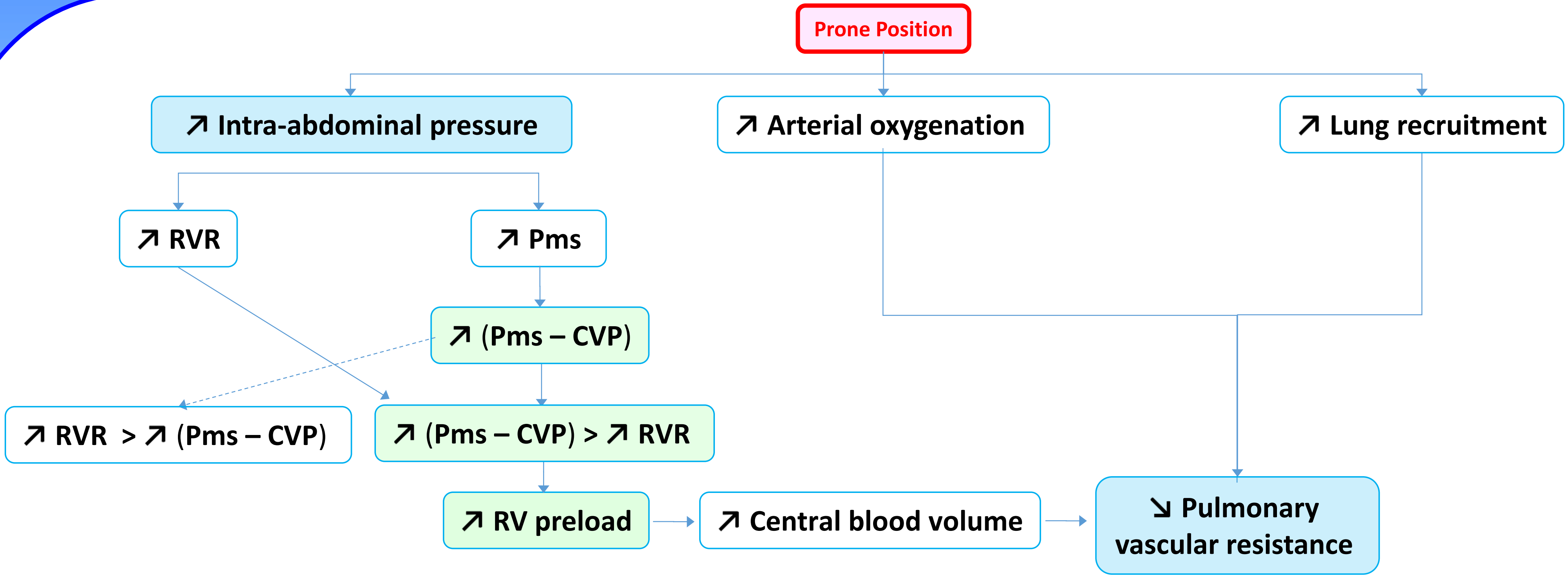
↗ Lung recruitment
↗ RVR
↗ Pms
↗ (Pms – CVP)
↗ RVR > ↗ (Pms – CVP)
↗ (Pms – CVP) > ↗ RVR
↗ RV preload
↗ Central blood volume
↘ Pulmonary vascular resistance



Prone Position
↗ Intra-abdominal pressure
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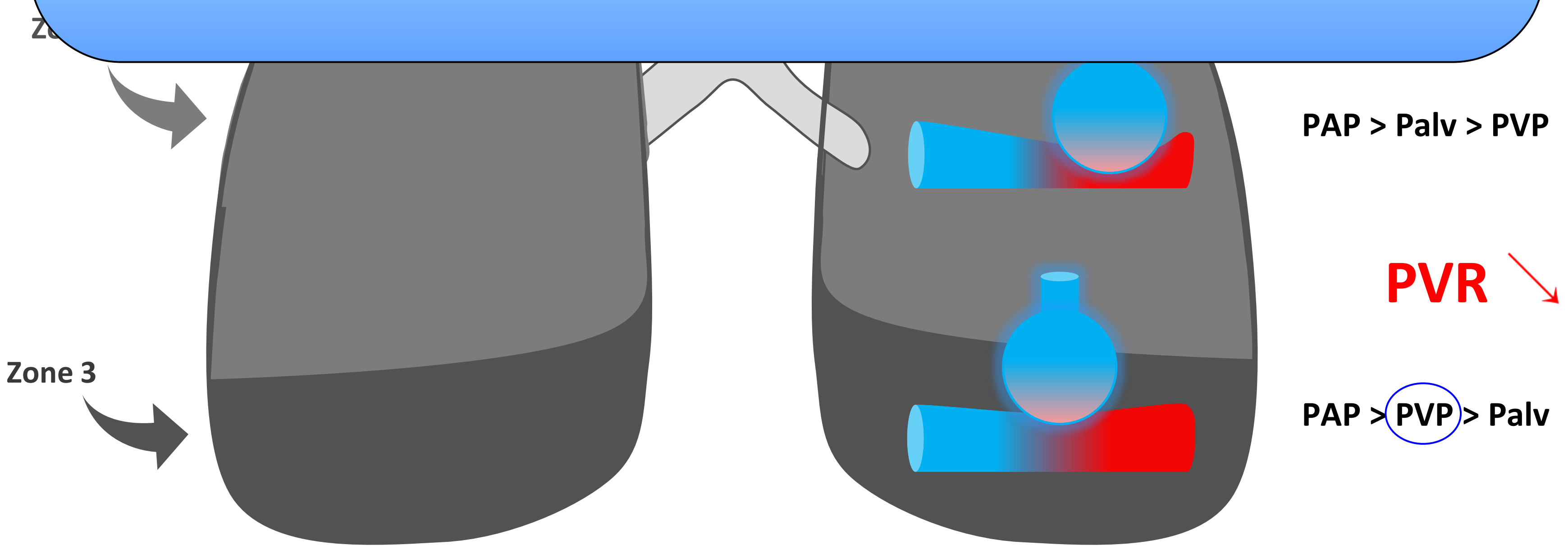
↗ RVR
↗ Pms
↗ (Pms – CVP)
↗ RVR > ↗ (Pms – CVP)
↗ (Pms – CVP) > ↗ RVR
↗ RV preload
↗ Central blood volume
↘ Pulmonary vascular resistance

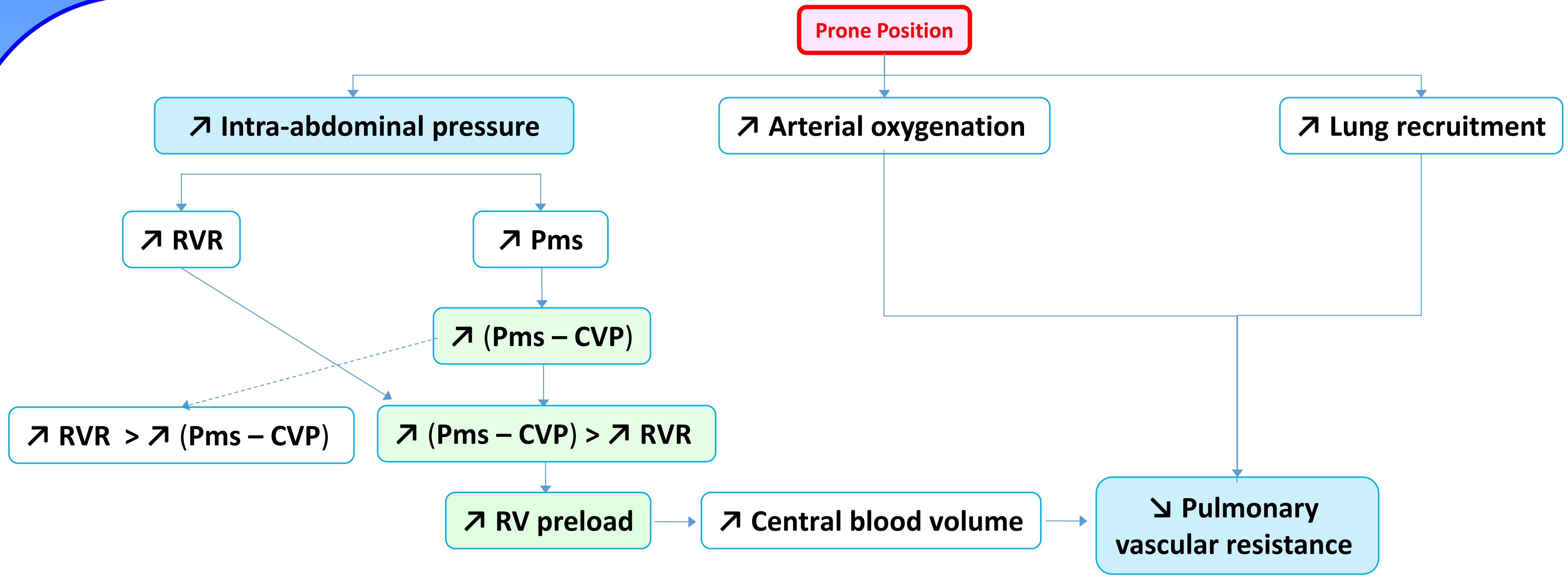
**Increase** in **central blood volume**

by **increasing** the **pulmonary venous pressure**,

will increase the extent of **Zone 3**, and thus,

**decreases** the **pulmonary vascular resistance**

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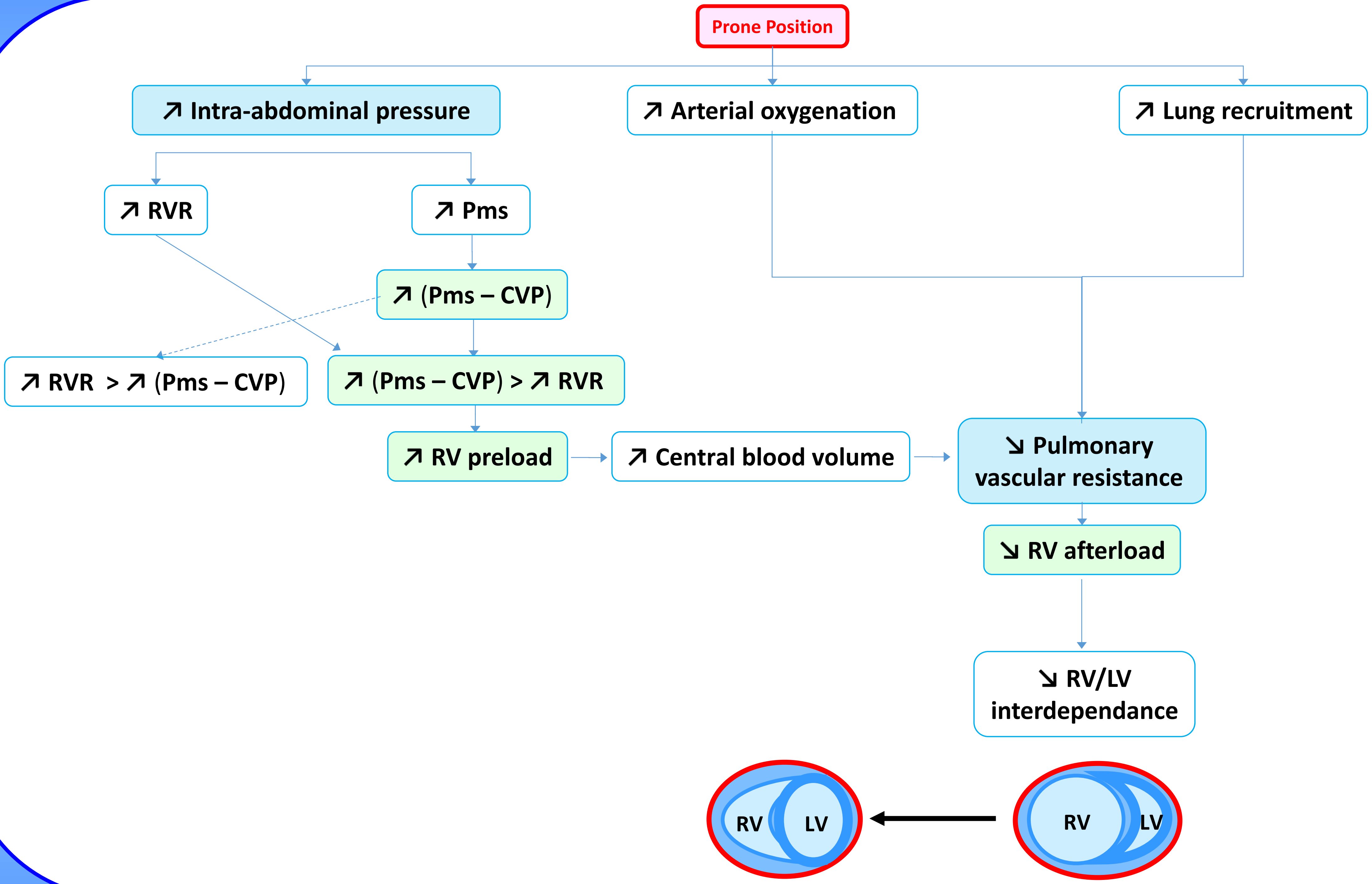
Am J Respir Crit Care Med Vol 188, Iss. 12, pp 1428–1433, Dec 15, 2013

| Hemodynamic variables | supine | | prone |
|---|---|---|---|
| Cardiac index (L/min/$m^2$) | 3.1 [2.5-3.4] | | 3.4 [3.1-4.2] * |
| RAP (mmHg) | 13 [10-15] | | 17 [15-18] * |
| mean PAP (mmHg) | 33 [32-40] | | 32 [28-36] |
| PAOP (mmHg) | 17 [15-20] | | 20 [17-25] * |
| mean PAP - PAOP (mmHg) | 16 [15-20] | | 13 [9-17] * |
| **Pulm. Vasc. Resist.** (dynes.s/$cm^5$/$m^2$) | 463 [304-571] | ↓ 39% | 279 [156-429] * |



Prone Position
↗ Intra-abdominal pressure
↗ Arterial oxygenation
↗ Lung recruitment
↗ RVR
↗ Pms
↗ (Pms – CVP)
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↗ (Pms – CVP) > ↗ RVR
↗ RV preload
↗ Central blood volume
↘ Pulmonary vascular resistance
↘ RV afterload
↘ RV/LV interdependance
RV
LV
RV
LV

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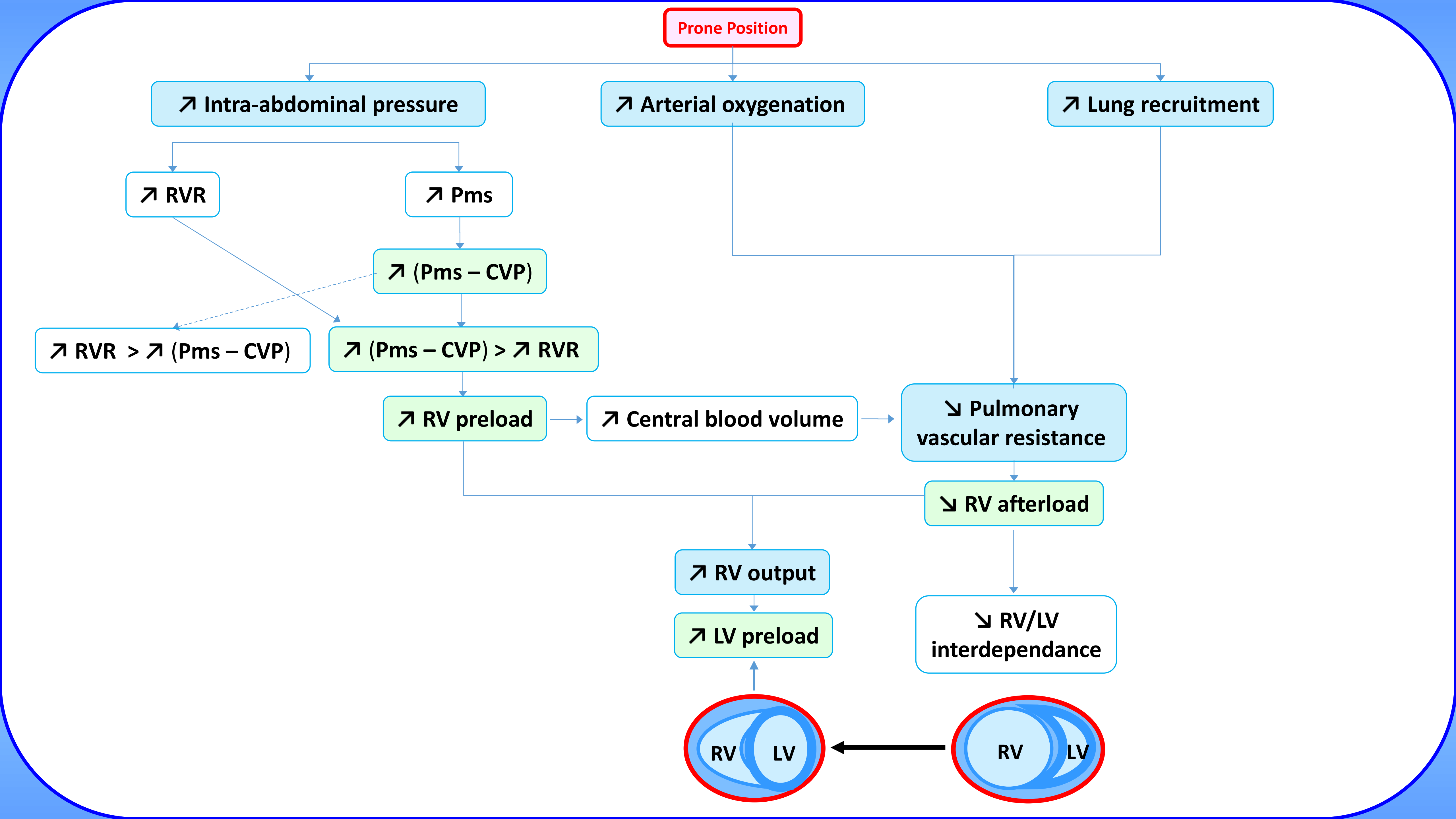
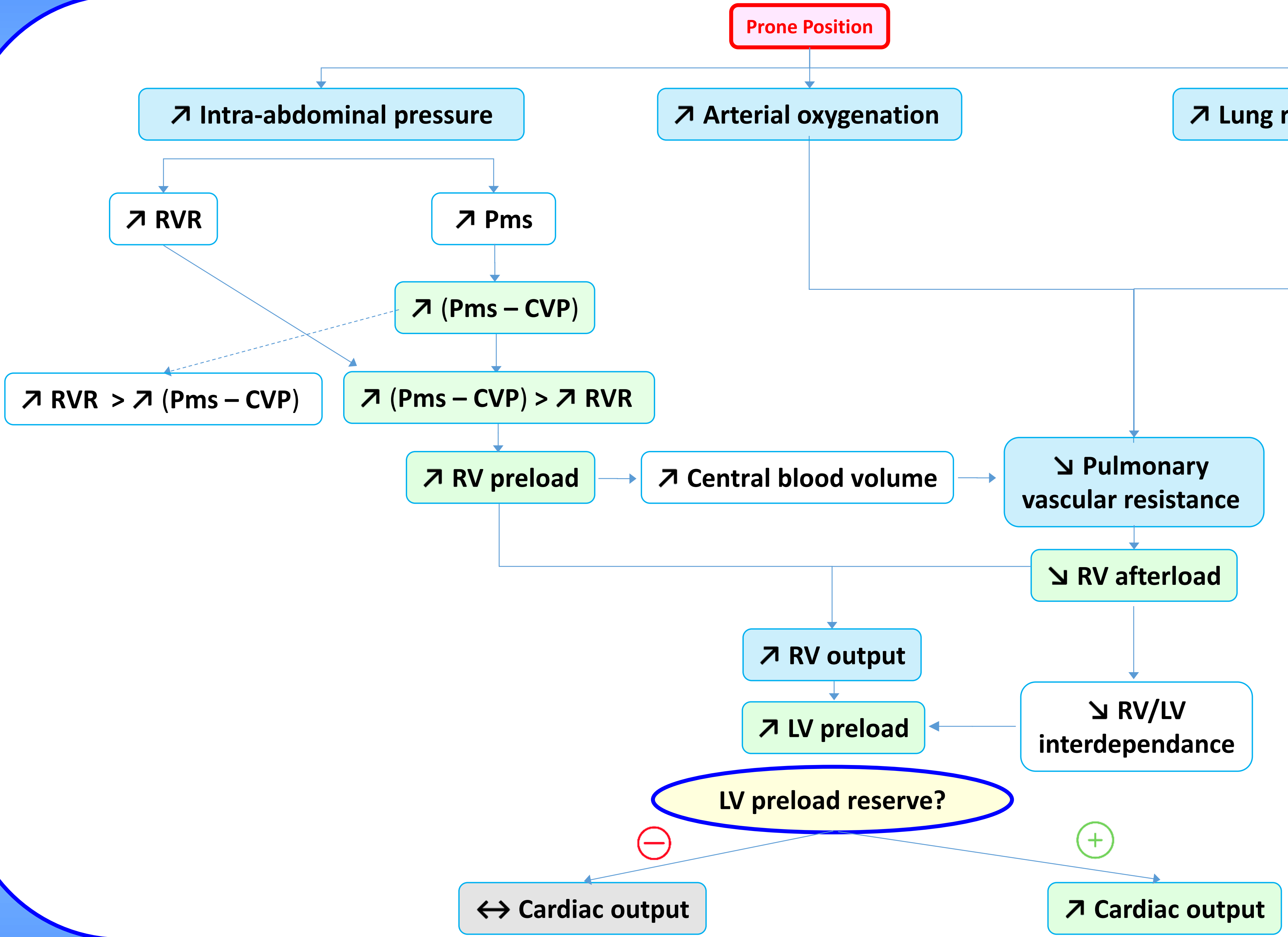
| **Pulm. Vasc. Resist.** (dynes.s/$cm^5$/$m^2$) | 463 [304-571] | 279 [156-429] * |
| **Echo variables** | | |
| LVEF (%) | 50 [40-60] | 50 [40-60] |
| **RVEDA / LVEDA** | **0.65** [0.60-0.75] | **0.60** [0.50-0.65] * |
| **LV eccentricity index** | **1.07** [1.03-1.15] | **1.00** [1.00-1.06] * |



Prone Position
↗ Intra-abdominal pressure
↗ Arterial oxygenation
↗ Lung recruitment
↗ RVR
↗ Pms
↗ (Pms – CVP)
↗ RVR > ↗ (Pms – CVP)
↗ (Pms – CVP) > ↗ RVR
↗ RV preload
↗ Central blood volume
↘ Pulmonary vascular resistance
↘ RV afterload
↗ RV output
↗ LV preload
↘ RV/LV interdependance
RV
LV
RV
LV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↗ Pms
↗ (Pms – CVP)
↗ RVR > ↗ (Pms – CVP)
↗ (Pms – CVP) > ↗ RVR
↗ RV preload
↗ Central blood volume
↘ Pulmonary vascular resistance
↘ RV afterload
↗ RV output
↗ LV preload
↘ RV/LV interdependance
LV preload reserve?
↔ Cardiac output
↗ Cardiac output

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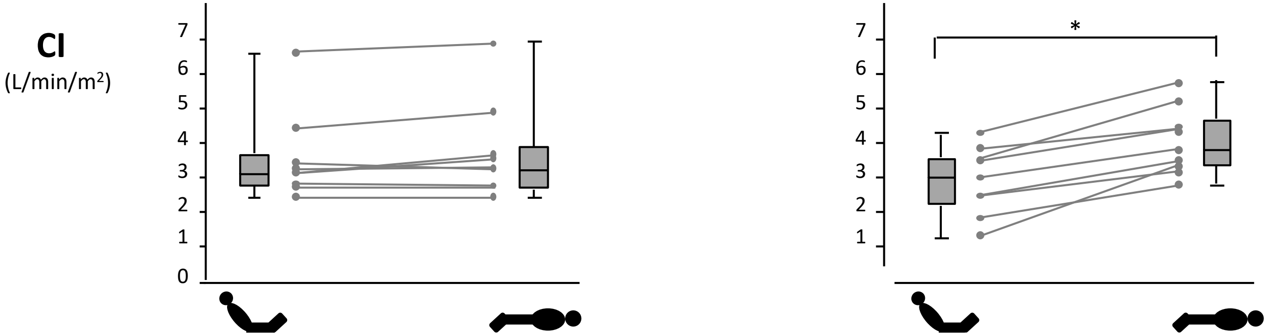
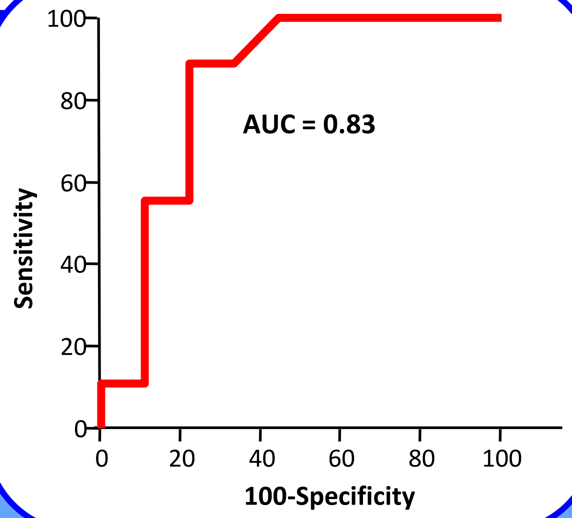
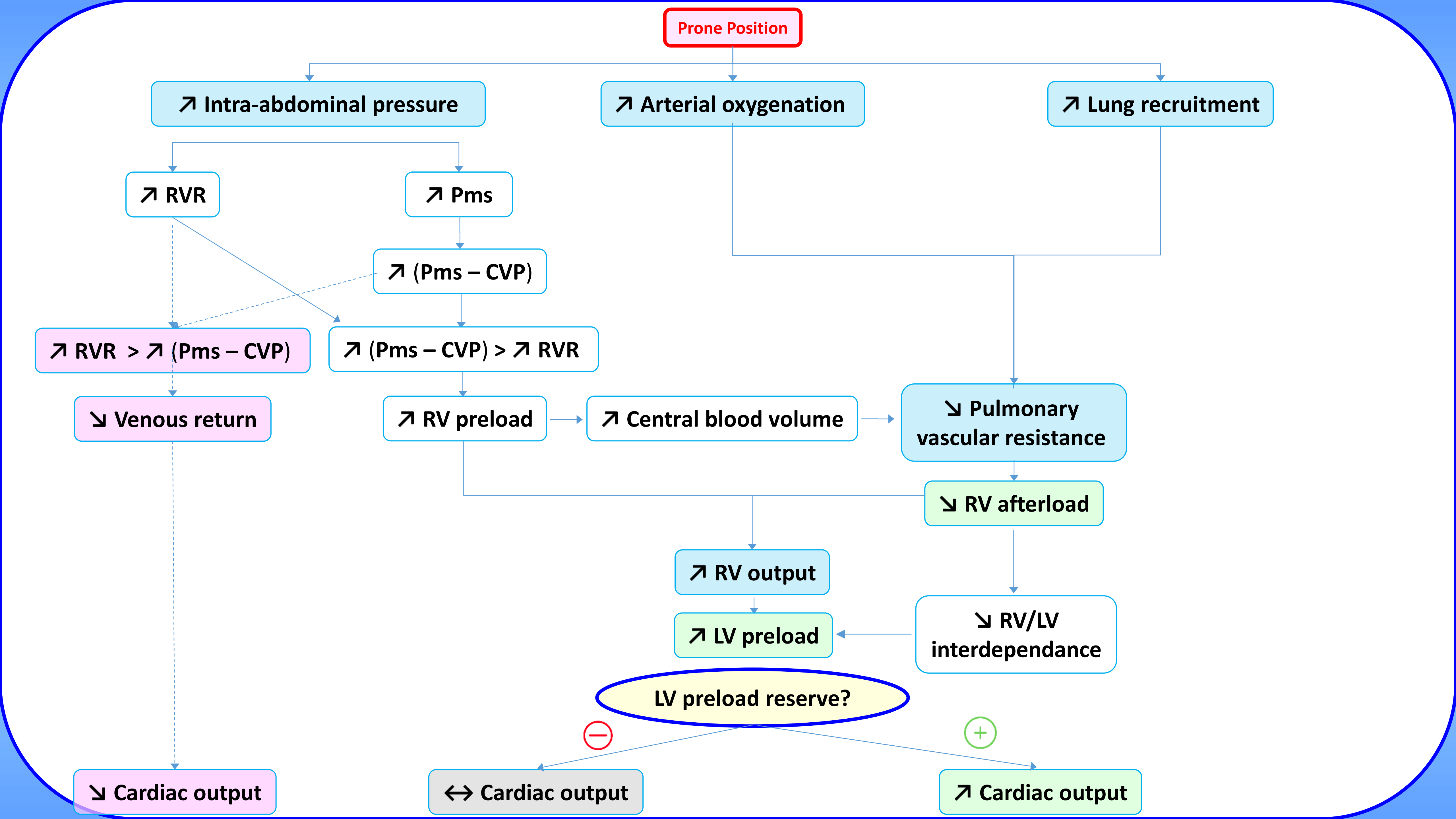
No increase in CI ≥ 15% during PP

Increase in CI ≥ 15% during PP




An **increase** in **CO > 8%** during **PLR** predicted an **increase** in **CO > 15%** during **PP** with **Se 89%** and **Sp 78%**

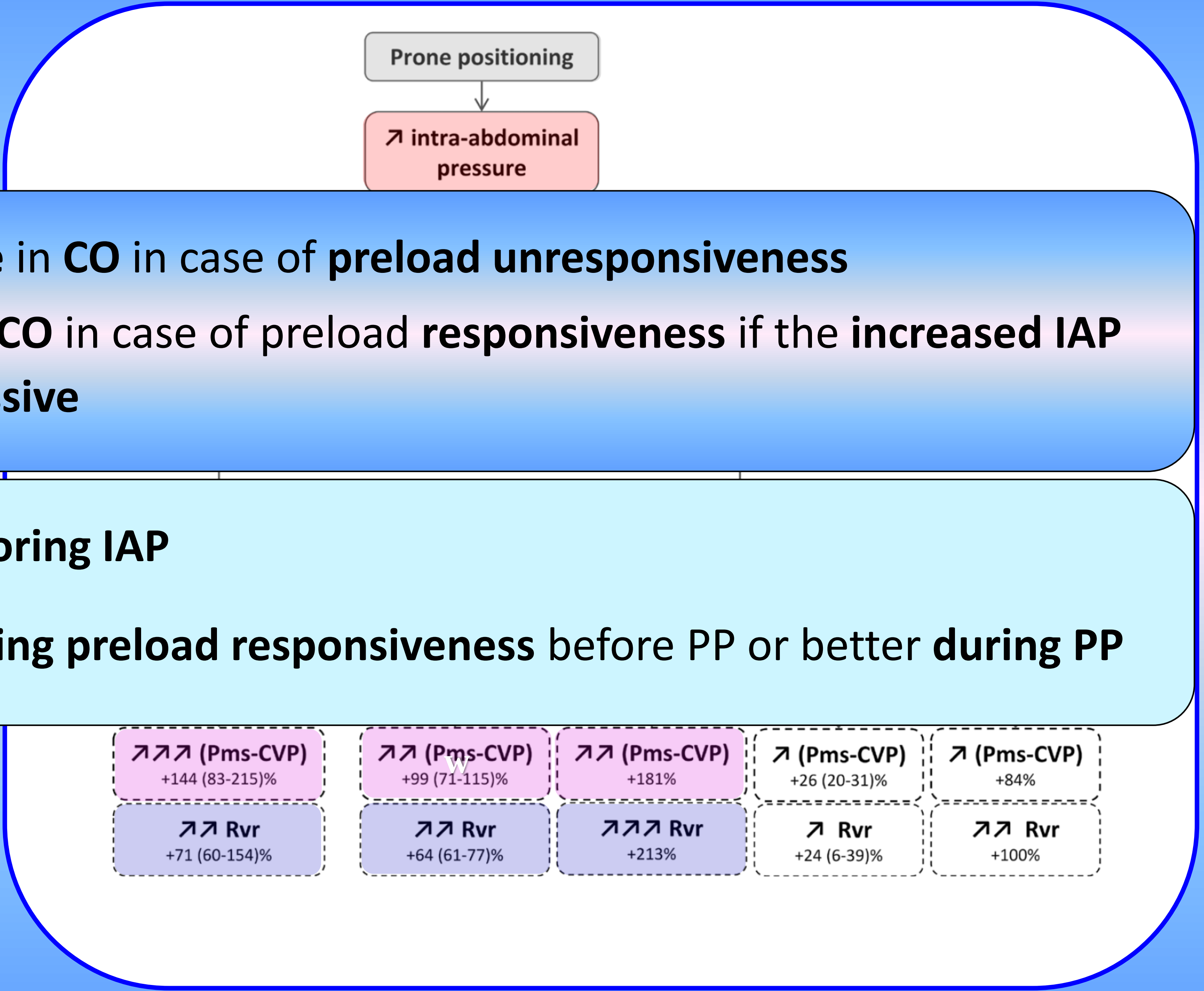



Prone Position
↗ Intra-abdominal pressure
↗ Arterial oxygenation
↗ Lung recruitment
↗ RVR
↗ Pms
↗ (Pms – CVP)
↗ RVR > ↗ (Pms – CVP)
↗ (Pms – CVP) > ↗ RVR
↘ Venous return
↗ RV preload
↗ Central blood volume
↘ Pulmonary vascular resistance
↘ RV afterload
↗ RV output
↗ LV preload
↘ RV/LV interdependance
LV preload reserve?
⊖
⊕
↘ Cardiac output
↔ Cardiac output
↗ Cardiac output

**Effects of Prone Positioning on Venous Return in Patients With Acute Respiratory Distress Syndrome**

Christopher Lai, MD
Imane Adda, MD
Jean-Louis Teboul, MD, PhD
Romain Persichini, MD
Francesco Gavelli, MD

Crit Care Med 2021; 49:781-




- **No increase** in **CO** in case of **preload unresponsiveness**
- **Increase** in **CO** in case of preload **responsiveness** if the **increased IAP** is **not excessive**

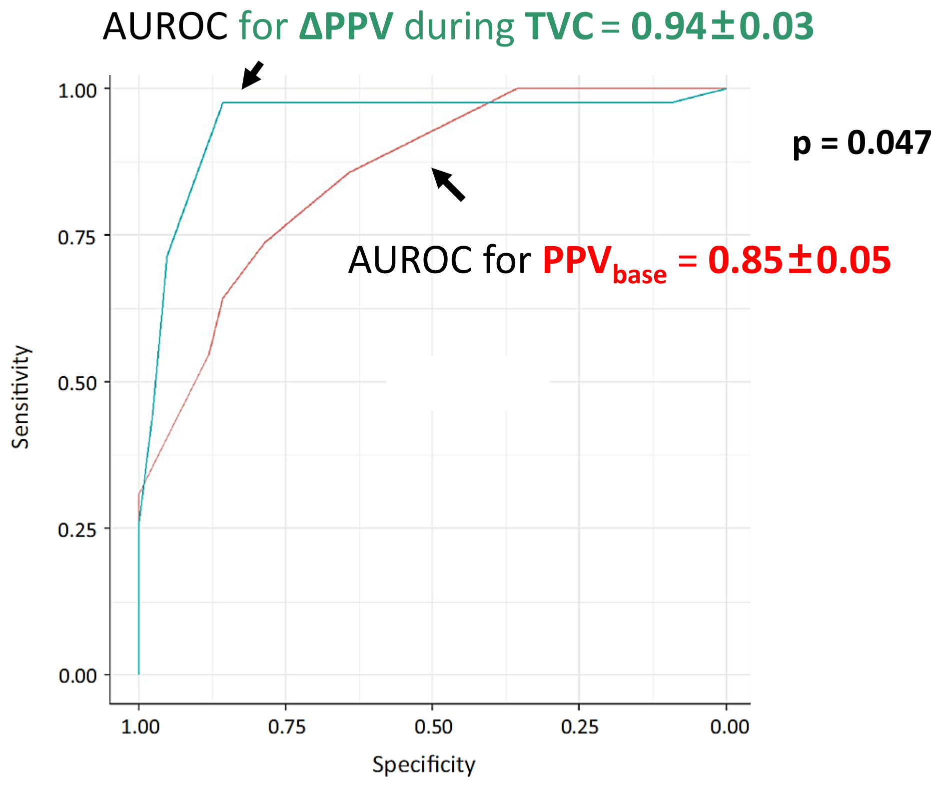
- Importance of **monitoring IAP**
- Importance of **assessing preload responsiveness** before PP or better **during PP**

RESEARCH Open Access

# Tidal volume challenge to predict preload responsiveness in patients with acute respiratory distress syndrome under prone position

Rui Shi[1], Soufia Ayed[1], Francesca Moretto[1], Danila Azzolina[2], Nello De Vita[1], Francesco Gavelli[1], Simone Carelli[1], Arthur Pavot[1], Christopher Lai[1], Xavier Monnet[1] and Jean-Louis Teboul[1*]

*Critical Care* (2022) 26:219



## Take-home messages

- In patients with **ARDS** under protective ventilation, **prone positioning** decreases **RV afterload**, which is **beneficial** in cases of **RV dysfunction**
- **Cardiac output** may **increase** in cases of **preload responsiveness** if the PP-induced **increase** in **IAP** is **not excessive**

REVIEW

# Hemodynamic Implications of Prone Positioning in Patients with ARDS

Christopher Lai*, Xavier Monnet and Jean-Louis Teboul

*Critical Care* (2023) 27:98