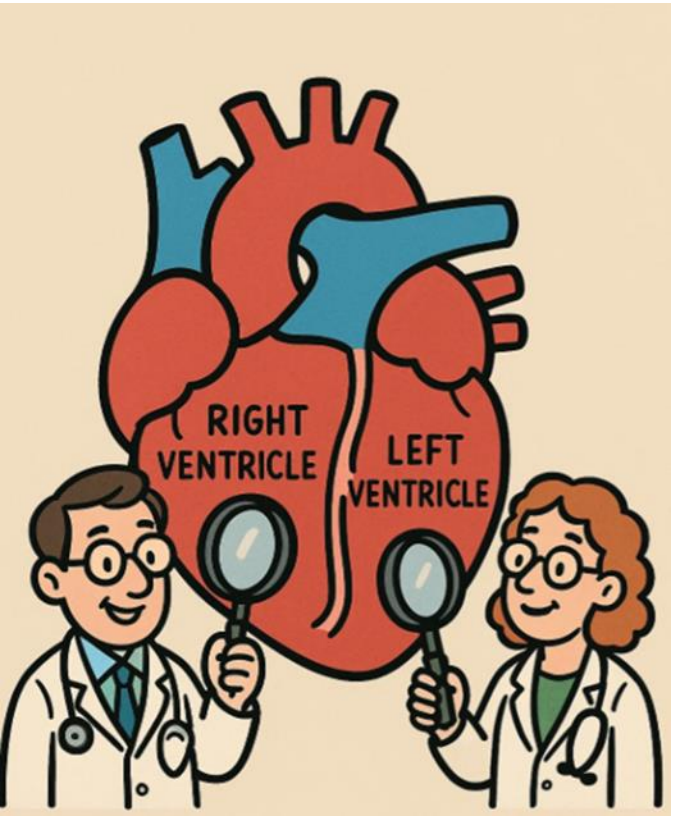
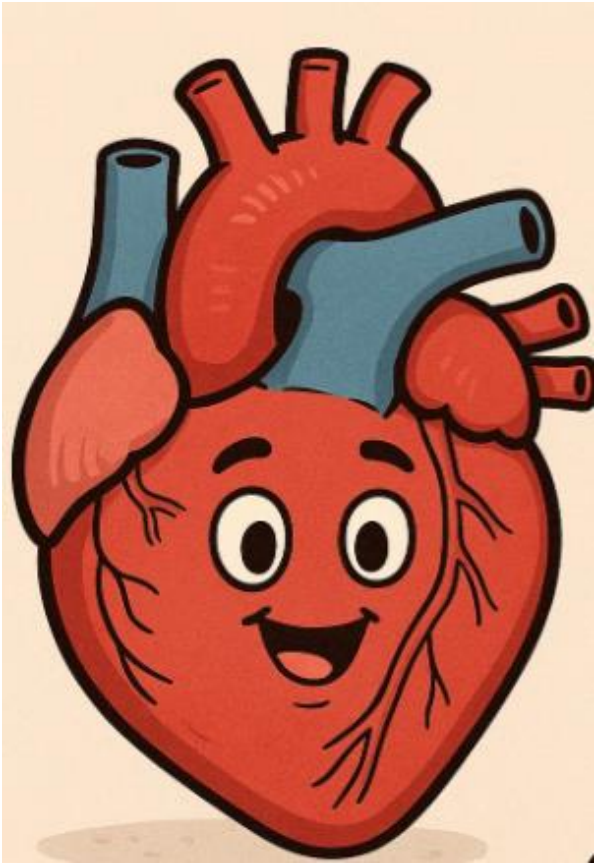
Diagnosis and Management of Acute Right ventricular dysfunction in ICU



인제의대 해운대백병원
장항제



Contents

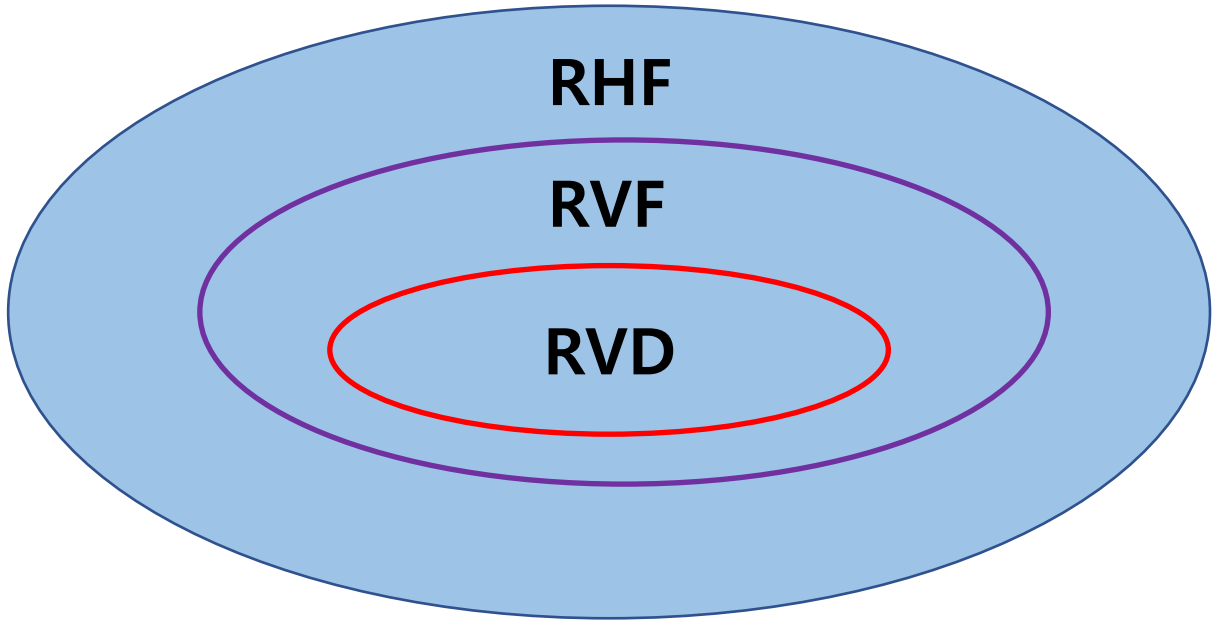
- 정의/병태생리
- ICU 에서 흔히 겪는 질환/상황
- 진단

  호흡기 intensivist 가 bedside 에서 echo assessment

  Pulmonary artery catheterization
- 주요 증례
- 치료/대처

Terminology

- RV dysfunction (RVD)
- RV failure (RVF)



- Right heart failure (RHF)

: a clinical syndrome due to an alteration of structure and/or function of the right heart circulatory system

Acute Cor Pulmonale (ACP)

📘 Definition: Acute Cor Pulmonale (ACP)

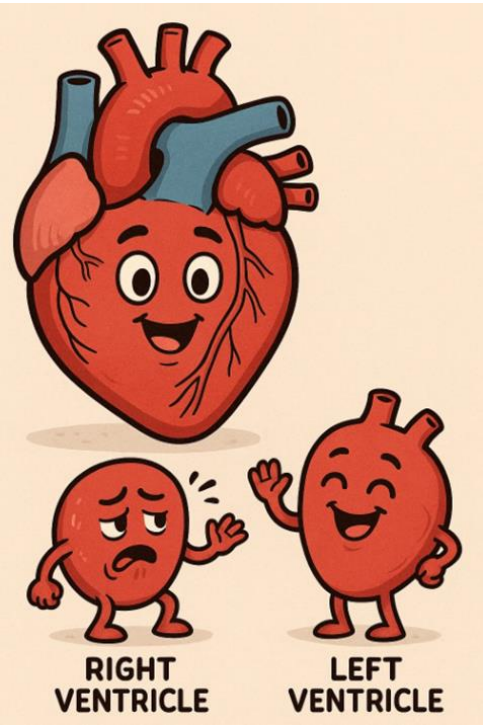
Acute cor pulmonale (ACP) is defined as:

> **A sudden dysfunction of the right ventricle (RV) resulting from an acute increase in pulmonary vascular resistance (PVR), leading to RV dilation, impaired RV output, and potential hemodynamic collapse**, in the **absence of left heart failure**.

🫀 Key Features

- **Cause**: Acute pressure overload of the RV
- **Common precipitants**:
  - **Massive pulmonary embolism (PE)**
  - **Severe acute respiratory distress syndrome (ARDS)** with hypoxic pulmonary vasoconstriction and high ventilator pressures
  - **Thoracic trauma** or acute pulmonary hypertension from other causes

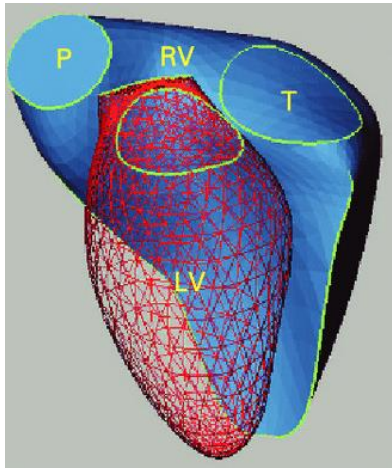
RV 생리학적 특성

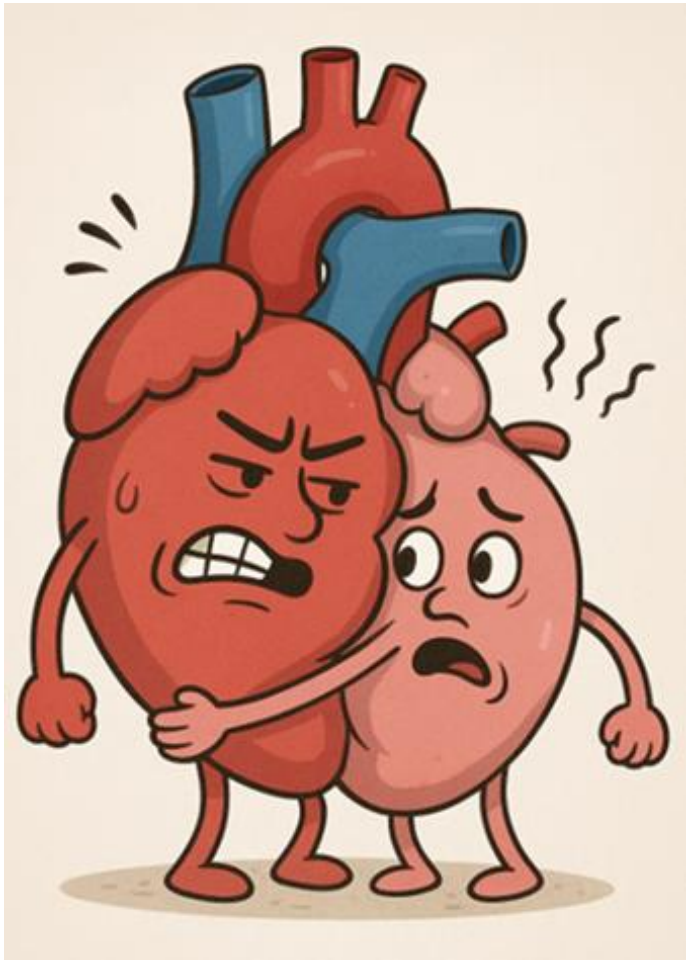


1. Passive crescent chamber promoting venous return From the systemic to pulmonary circulation

2. 수축력 reserve 없다

3. 후부하가 증가하면 우심실을 팽창시키는 방법 외의 급성 적응 기전이 없다





Fluid overload
Shunt (ASD)

Ischemia
Sepsis
acidosis

Embolism
LV failure
Mechanical ventilation

Contractility ↓

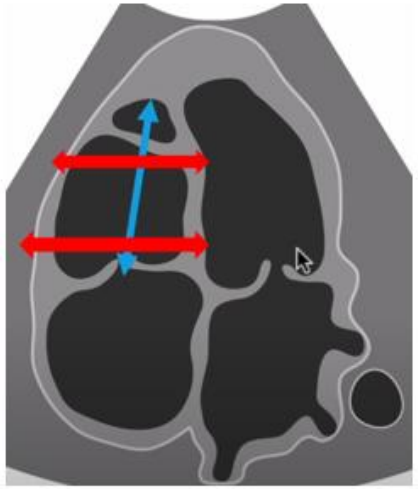
Preload ↑

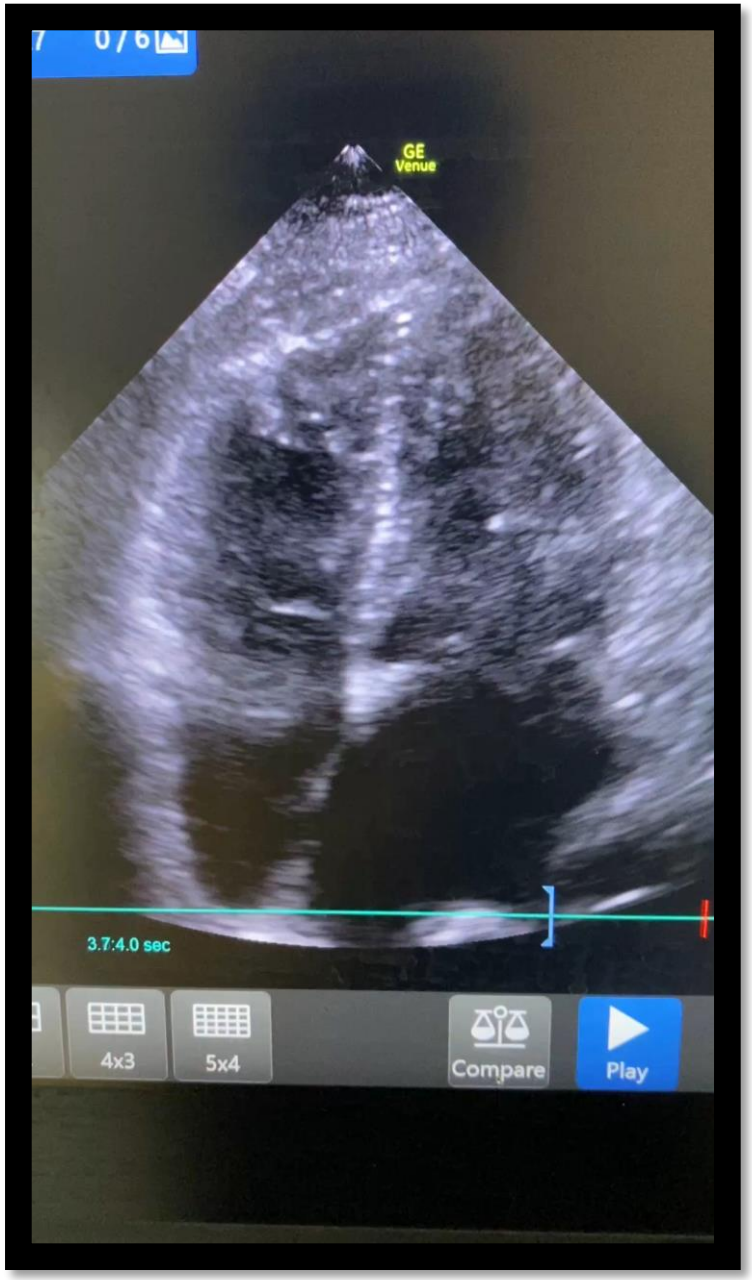
Afterload ↑

RV distension

RV size

- Normal <2/3 of LV
- Mild normal ←→ moderately
- Moderately RV = LV
- Severely RV > LV





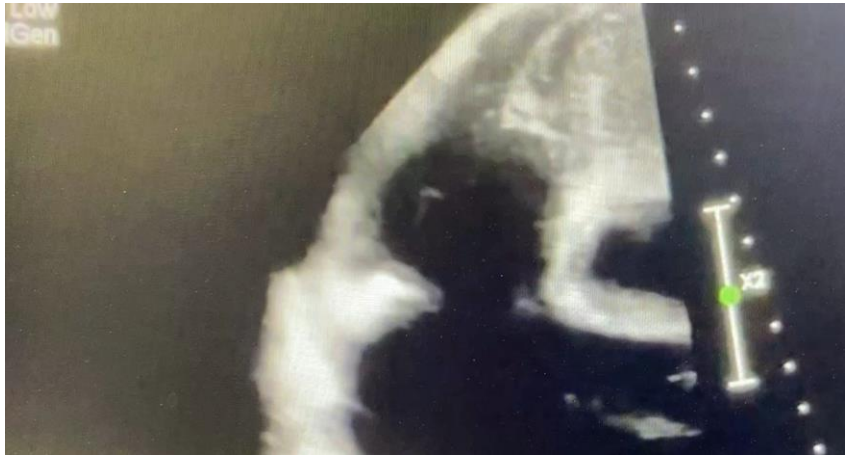
Normal RV size with RV dysfunction (**No afterload ↑**)

- inferior myocardial infarction (MI)
- Stress CMP/Myocarditis involving RV

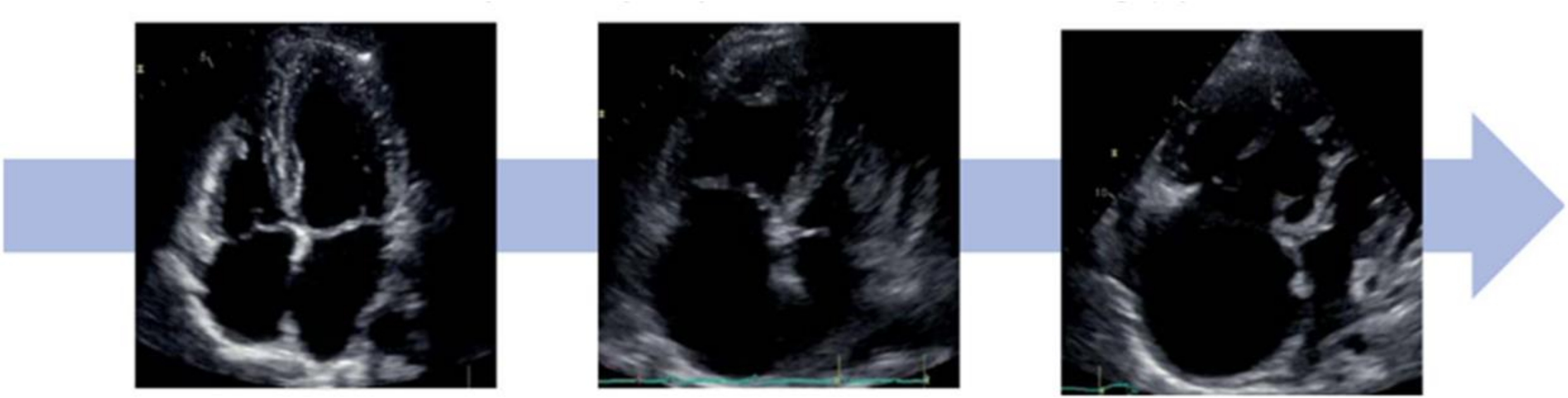
- while it may be normal in size,
- It can still exhibit dysfunction.
- often associated with hemodynamic compromise,

hypotension, clear lungs, RAP ↑

despite the LV maintaining relatively normal function.

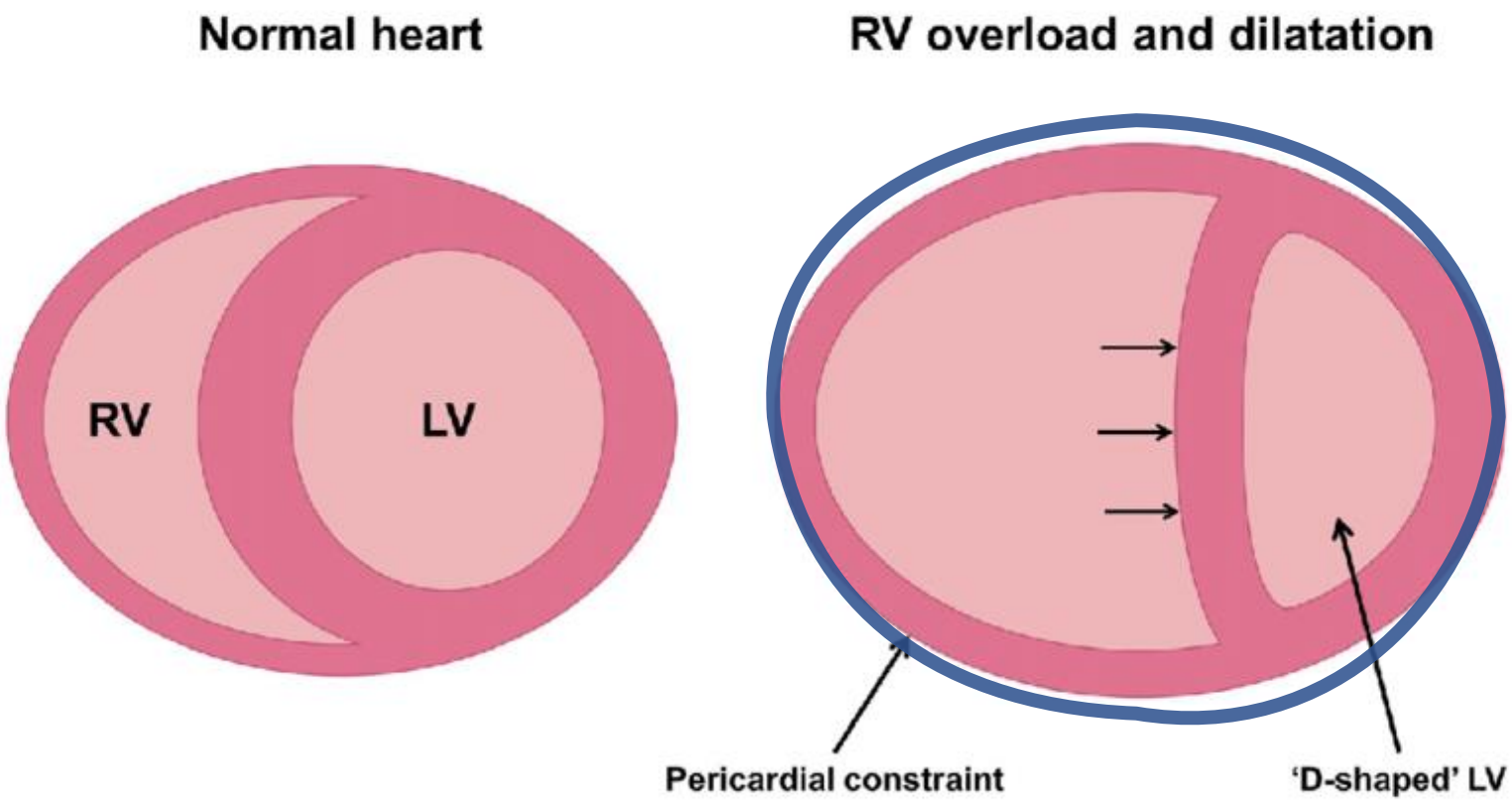


RV/RA dilatation → RV dysfunction

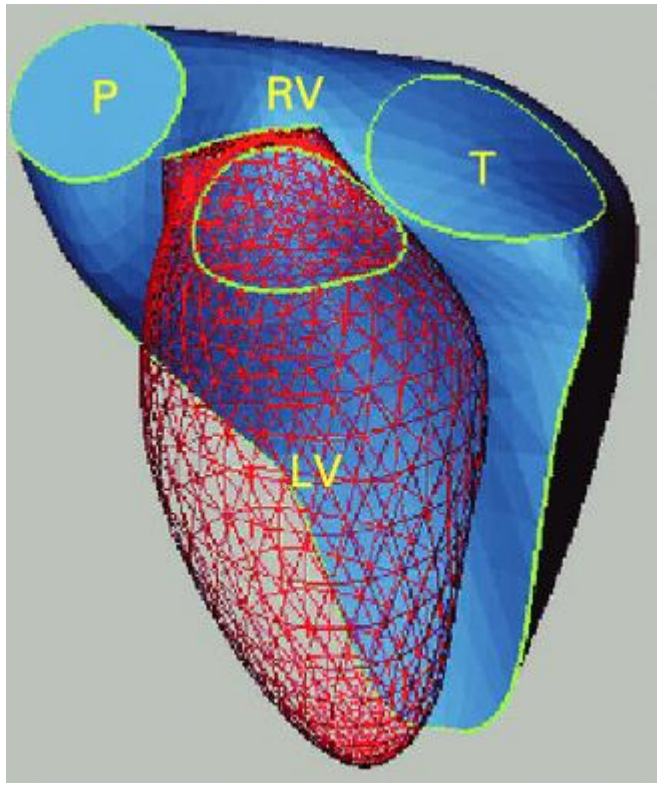


Nikkho et al, Pulmonary Circulation. 2022;12:e12127

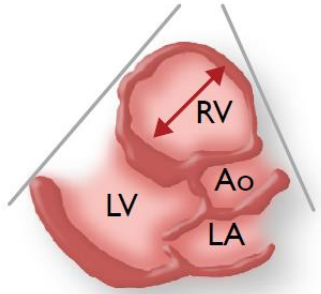
ventricular interdependence



Right heat function: **RV size, RA size, IVC diameter**

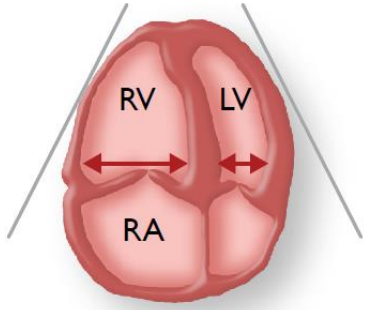


A



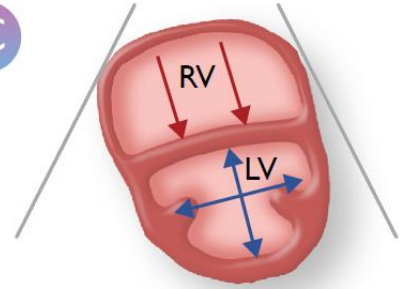
Enlarged right ventricle;
parasternal long-axis view

B



Dilated RV with basal RV/LV ratio >1.0;
four-chamber view

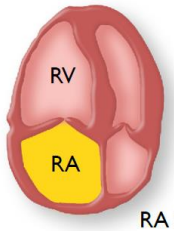
C



Flattened interventricular septum (arrows) leading to 'D-shaped' LV; decreased LV eccentricity index; parasternal short-axis view

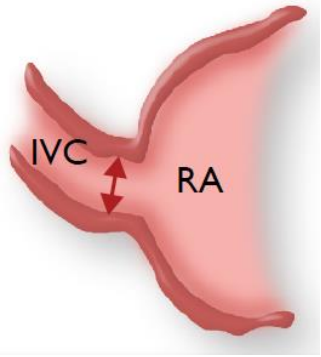
I

End-systolic

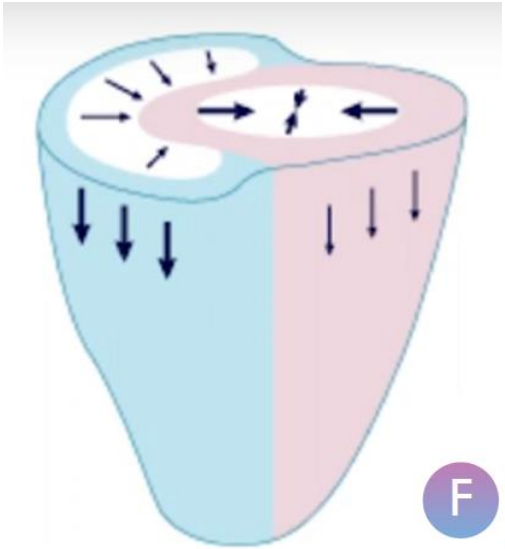


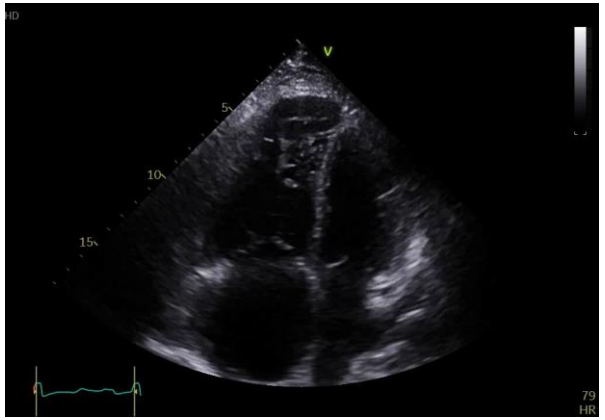
RA >18 cm^2

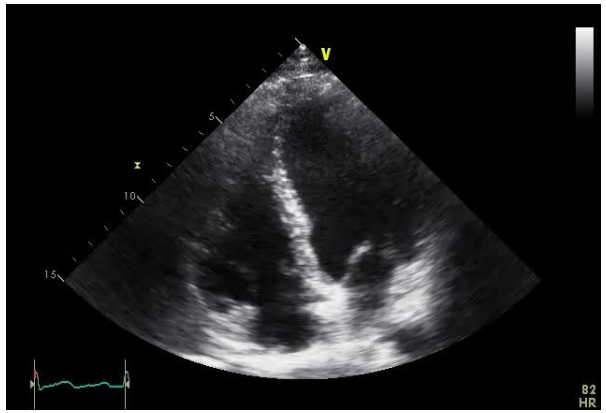
Enlarged right atrial area (>18 cm^2);
four-chamber view

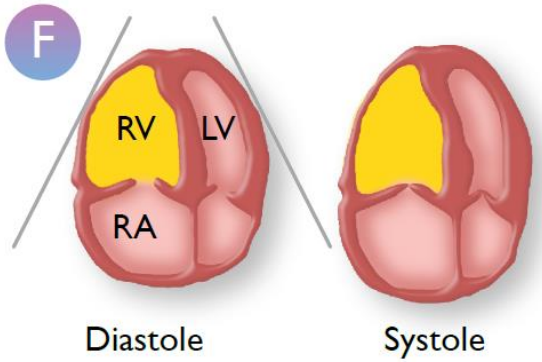


Right heart function – **RV contractility**

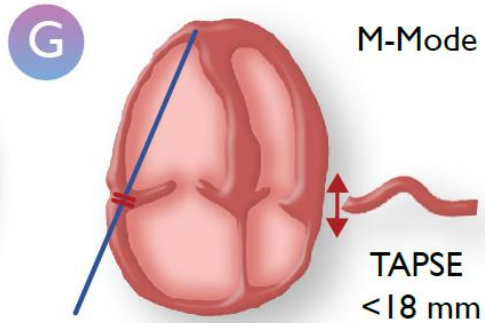




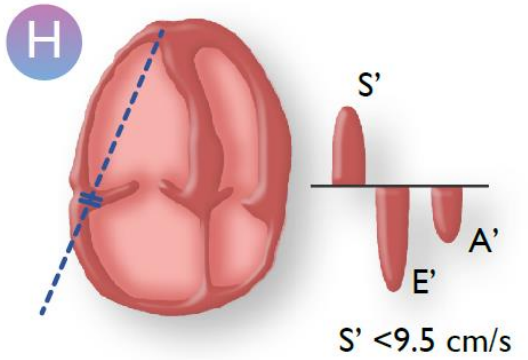




Reduced right ventricular fractional area change (<35%); four-chamber view



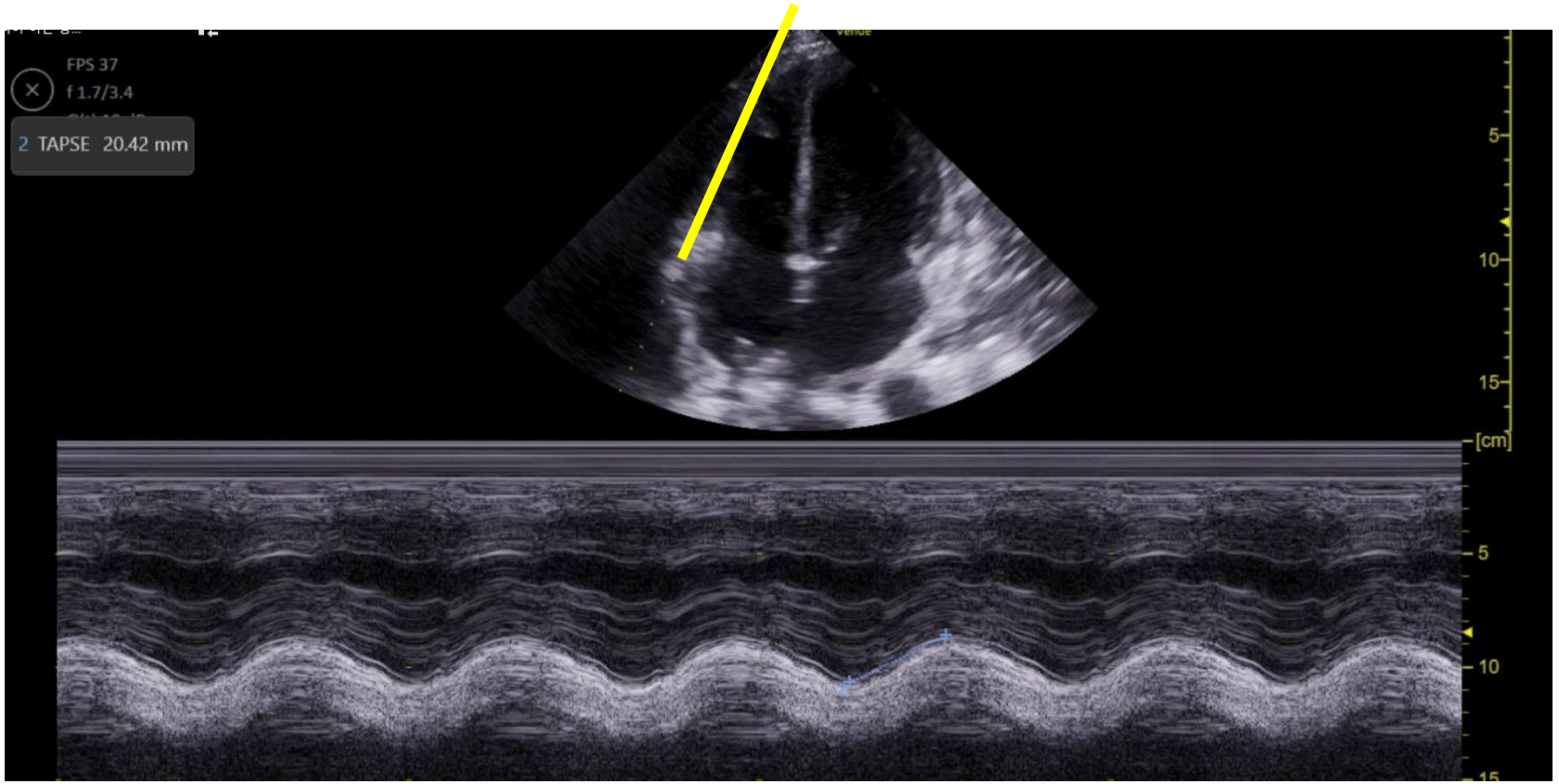
Decreased tricuspid annular plane systolic excursion (TAPSE) measured with M-Mode (<18 mm)

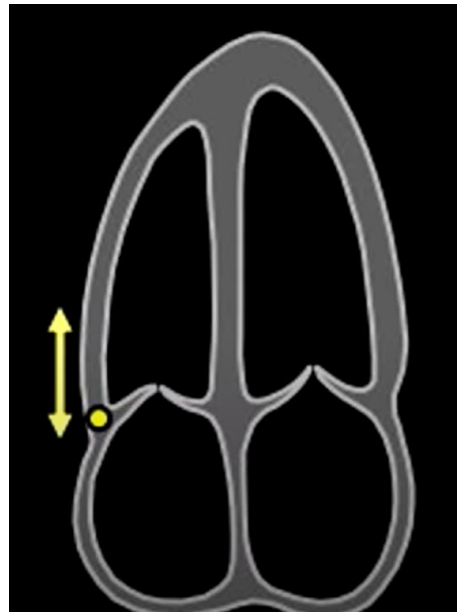


Decreased peak systolic (S') velocity of tricuspid annulus (<9.5 cm/s) measured with tissue Doppler

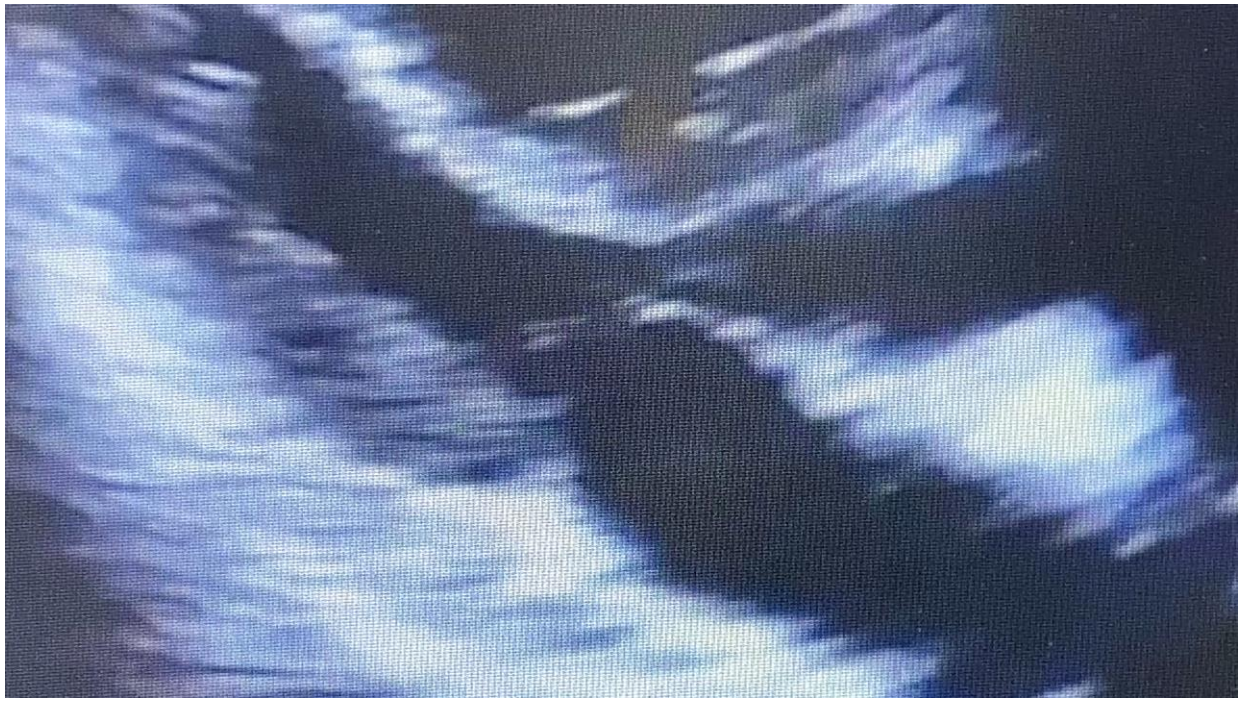
Bedside Echo
RV Function evaluation by intensivist

TAPSE : Tricuspid Annular Plane Systolic Excursion < 18 mm



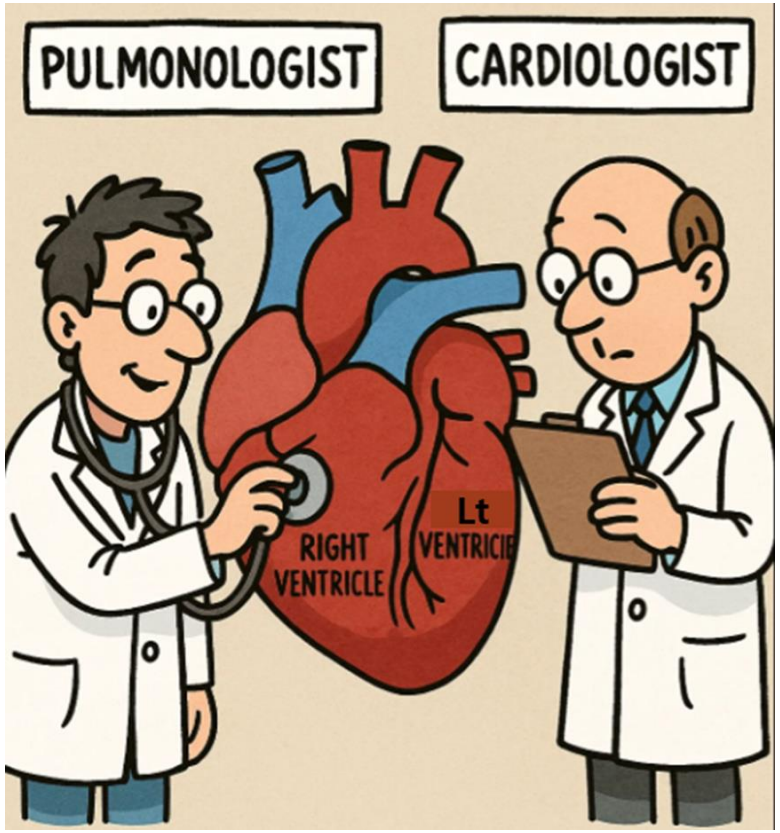


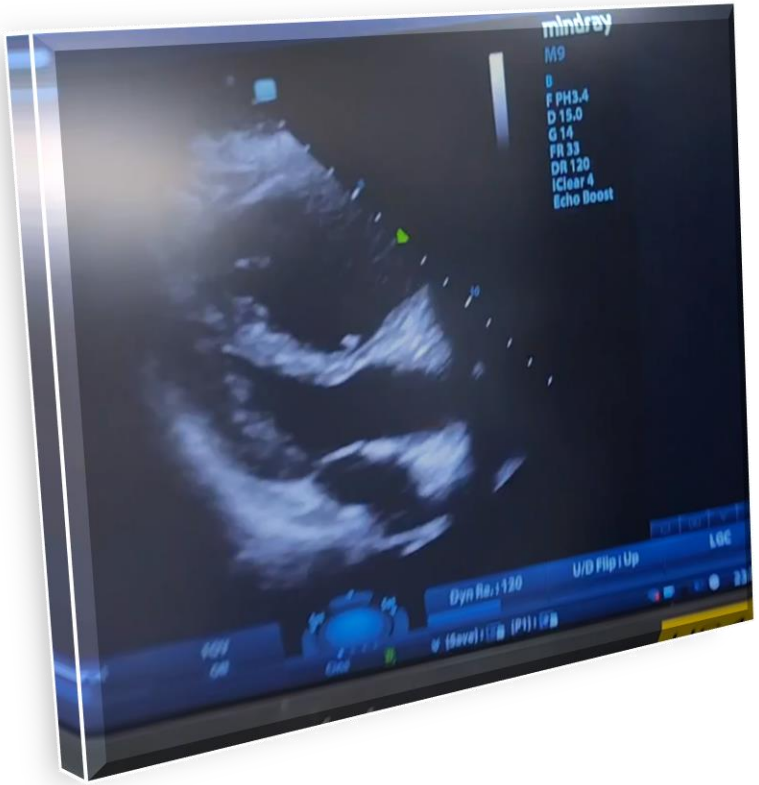
Sudden cardiac arrest in general ward
→ transfer to ICU after ROSC

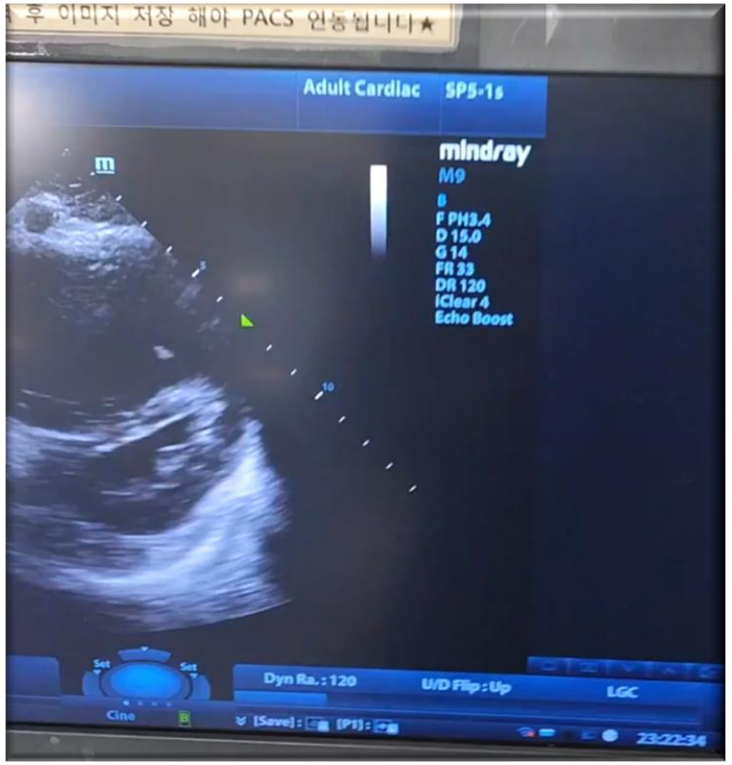


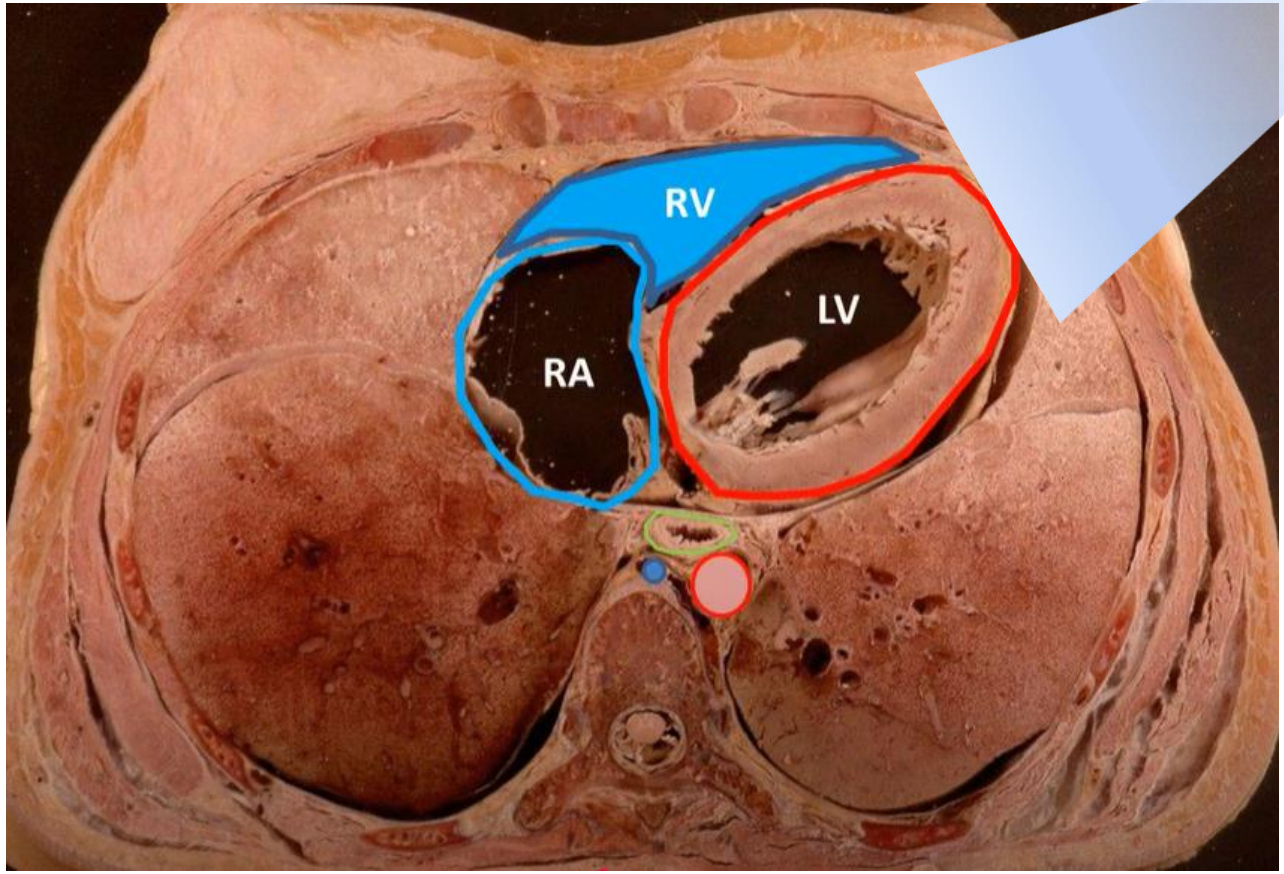
Hyperdynamic LV!!

What the hell in RV ?

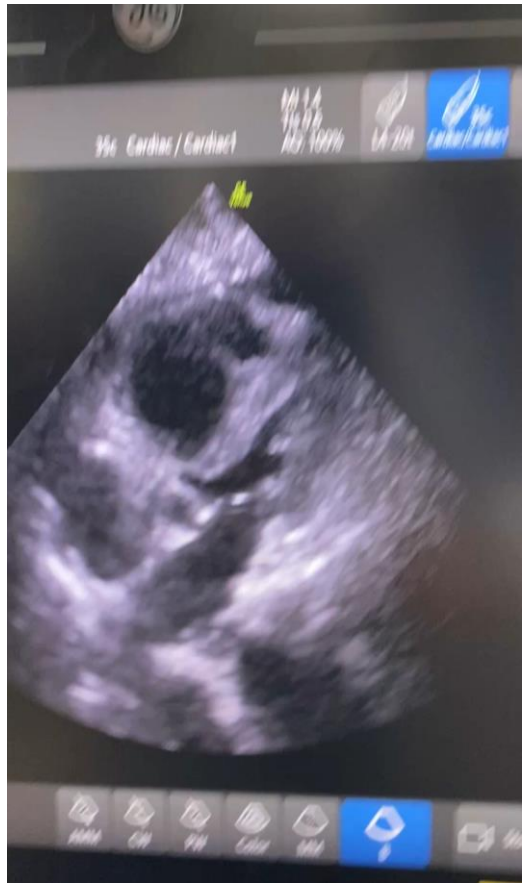


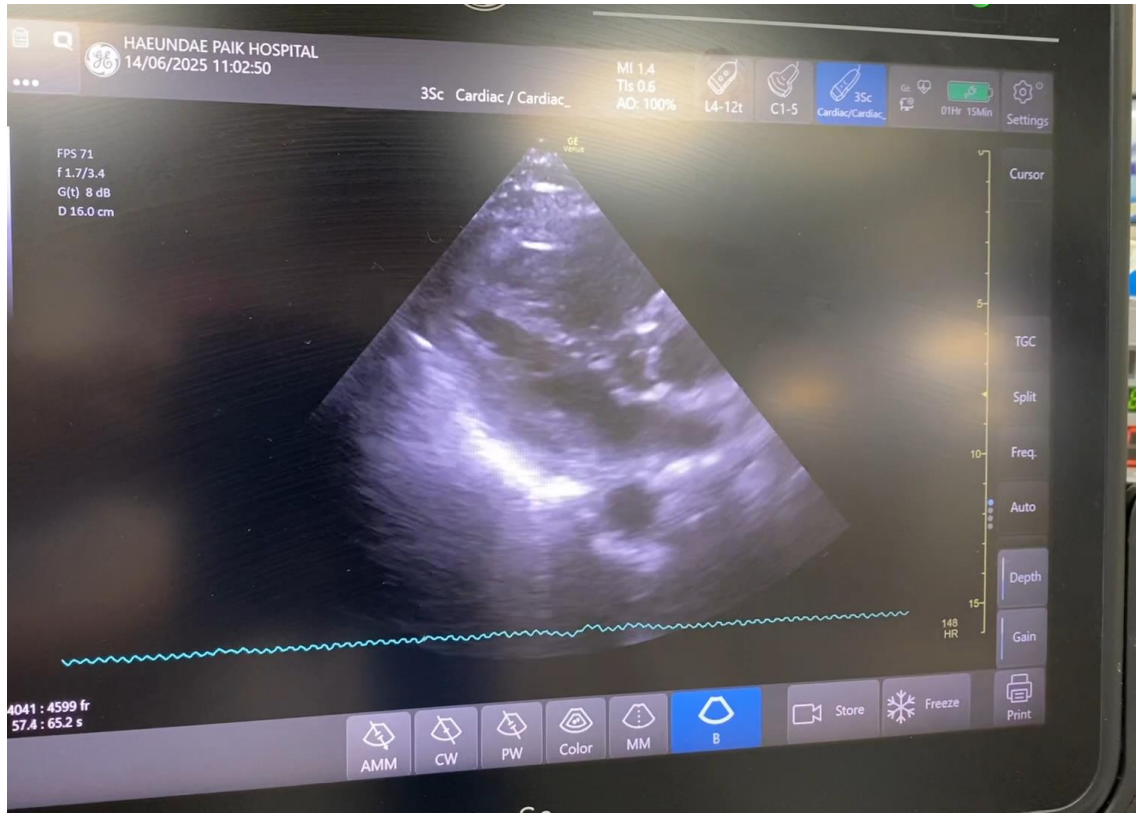




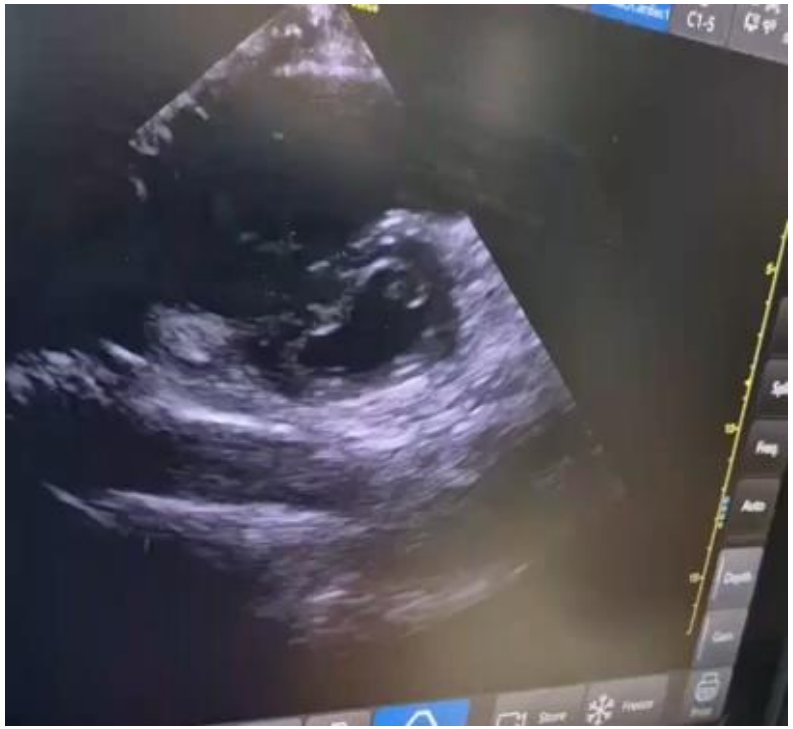

RV
LV
RA

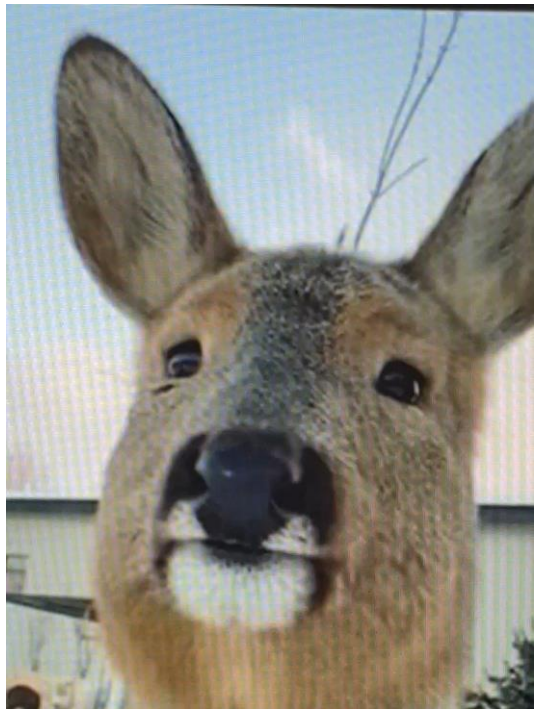
Massive PTE impending cardiac arrest

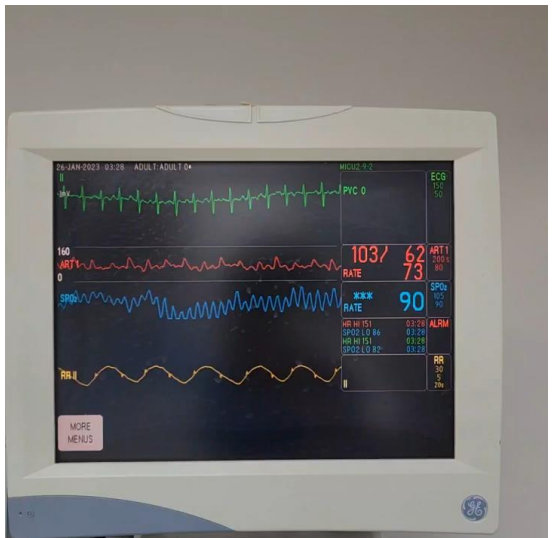


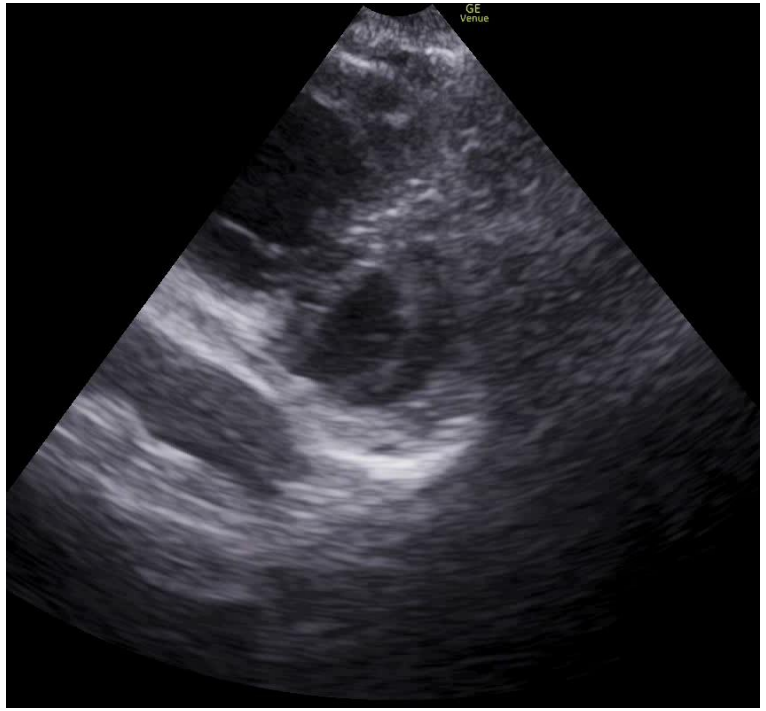


Massive PTE impending cardiac arrest



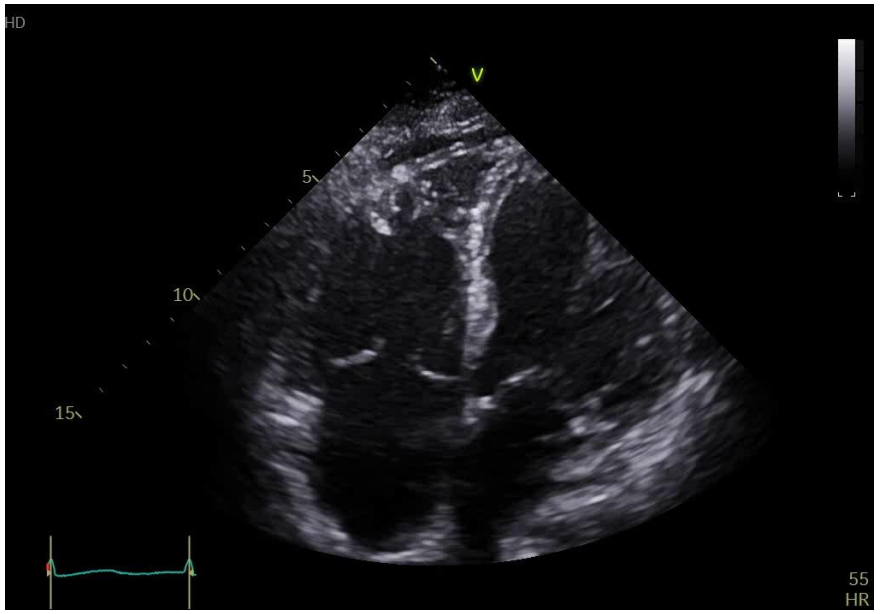


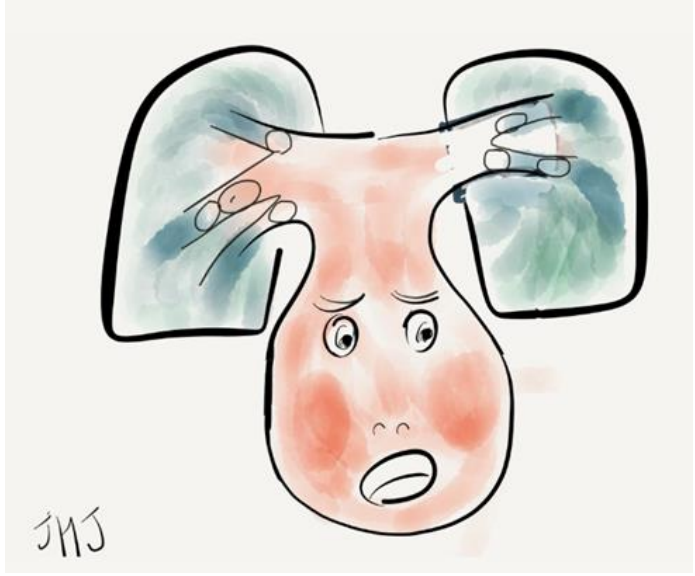


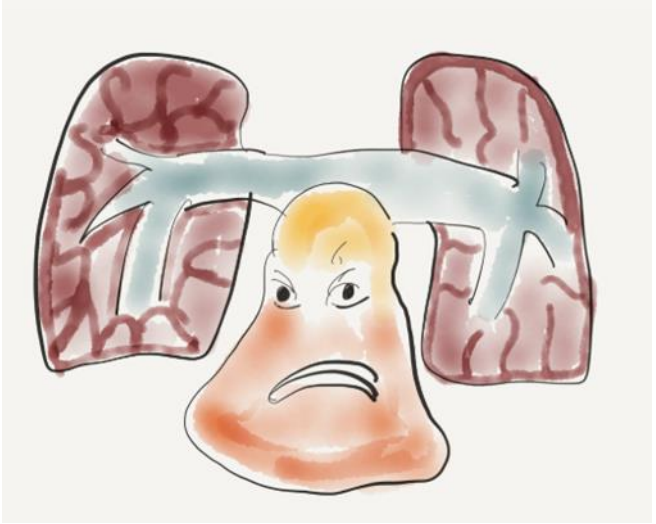


"Sudden deterioration in mechanically ventilated patients"

RV dysfunction in bedside echo







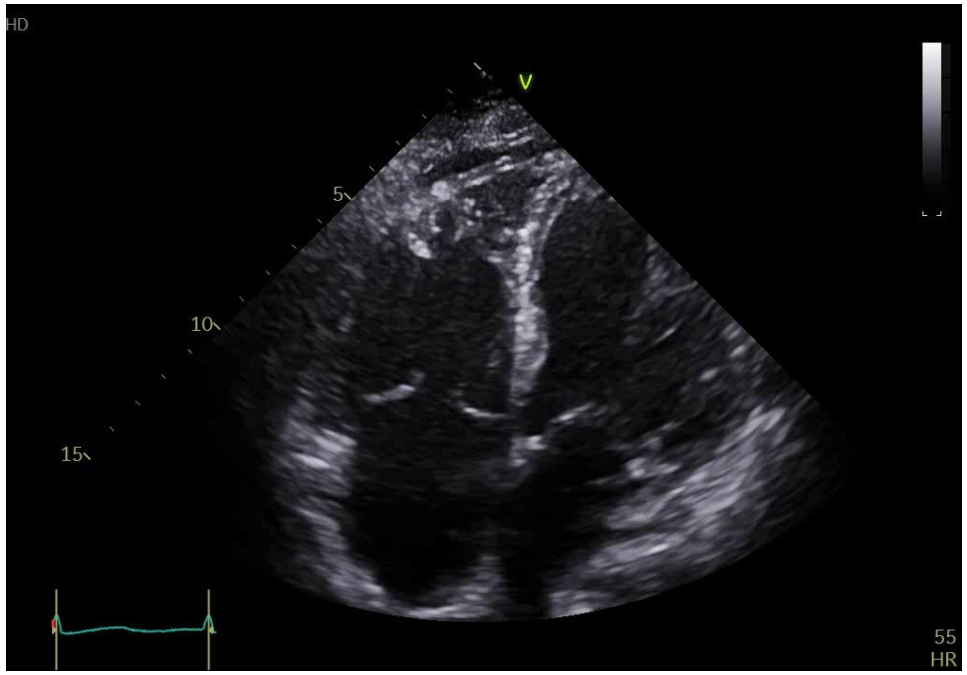
Massive PTE

Massive aspiration
Bronchospasm
Sepsis

Echo 로 감별 가능할까? **McConnell's Sign**

- is an echocardiographic finding that is
- **highly specific for acute pulmonary embolism**

- **하지만 다른 원인에서도 보일 수 있을까?**



🔬 Physiologic Mechanism

- In **acute PE**, sudden rise in pulmonary vascular resistance leads to **RV pressure overload**.
- The **RV free wall becomes stunned or akinetic**, while the **apex retains motion** due to shared fibers with the LV.
- This regional difference creates a "trampoline-like" appearance.

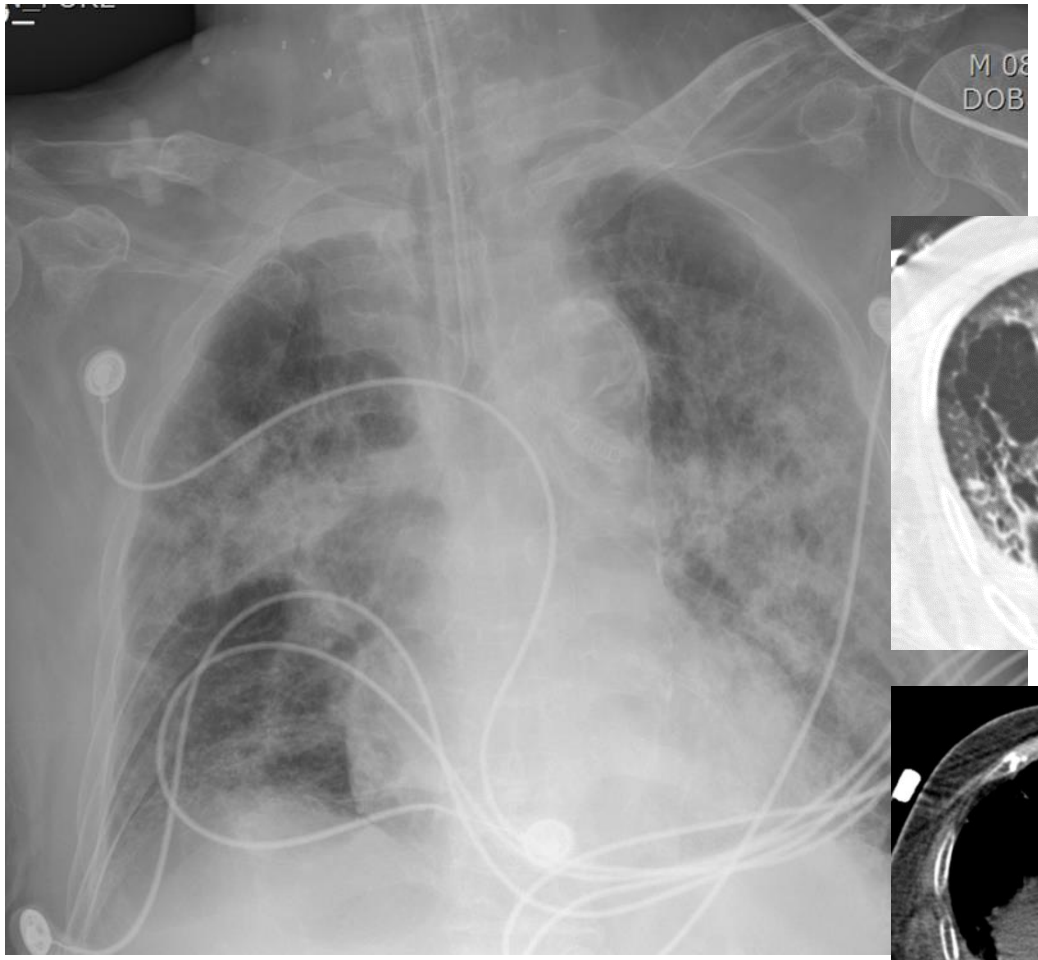
No pulmonary embolism, Cardiac arrest due to PH crisis

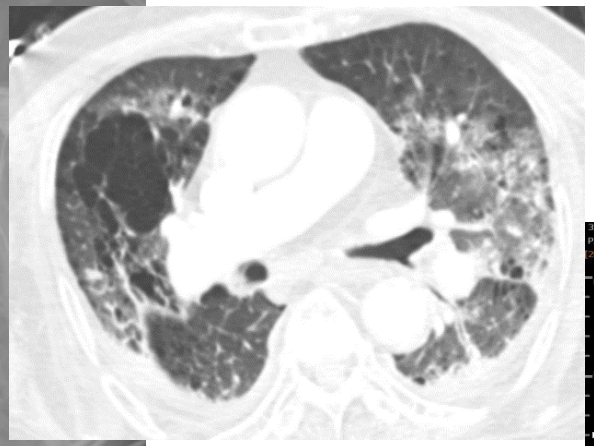
"Pulmonary capillary hemangiomatosis"

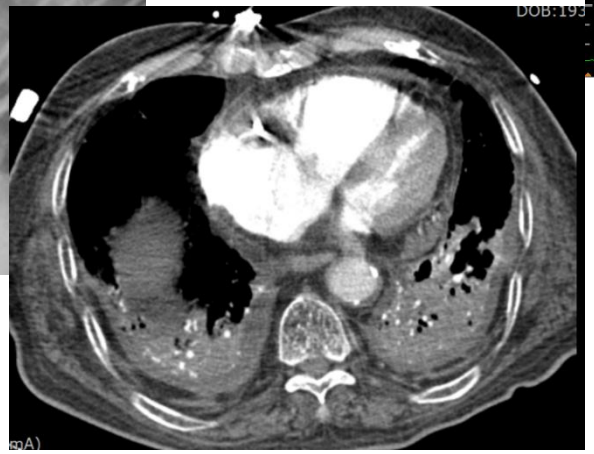
A R D S

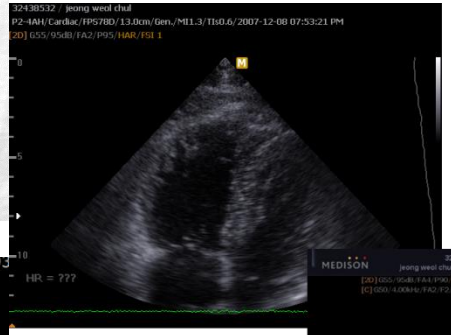
Severe pneumonia ARDS with septic shock

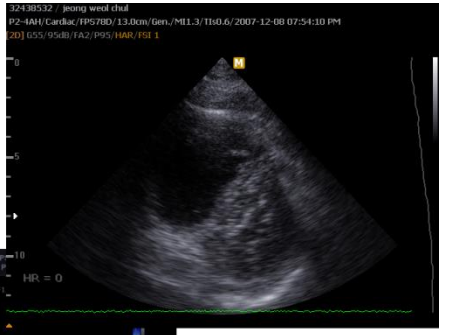
Hypoxic pulmonary vasoconstriction
→ RV pressure overload
→ **acute cor pulmonale**

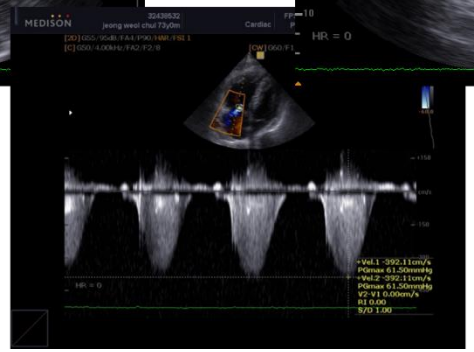


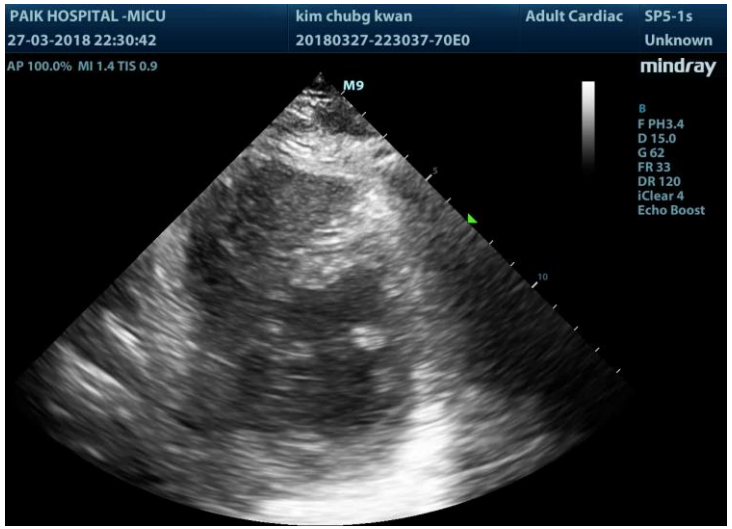








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kim chubg kwan
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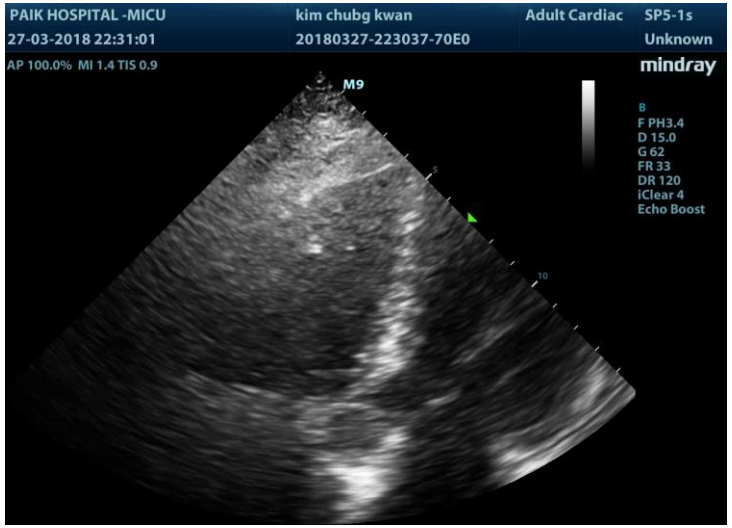
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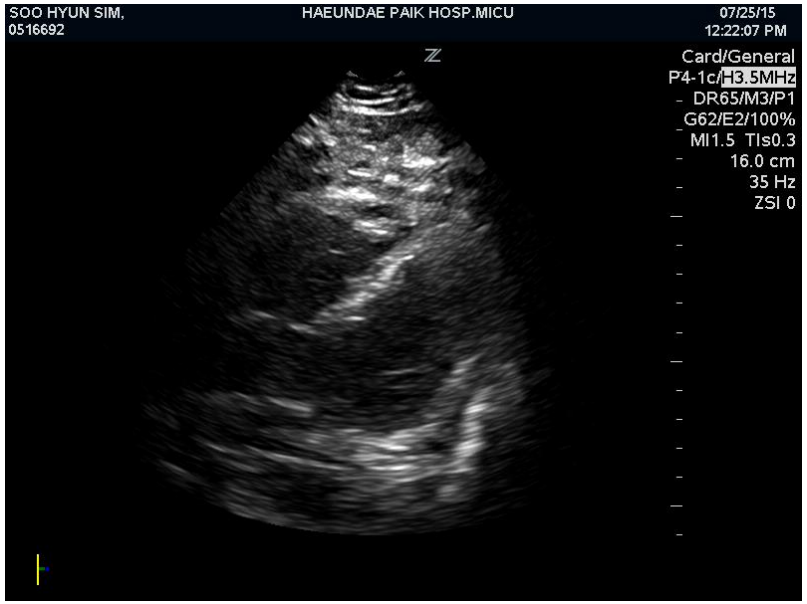
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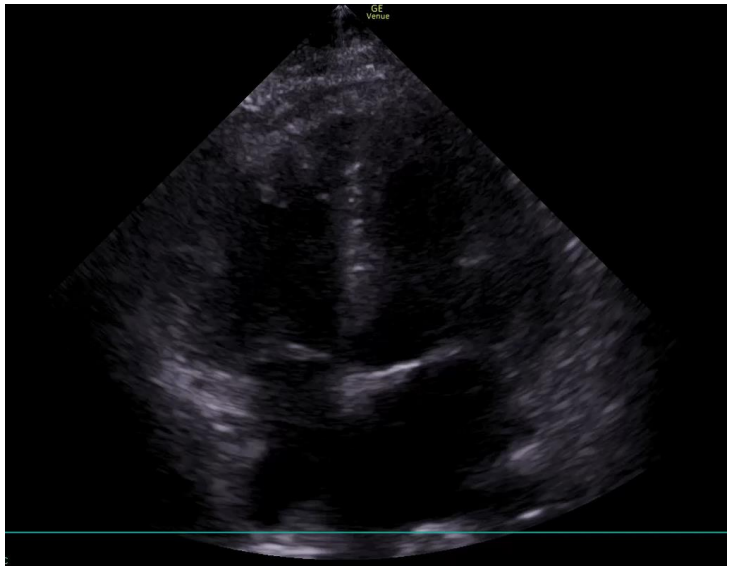
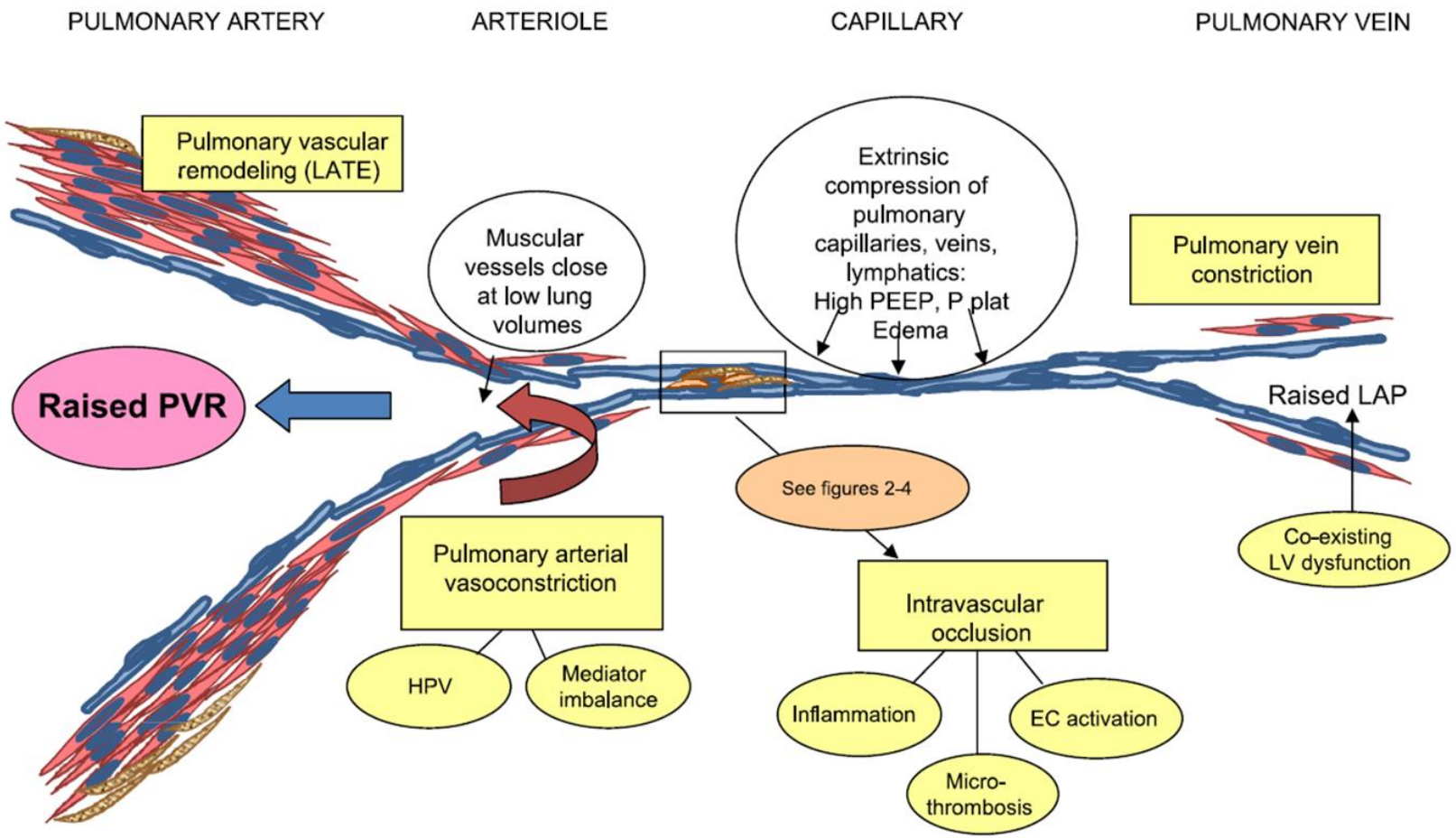
35 Hz
ZSI 0

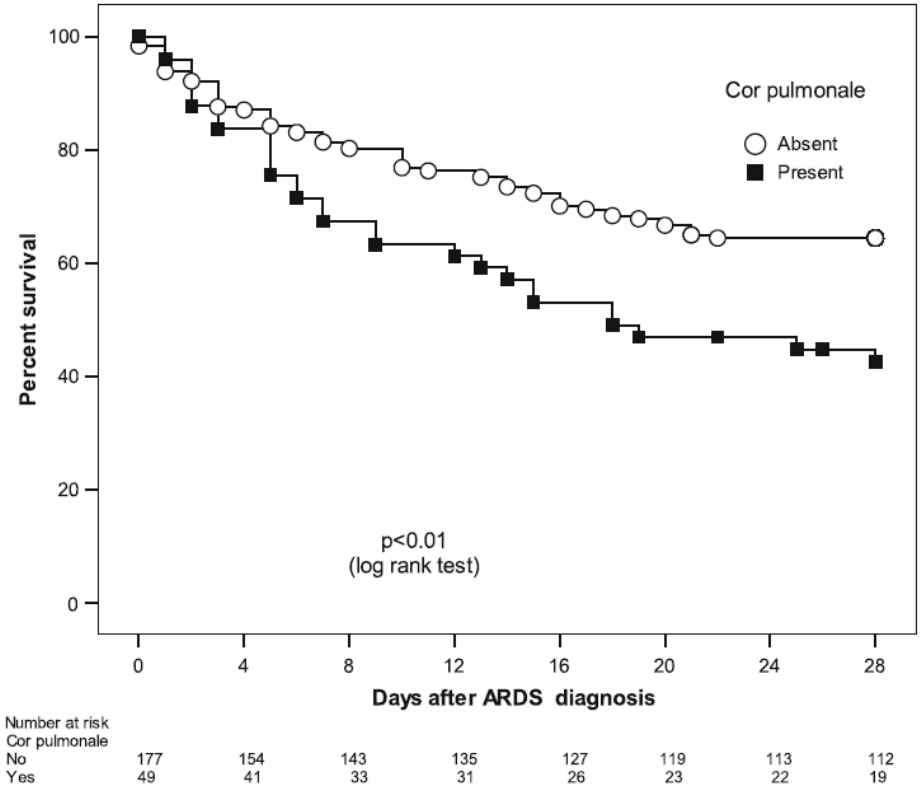

GE
Venue

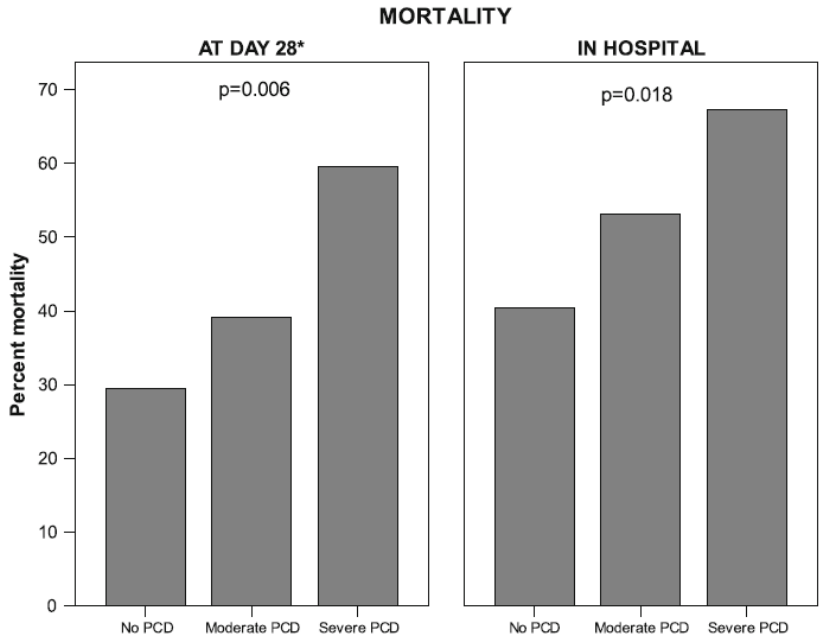
Pathophysiology of PH in **ARDS**



Laura C. et al, Am J Physiol Lung Cell Mol Physiol 302: L803–L815, 2012.

Prevalence and prognosis of cor pulmonale during protective ventilation for acute respiratory distress syndrome

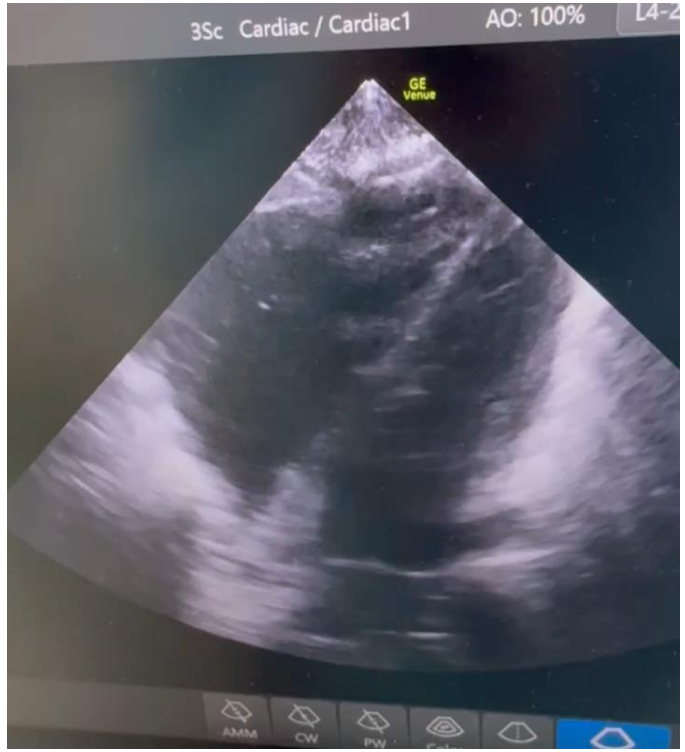




Boissier F et al Intensive Care Med. 2013 Oct;39(10):1725-33

RV dysfunction
as a complication of **ARDS**

- More gradual than in patients with massive PE
- Usually occurring at least 48 hours after ventilator support
- 25% incidence of acute right ventricular failure
- reversible in patients who recovered



RV dysfunction
as a complication of **ARDS**

- The initial magnitude of PH was not an indicator of mortality rate
- **Mean PAP** increased in non-survivors
- not in survivors when followed for 7 days
- Development of PH in ARDS patients

  → seems to be **a sign of poor prognosis**

Armand Mekontso Dessap
Florence Boissier
Cyril Charron
Emmanuelle Bégot
Xavier Repessé
Annick Legras
Christian Brun-Buisson
Philippe Vignon
Antoine Vieillard-Baron

Acute cor pulmonale during protective ventilation for acute respiratory distress syndrome: prevalence, predictors, and clinical impact

- Independently associated with **acute cor pulmonale**

Table 3 The acute cor pulmonale risk score

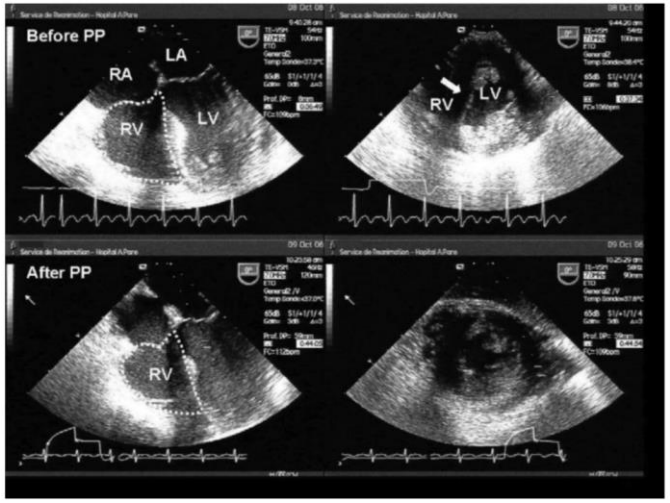
Parameter	Score
Pneumonia as cause of ARDS	1
Driving pressure $\geq$18 cmH_2O[a]	1
PaO_2/FiO_2 ratio <150 mmHg	1
$PaCO_2$ $\geq$48 mmHg	1
Total score	0–4

Intensive Care Med (2016) 42:862–870

Prone Positioning Unloads the Right Ventricle in Severe ARDS*

Antoine Vieillard-Baron, MD; Cyril Charron, MD; Vincent Caille, MD; Guillaume Belliard, MD; Bernard Page, MD; and François Jardin, MD

CHEST 2007; 132:1440 –1446



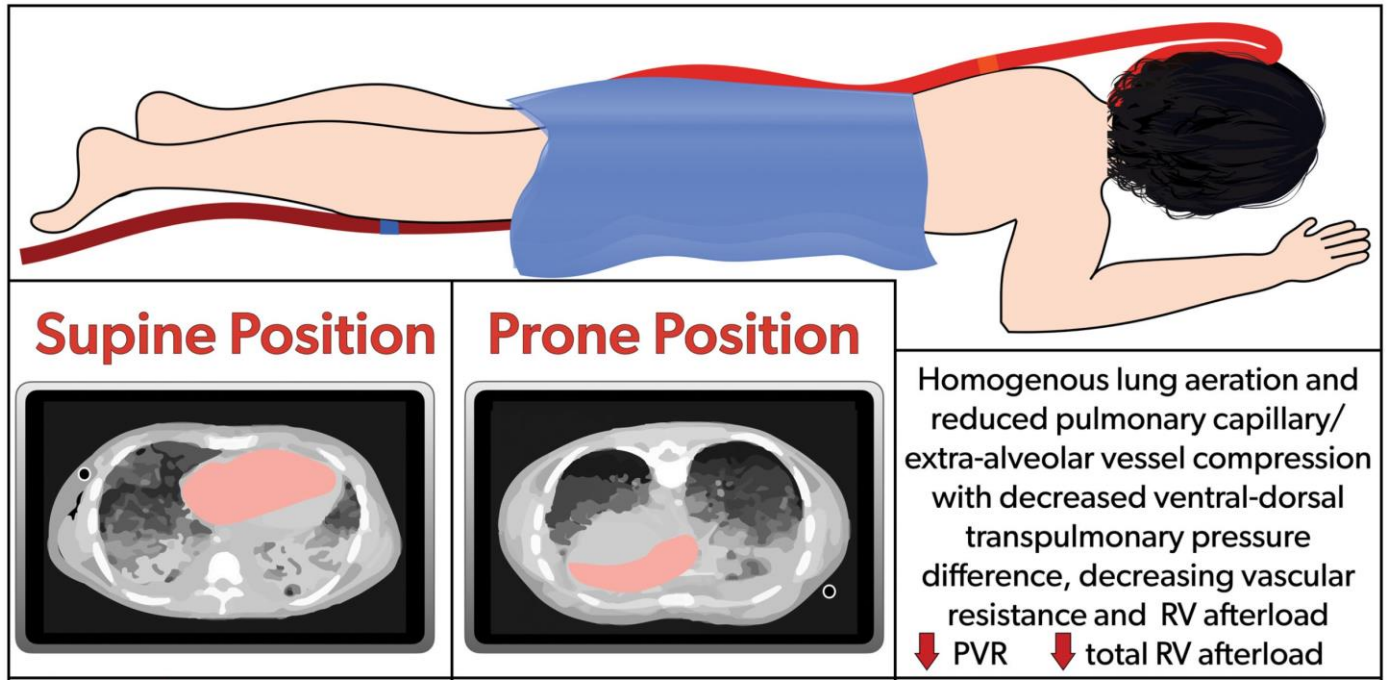
42 ARDS patients treated by Prone position (PP)
21 patients (50%) had **acute cor pulmonale**

significant airway pressure ↓ PaCO2 ↓.

produced a significant decrease in mean **RV enlargement** after 18 h of PP (p =0.000)
significant reduction in mean **septal dyskinesia** after 18 h of PP (p =0.000)

Conclusion: In the most severe forms of ARDS,
PP was an efficient means of controlling RV pressure overload.

Prone Positioning and Right Ventricular Protection During Extracorporeal Membrane Oxygenation for Severe ARDS



Recruitment of collapsed alveoli in dorsal lung regions
→ overdistension ↓ atelectotrauma

Increased thoracic circulation blood volume
→ Pulmonary microvasculature ↑
→ PVR ↓ RV afterload ↓

Zochios, Vasileios, Yusuff, Hakeem, Antonini, Marta Velia for Protecting the Right Ventricle Network (PRORVnet) ASAIO Journal 70(9):p e119-e122, September 2024.

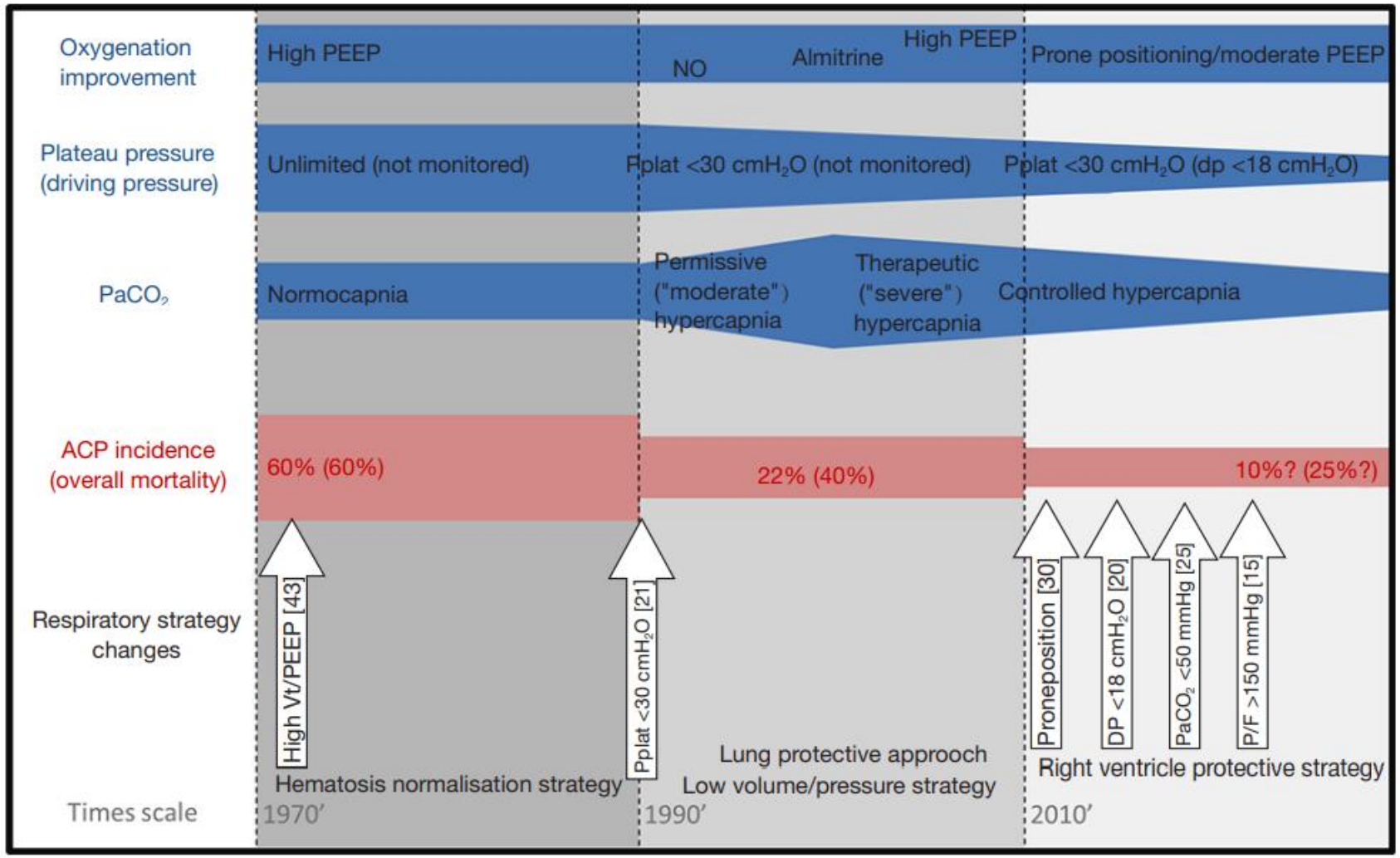
RV-protective ventilatory strategy

1. Lung-Protective Ventilation:

- **Low tidal volume ventilation:** Reducing tidal volume (typically to 6 mL/kg of predicted body weight) helps minimize alveolar overdistension and barotrauma, which can increase RV afterload.
- **Optimal PEEP titration:** Positive end-expiratory pressure (PEEP) is used to prevent alveolar collapse, but excessive PEEP can increase RV afterload. Adjusting PEEP based on RV function and hemodynamic parameters is crucial.
- **Limiting plateau pressure:** Maintaining plateau pressure below 27-30 cmH2O helps prevent overdistension and reduces the risk of barotrauma.
- **Permissive hypercapnia:** Accepting a slightly elevated PaCO2 (permissive hypercapnia) can reduce the need for high ventilator settings and minimize RV strain.
- **Driving pressure:** Lowering driving pressure (plateau pressure - PEEP) is associated with improved lung mechanics and can be used as a target to optimize ventilation.

Changes in respiratory strategy

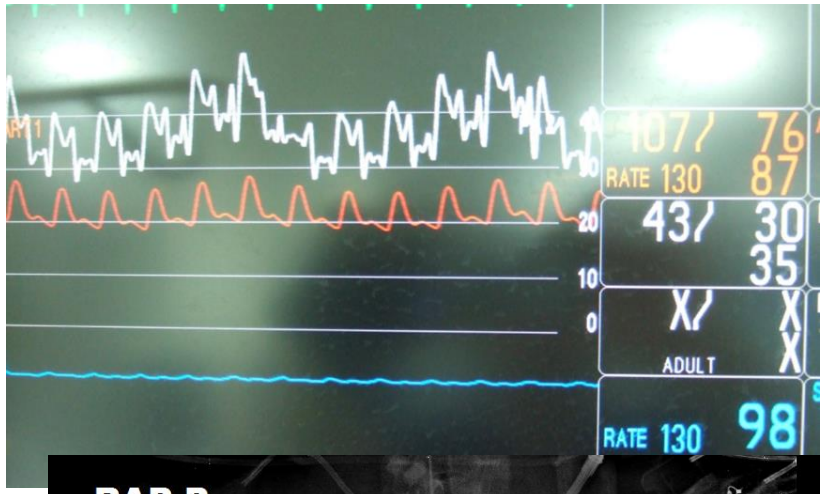
three main risk-identified factors for **acute cor pulmonale in ARDS**

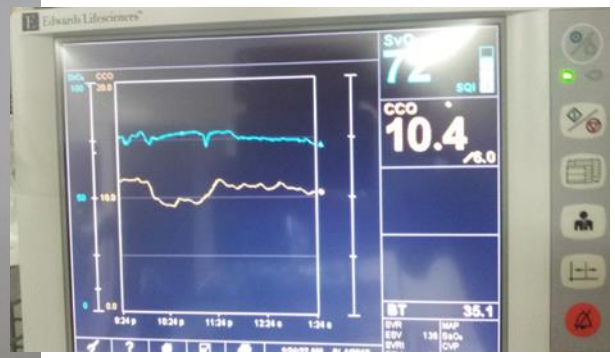


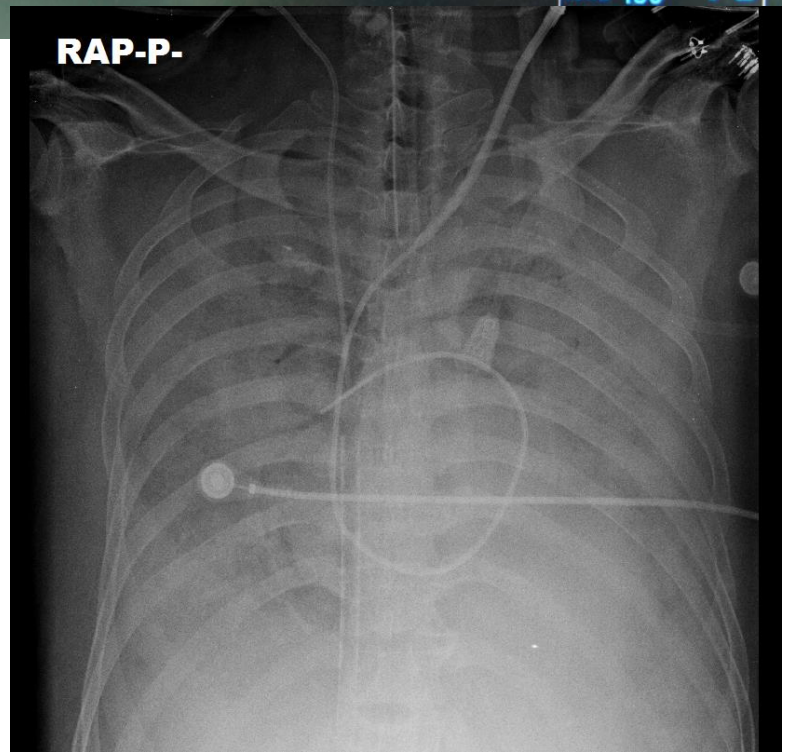
V-V ECMO
ECCO2R

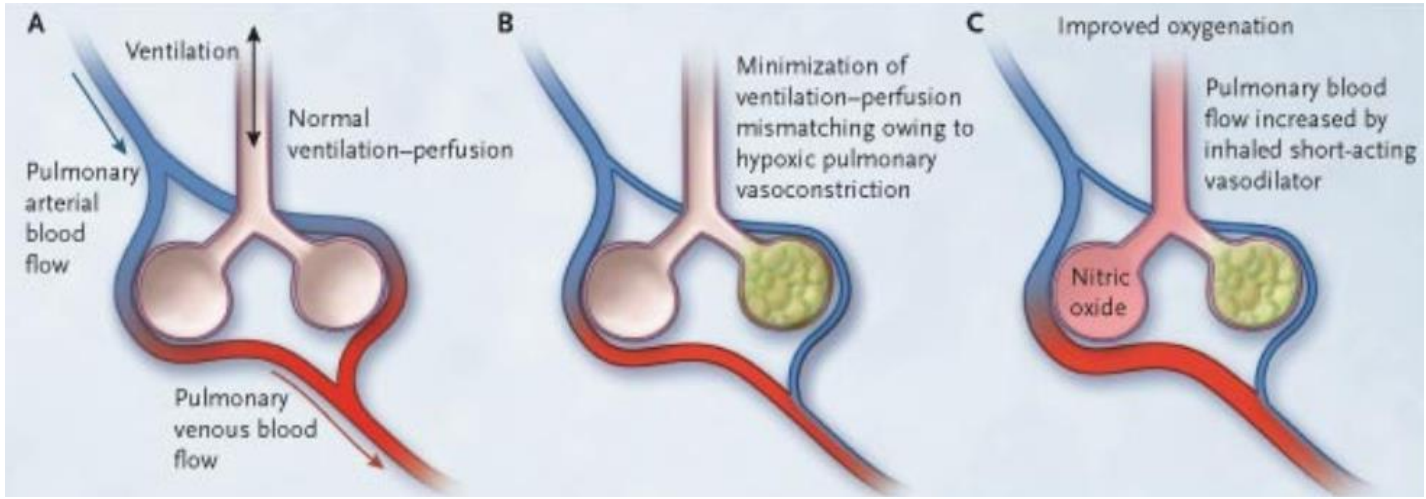
Xavier Repessé et al Annals of Translational Medicine, Vol 5, No 14 July 2017

Pulmonary Vasodilator therapy – Nitric oxide gas, prostacycline inhalation









Mark J D Griffiths Timothy W Evans
N Engl J Med. 2005 Dec 22;353(25):2683-95

Haeberle *et al. Respiratory Research* (2023) 24:58
https://doi.org/10.1186/s12931-023-02346-0

Respiratory Research

RESEARCH Open Access

Inhaled prostacyclin therapy in the acute respiratory distress syndrome: a randomized controlled multicenter trial

Helene A. Haeberle[1], Stefanie Calov[1], Peter Martus[2], Lina Maria Serna-Higuita[2], Michael Koeppen[1], Almuth Goll[1], Alice Bernard[1], Alexander Zarbock[3], Melanie Meersch[3], Raphael Weiss[3], Martin Mehrländer[1], Gernot Marx[4], Christian Putensen[5], Tamam Bakchoul[7], Harry Magunia[1], Bernhard Nieswandt[6], Valbona Mirakaj[1†] and Peter Rosenberger[1*†]

Conclusions:
The primary result of our study was negative.
Our data suggest that inhaled prostacyclin might be benefcial treatment in patients with COVID-19 induced ARDS.

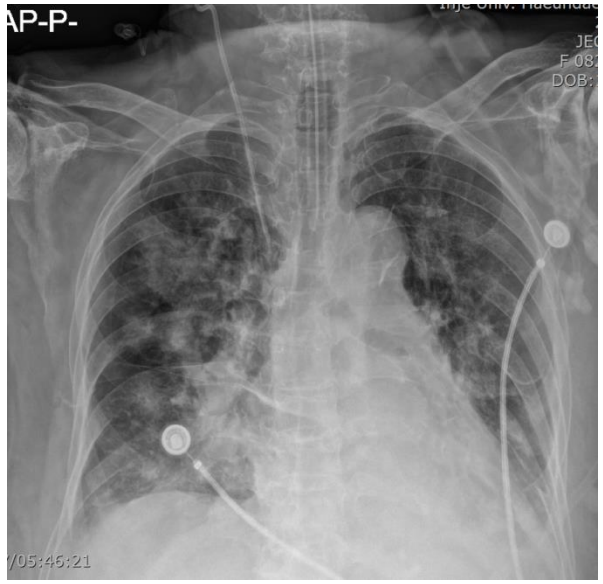
증례#1　84/F 구토 후 의식저하로 ICU 입원

응급실 도착 직후
Intubation and MV

- Past history

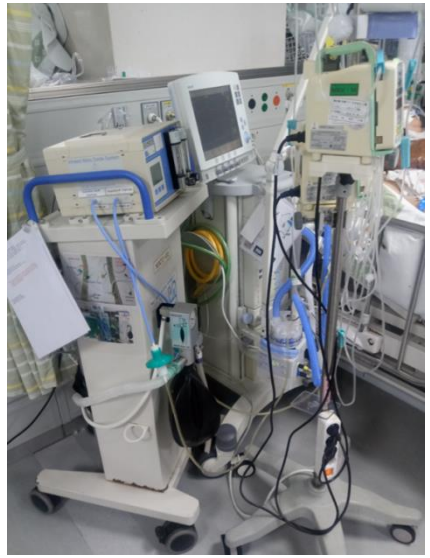
HCV-liver cirrhosis (child A)
Parkinson disease
Major Depression
Hypertension

3년 전 aspiration pneumonia 로 입원 치료력

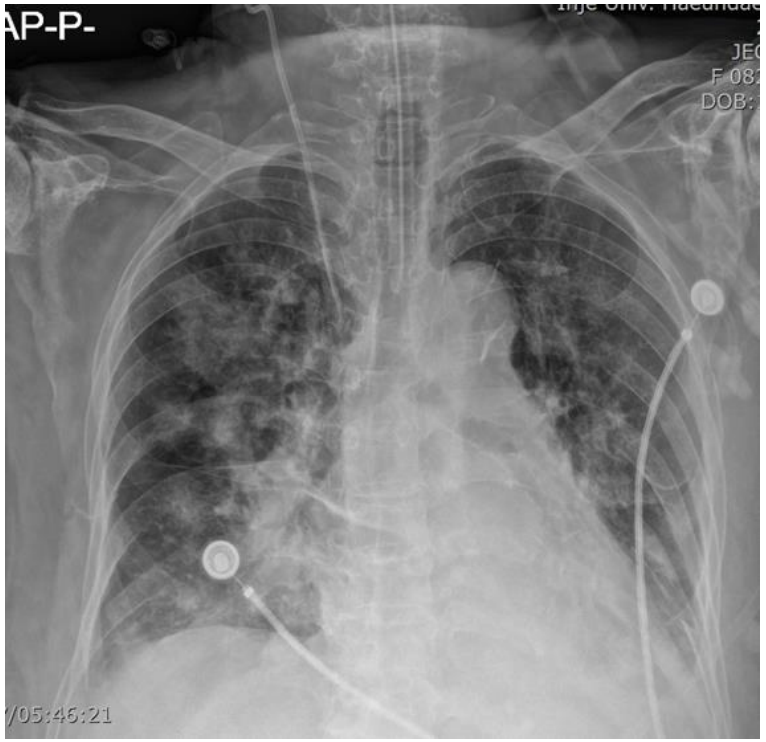


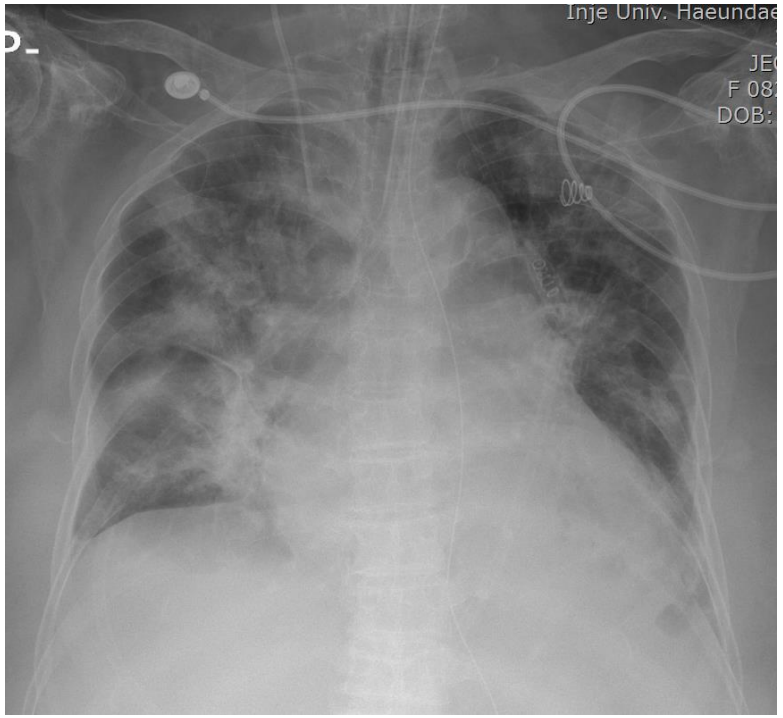
Dx: Aspiration pneumonia

Worsening to severe ARDS
Hypoxemia despite FiO2 100%
High PEEP no response
Prone position no response
→ Desaturation, vital signs 악화로 보호자 임종 면회

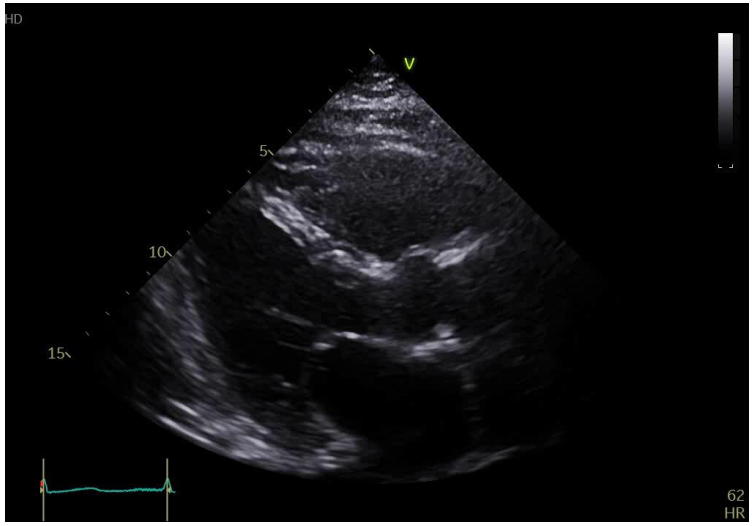


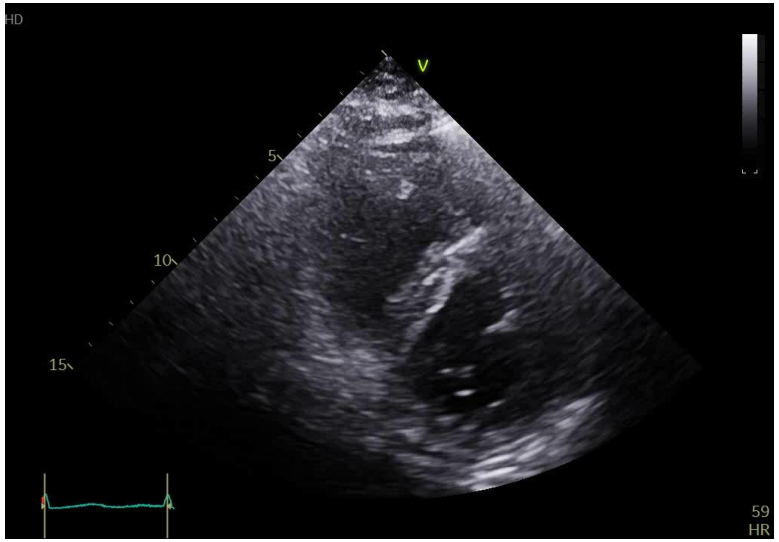
Inhaled nitric oxide applied 10 ~20 ppm
Response (++) : PF ratio ↑ hemodynamic stable

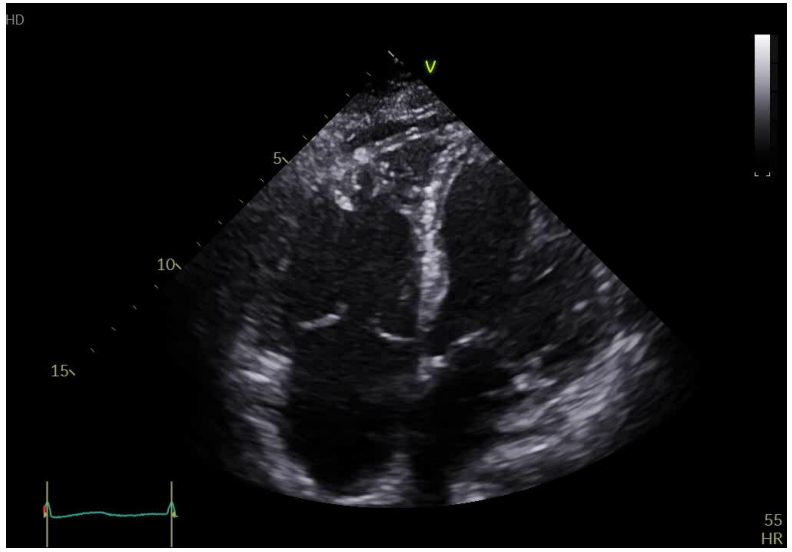




Bedside Echo







Small amount pericardial effusion
IVC plethora +
No visible shunt flow

TAPSE 19.2 mm
Peak TR Vmax 2.8 m/s
RA area 24

→ Suggestive of acute RV pressure overloading.
Recommend) embolism CT

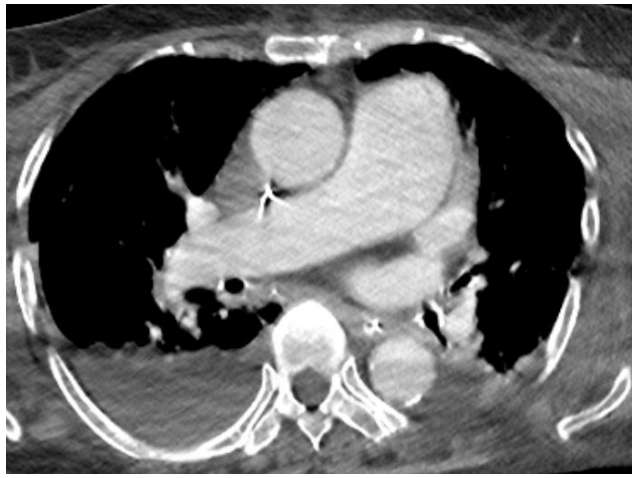
Treatment and hospital course

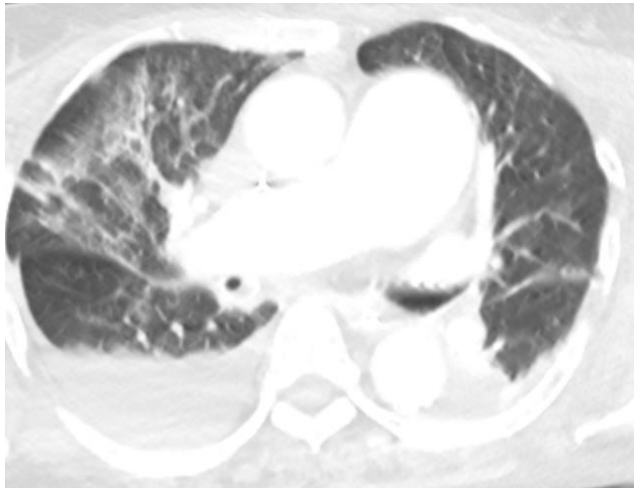
- Antibiotics
- Steroid 2mg/kg/day 7 days
- Anticoagulation IV heparin
- Supportive care

- 7일 경과 후 호전 awakening
- Pressure support ventilation
- FiO2 0.4

- Echo 시행 후 11일째 이동 가능하여 CTPA

No filling defect in pulmonary artery





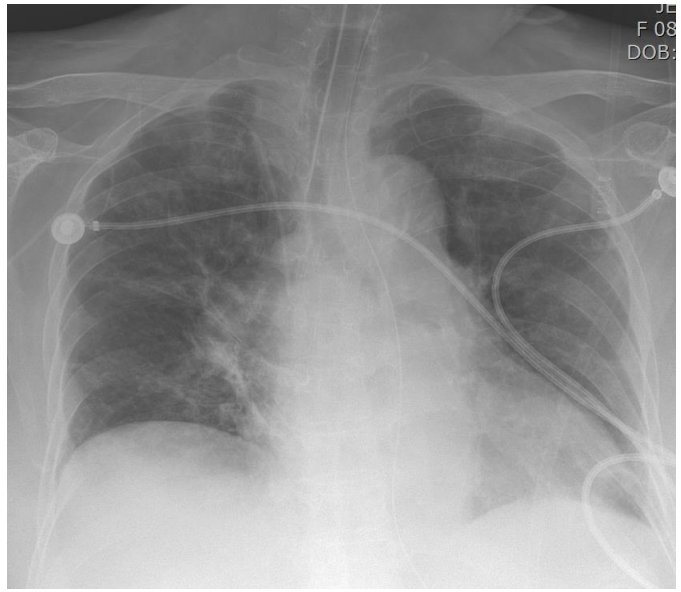
Treatment and hospital course

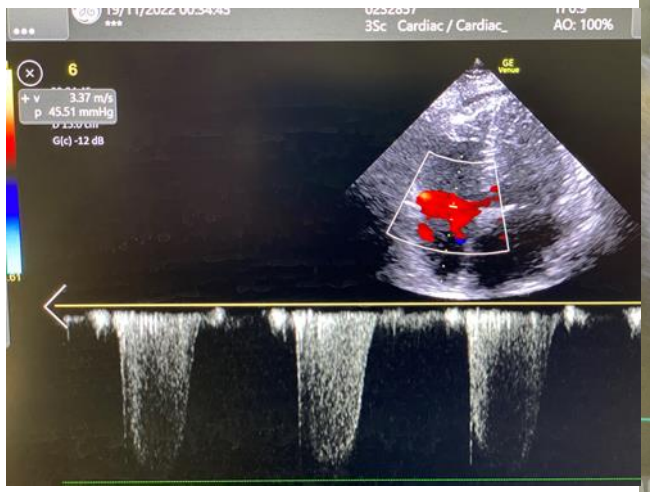
- ICU 입원 31일째

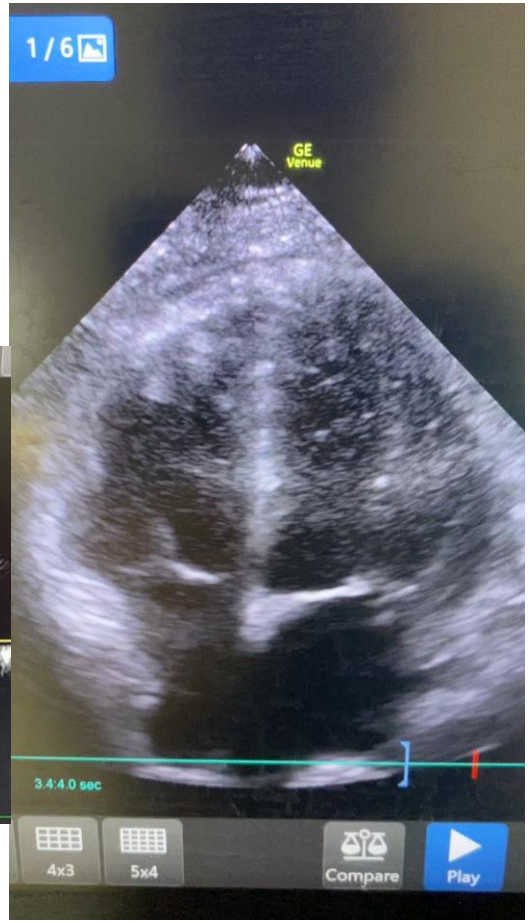
On ventilator weaning

Fio2 0.3 PSV mode

Inhaled Iloprost 10mcg q6hr start



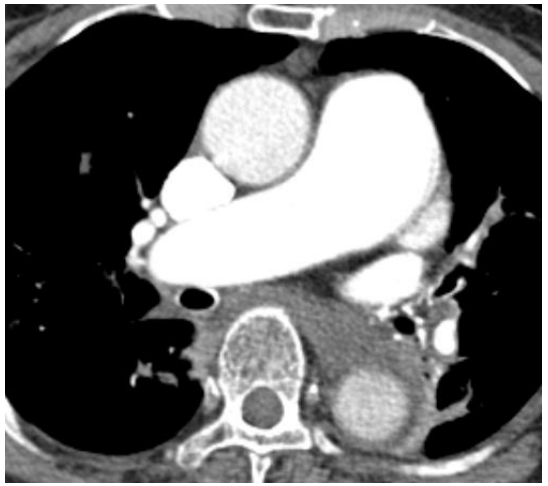


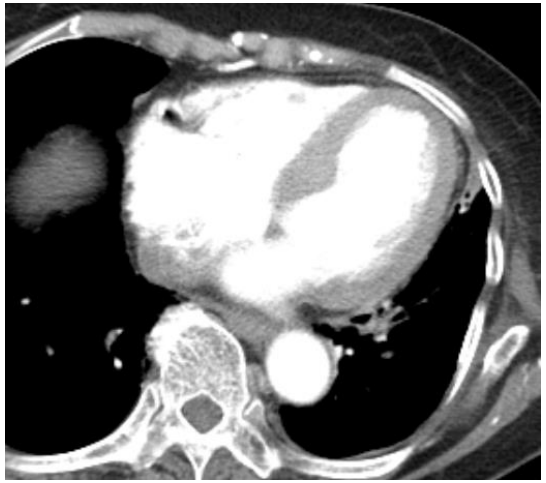


증례#1 정리

- Aspiration pneumonia ARDS
- Acute cor pulmonale
- Underlying PAH ?

HCV-LC associated portopulmonary hypertension ??



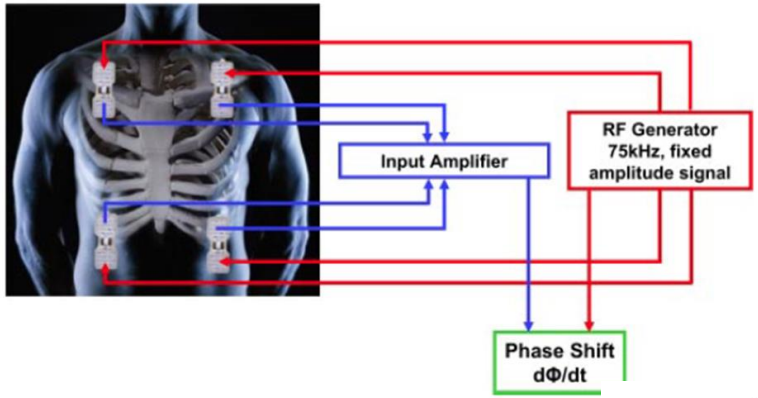


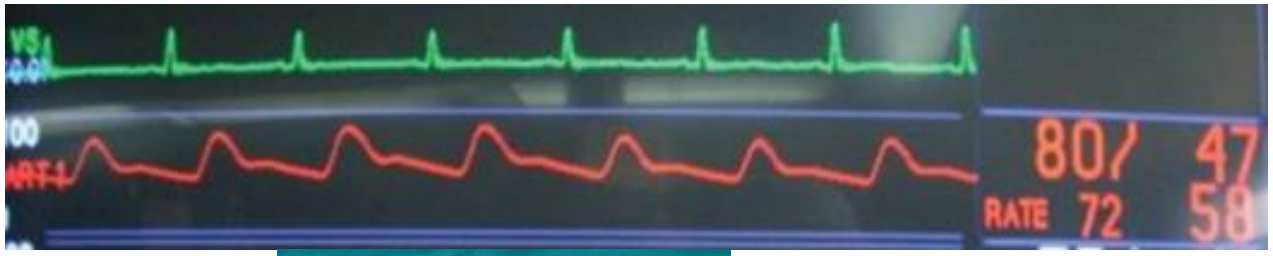
Invasive Hemodynamic monitoring

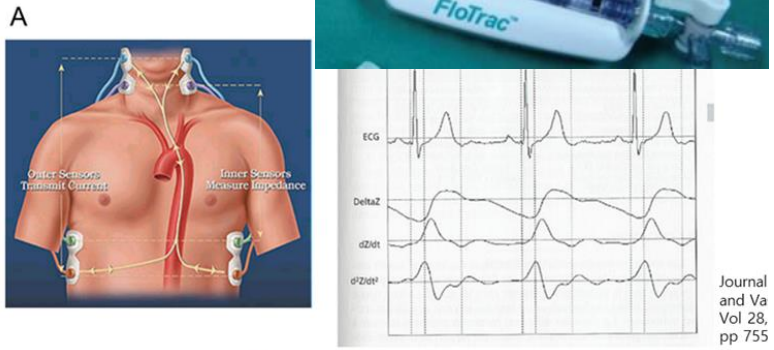
PA catheterization

Non-invasive cardiac output monitoring + bedside Echo

Bioreactance CO Monitor



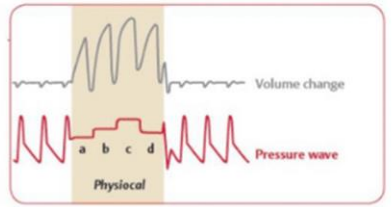


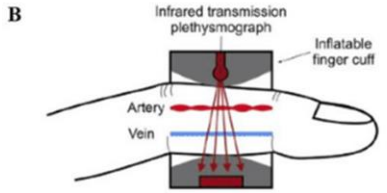


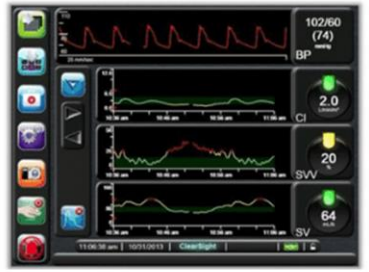
Journal
and Va
Vol 28,
pp 755

Fig 1. Measurement of changes in thoracic electrical bioimpedance during a cardiac cycle. A: Placement of skin electrodes at the ba
thorax (emitters) and at the base of the neck (detectors). B: Recording of thoracic electrical bioimpedance changes during systole and
(deltaZ) and its first (dZ/dt) and second (d^2Z/d^2t) derivatives over time.

ClearSight System

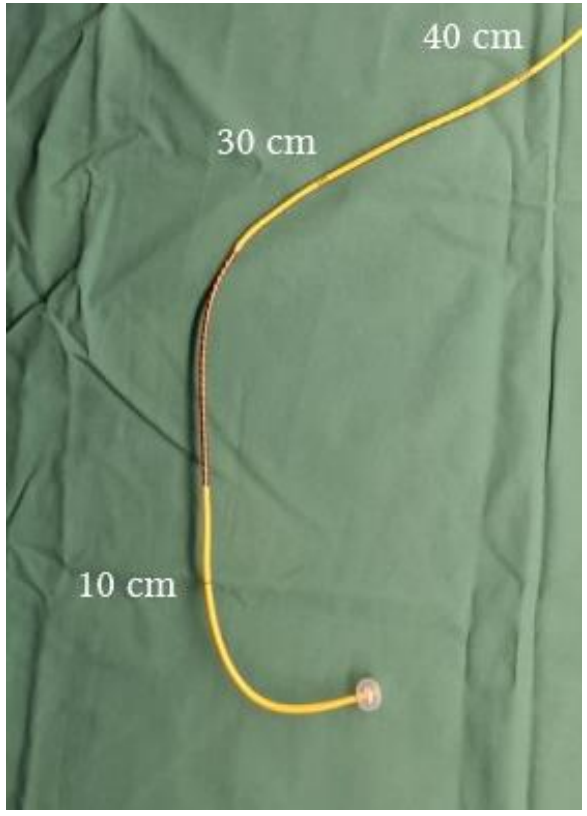


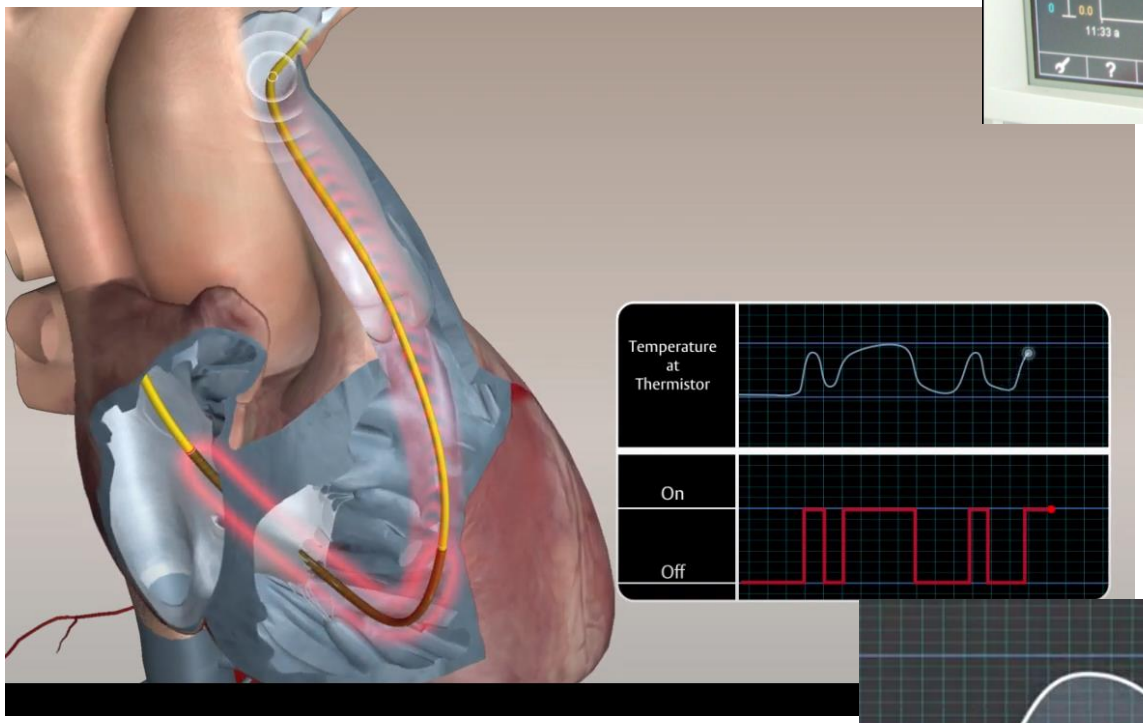


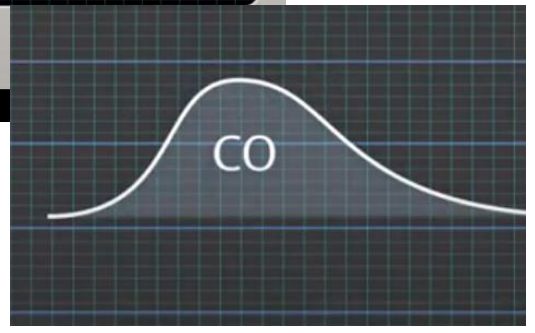


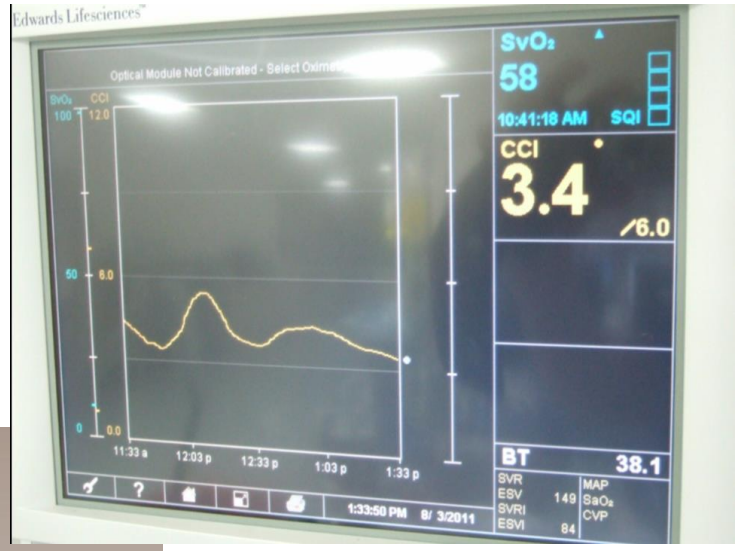
PA catheterization in ICU

- Monitoring Continuous cardiac output



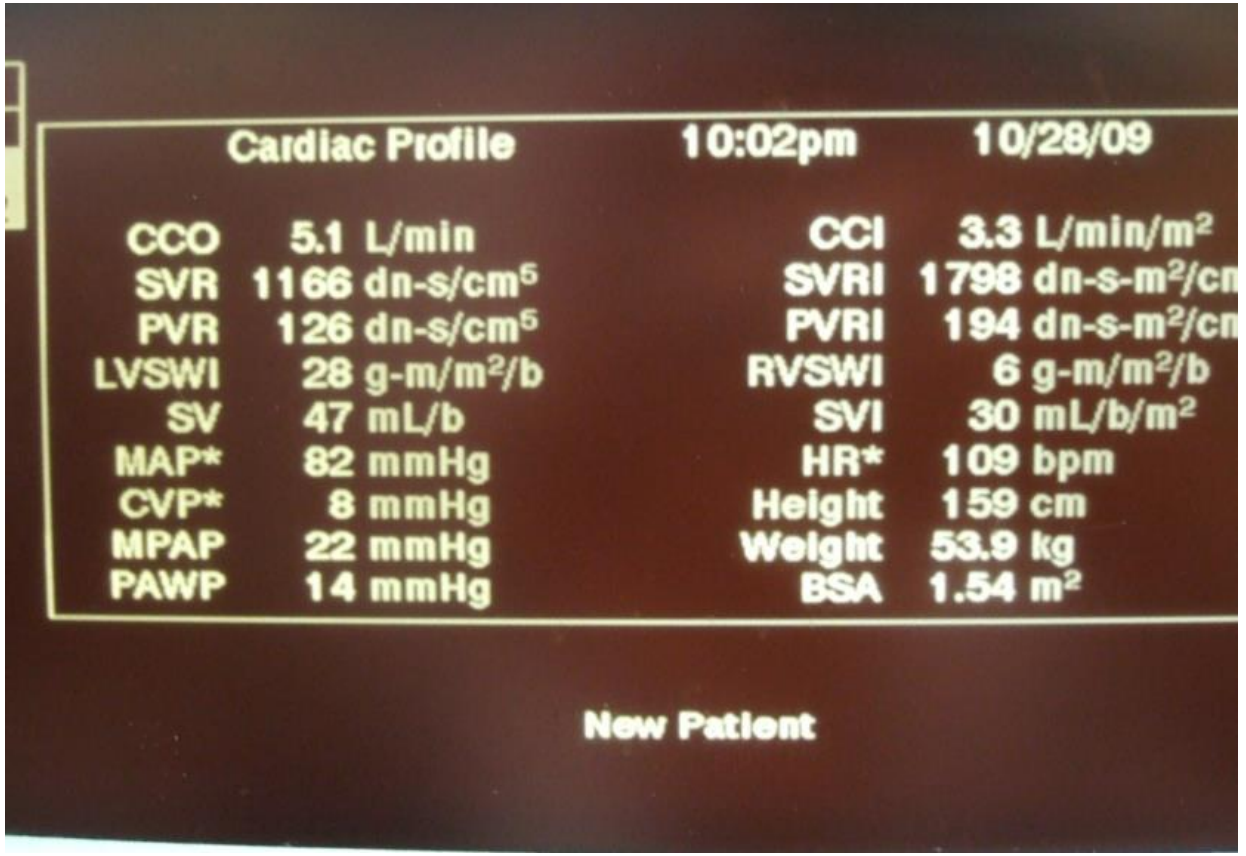






Edwards

PA catheterization in ICU 아직도 필요한가?



Pulmonary artery catheterization (PAC) for adult patients in intensive care

Need to maximize fluid resuscitation
Complicated combined shock

1970년대~2000년 초반까지 ICU에서
많이 사용되었음

PA catheterization in ICU　아직도 필요한가?

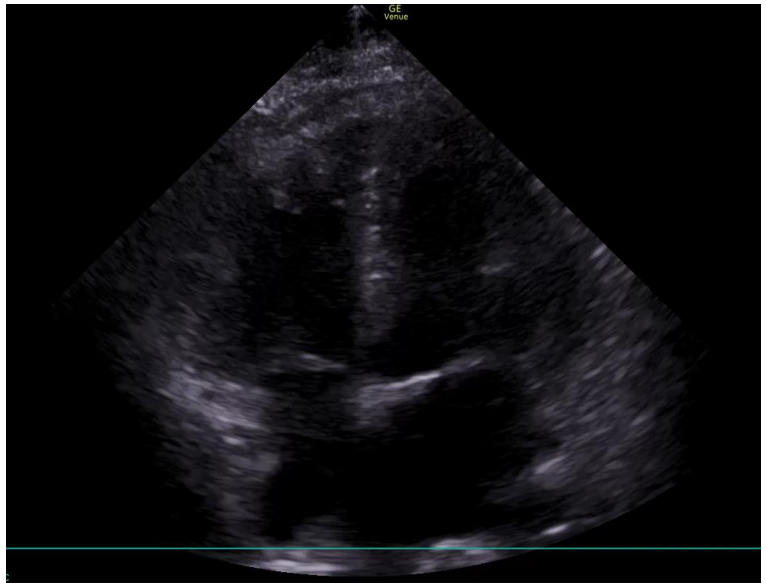
- **Extreme critically ill or perioperative patients with very high risk (eg. Cardiac surgery, liver transplantation)**

Question >>
clinical or noninvasive modality 로 충분하지 않은가
PAC data 로 management 가 달라지는가?

Ex) severe septic shock with high dose vasopressor & inotropics
+ stress induced cardiomyopathy + RV dysfunction
ARDS on high PEEP

Fluid responsiveness CO 올리고 vasopressor 줄이고

Septic shock due to Septic knee, lactic acidosis
Dobutamine, High dose vasopressor infusion
(norepinephrine, dopamine, vasopressin)
ARDS ventilator PEEP 16 cmH2O



CO 4.5 L/min PAP 47/23 PCWP 17

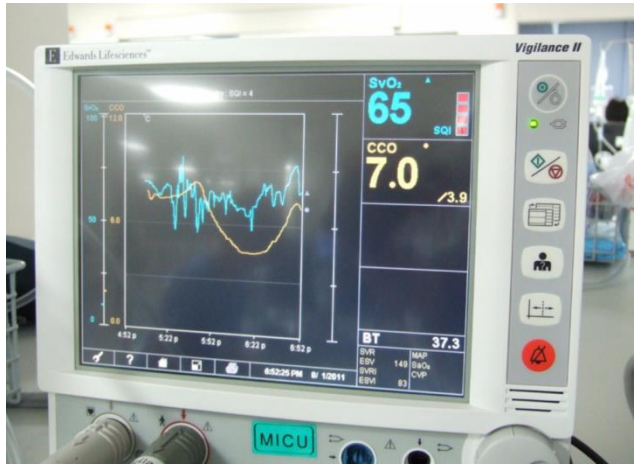
→ Normal saline 500ml full drip infusion

CO 5.2 L/min PAP 48/23 PCWP 18

→ Normal saline 1000 ml full drip infusion

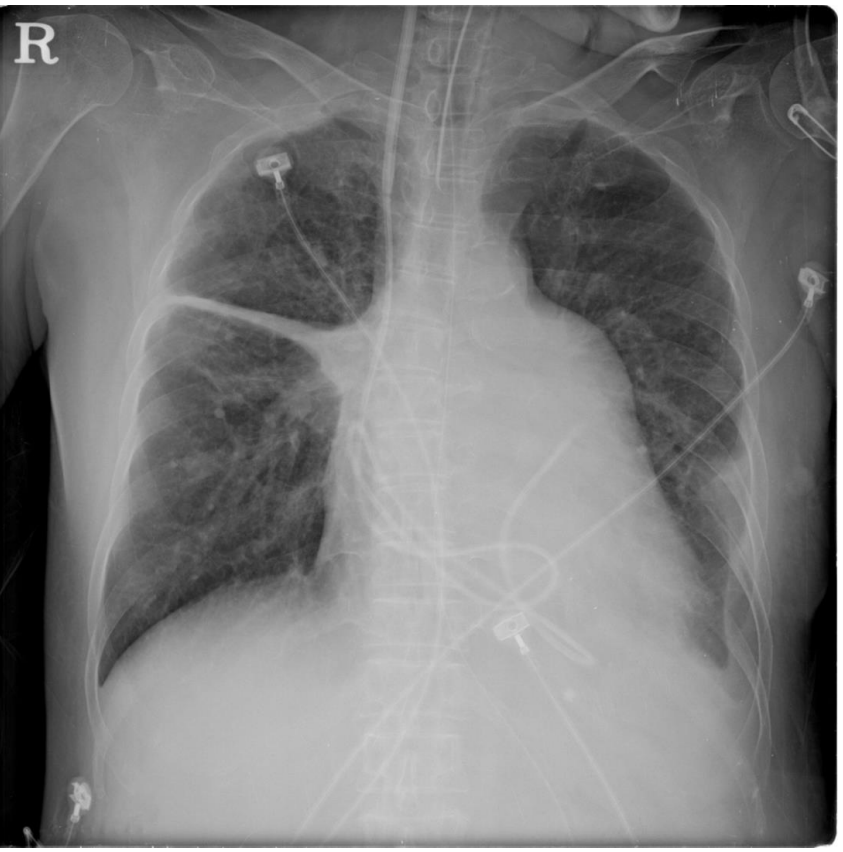
CO 6.5 L/min PAP 48/23 PCWP 18

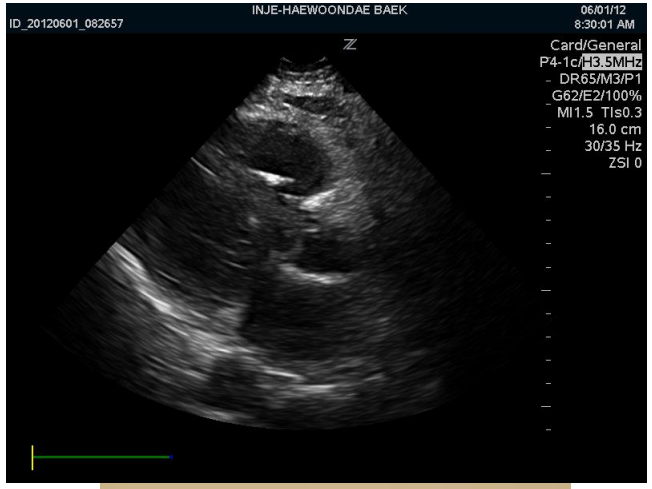
→ Normal saline 1000 ml infusion
CO 7.0 L/min PAP 50/25 PCWP 20

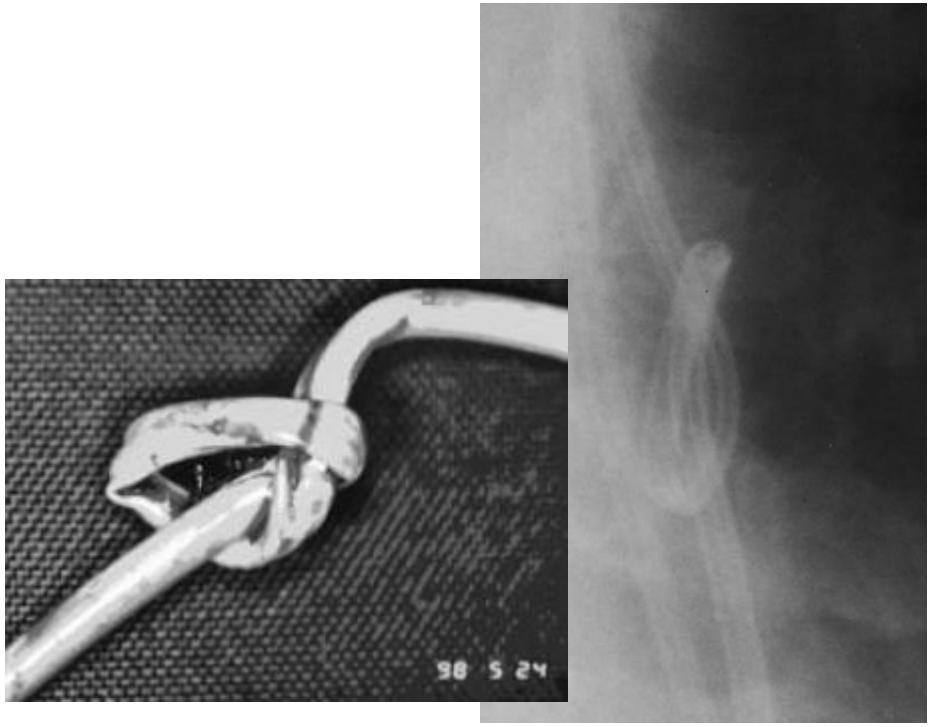


Complication of PA catheterization

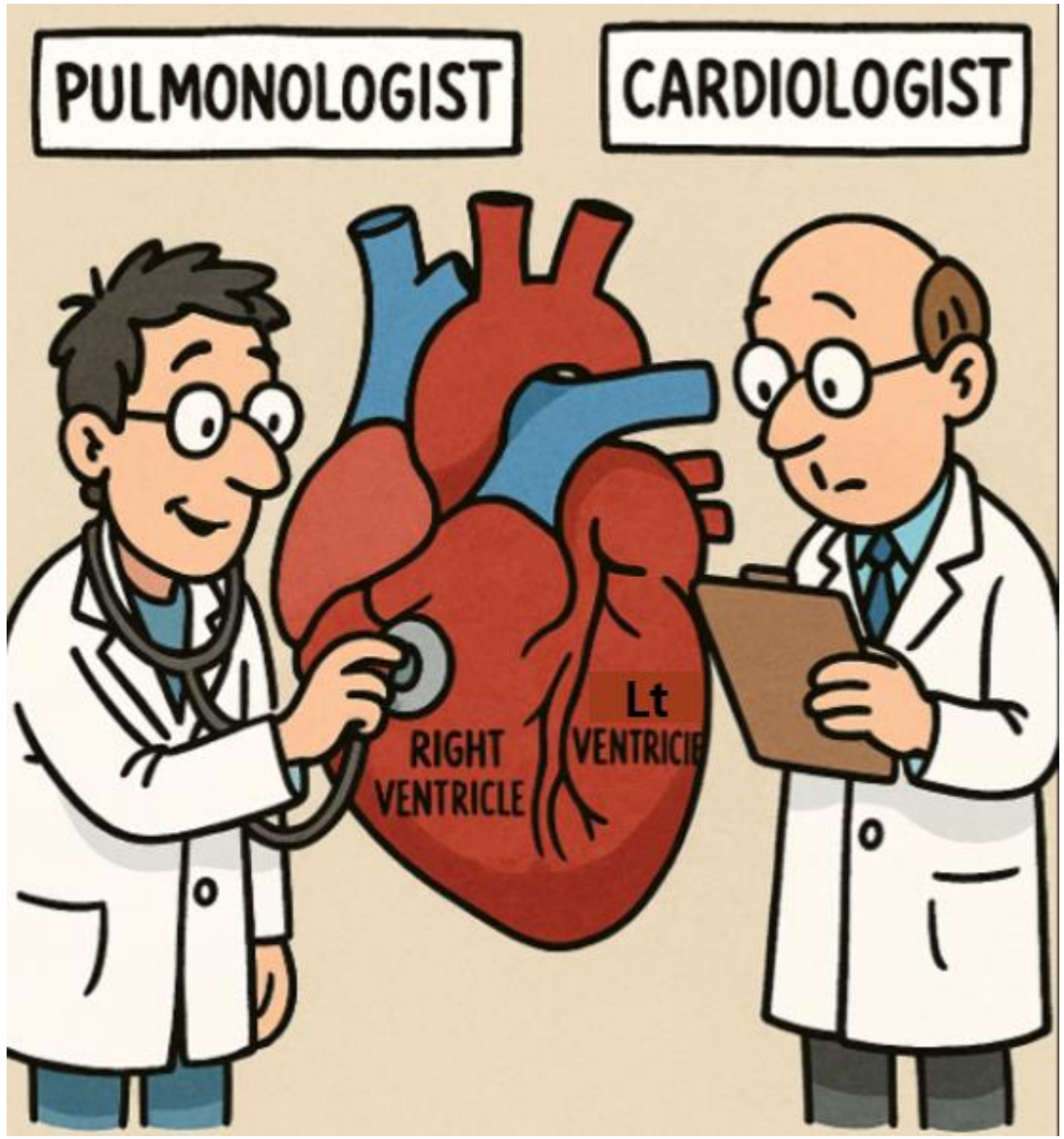
- Depend on experiences and skill of physician

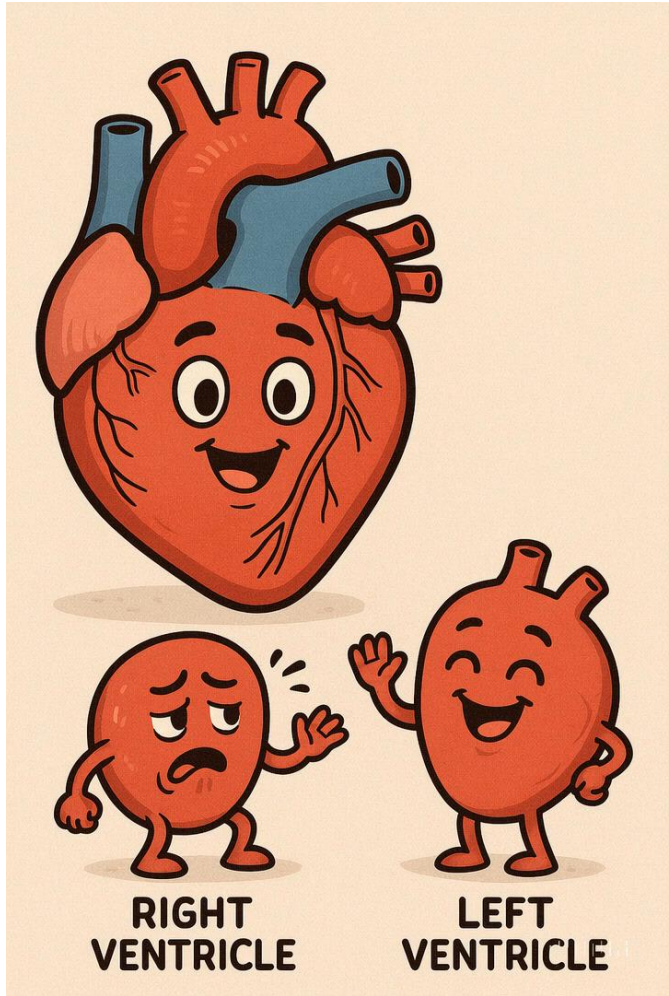






Torsten B. et al, J Card Surg 2006;21:292-295

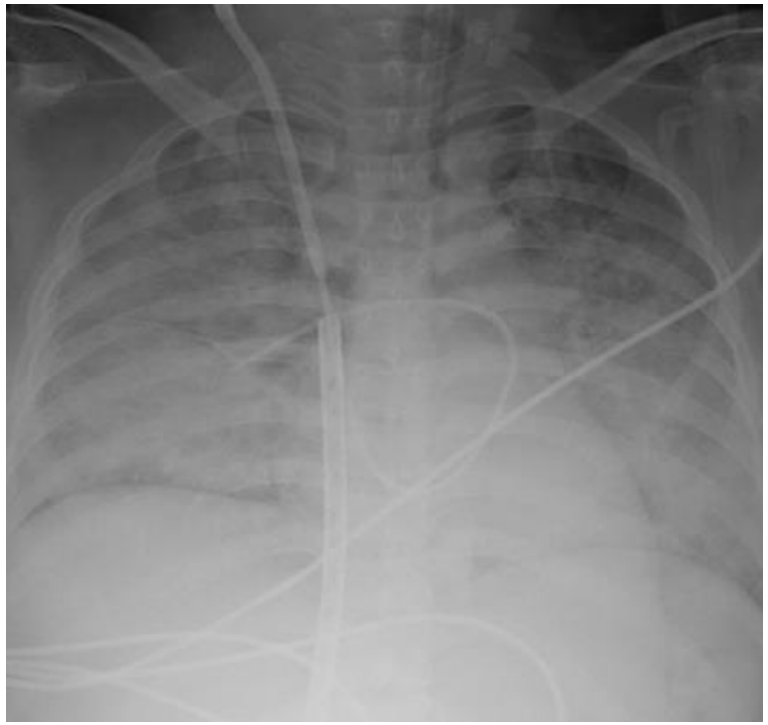

PULMONOLOGIST
CARDIOLOGIST
RIGHT VENTRICLE
Lt

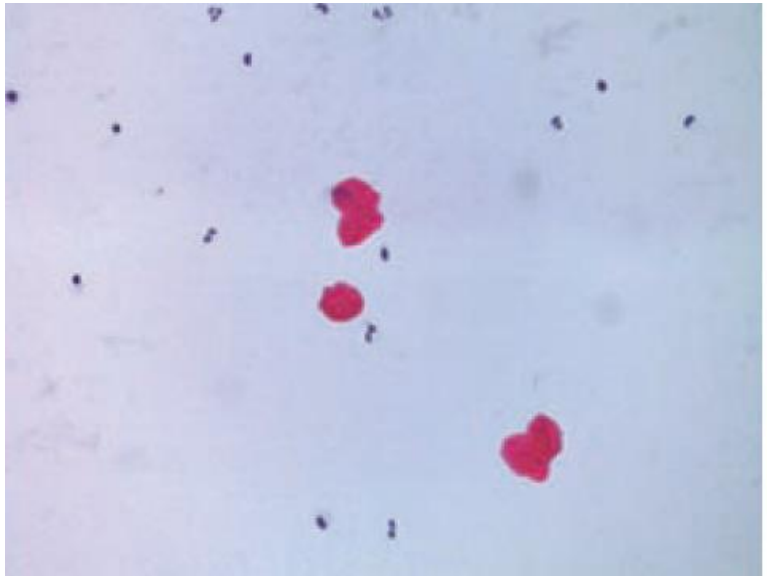

RIGHT
VENTRICLE
LEFT
VENTRICLE

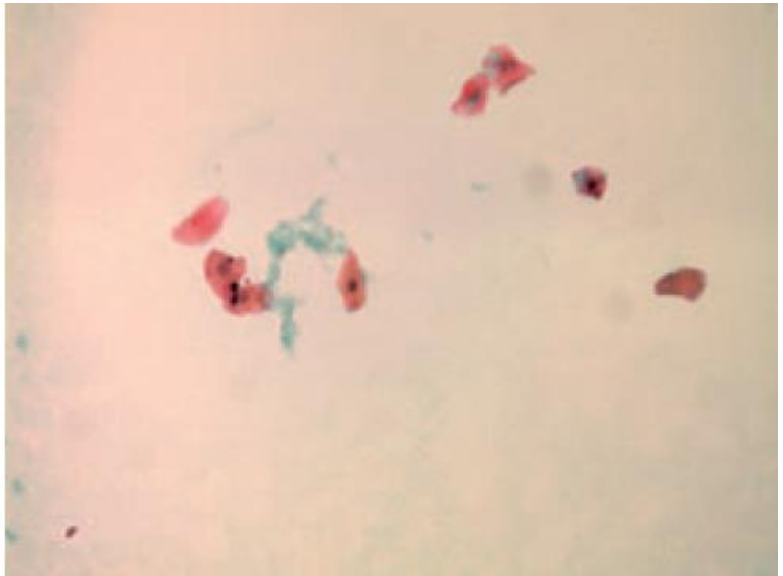

Thank you

Suspected **amniotic fluid embolism**

- Sudden cardiac arrest after delivery
  - on V-A ECMO
  - following ARDS
  - stress induced cardiomyopathy

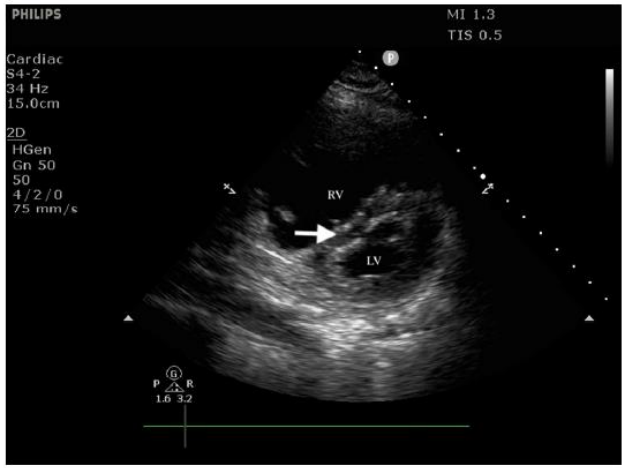


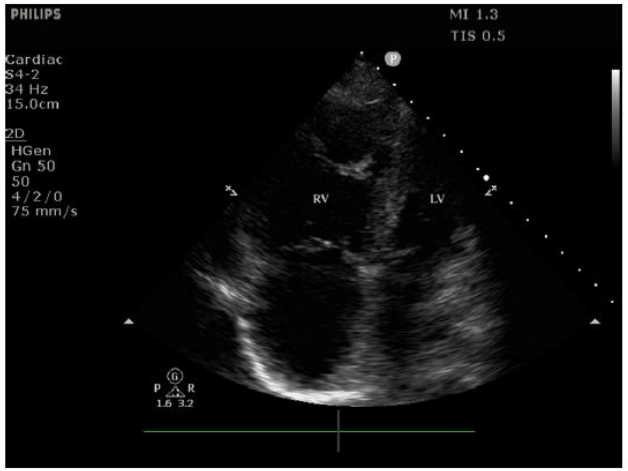




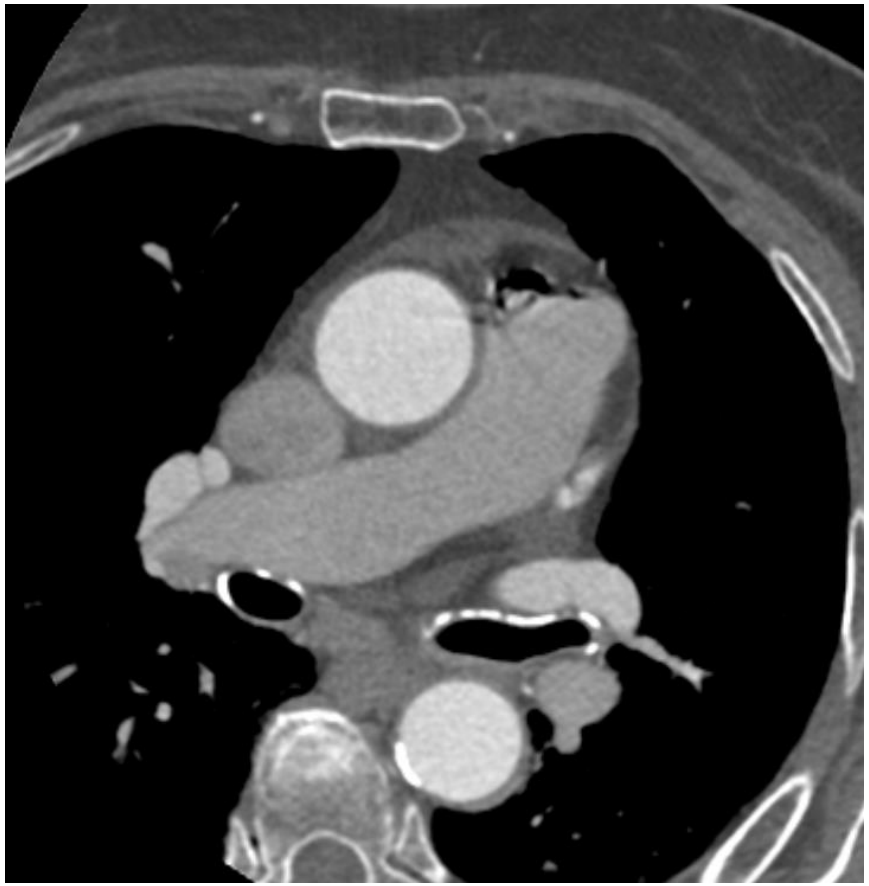
Hemodynamic response - **amniotic fluid embolism**

- Biphasic,
- initial severe pulmonary hypertension and right ventricular failure,
- → followed by LV failure





Transient RV dysfunction – Venous Air embolism



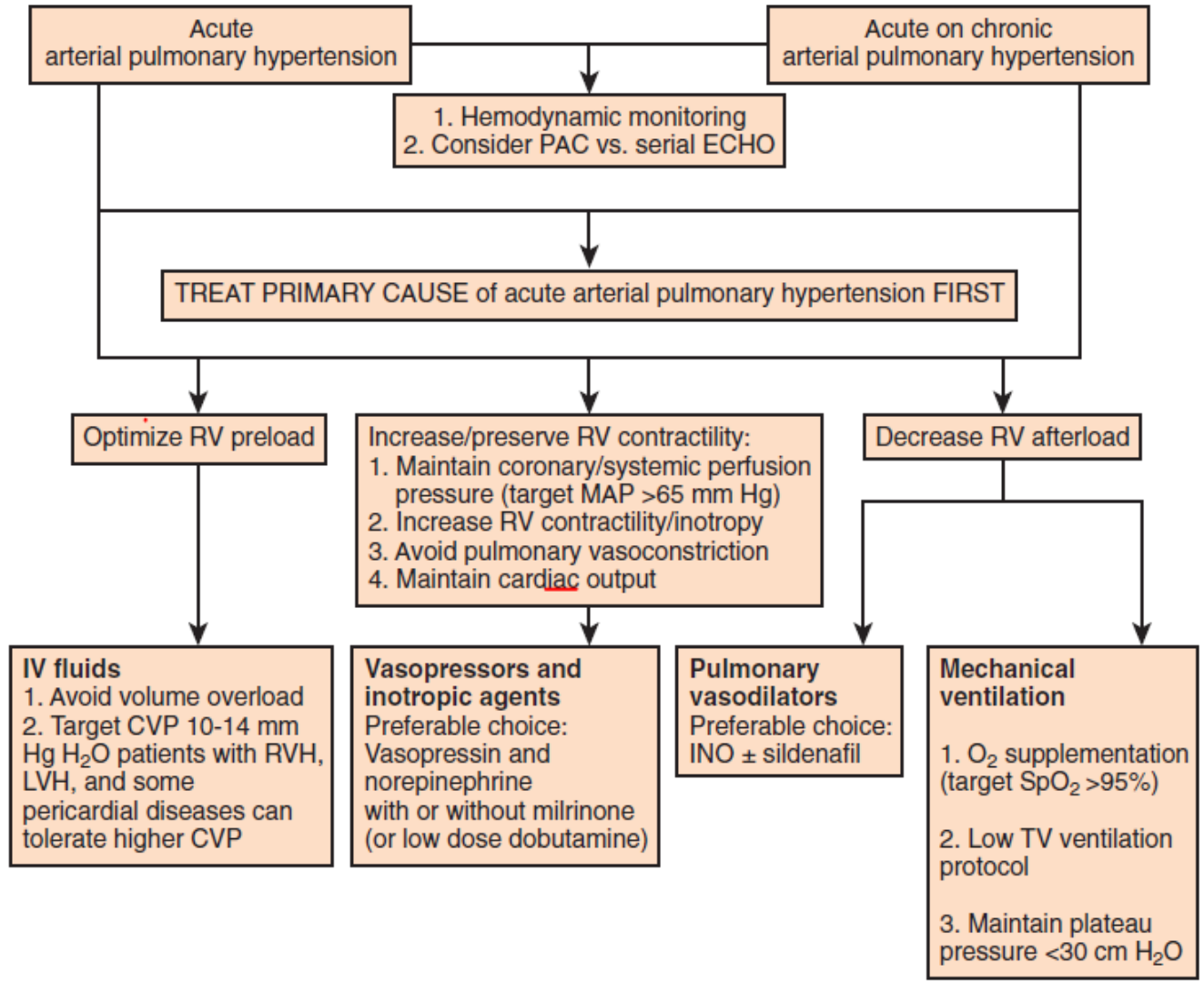
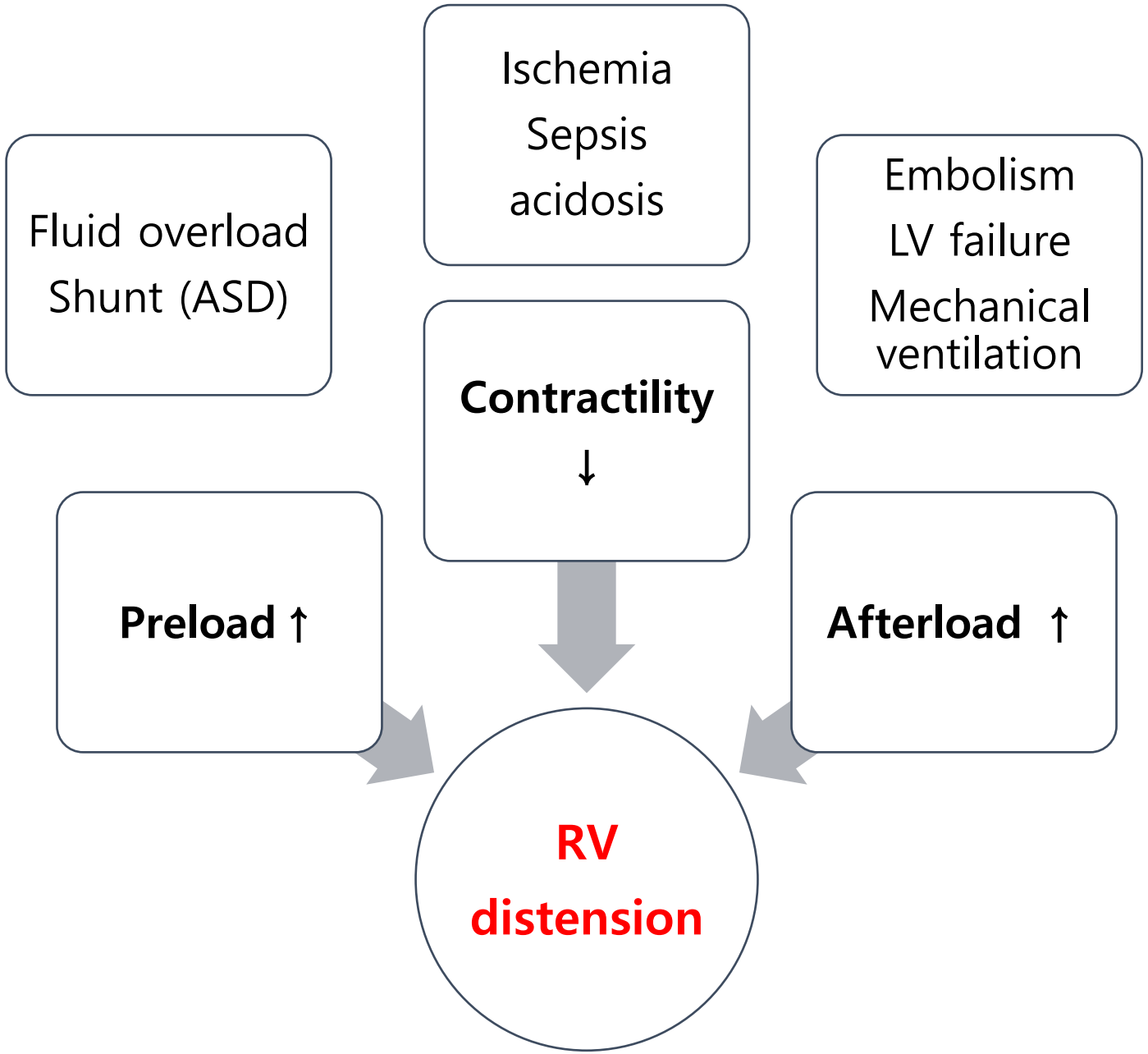
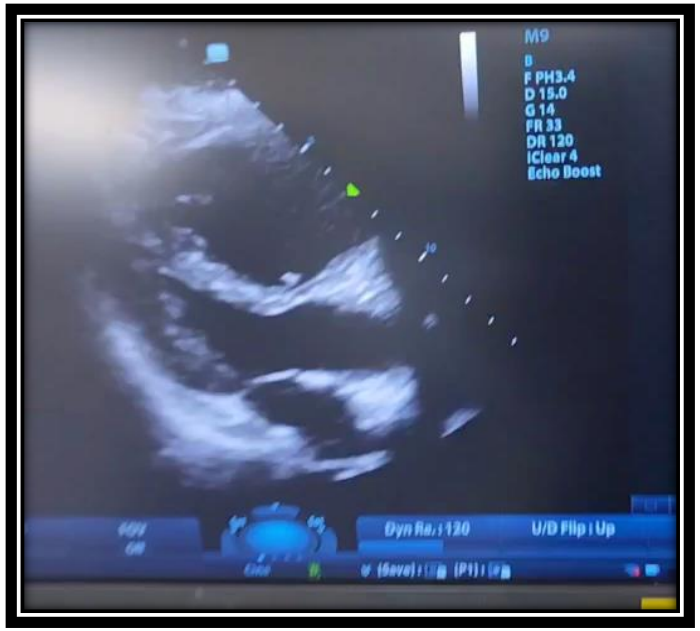


Figure 45.3 Therapeutic approach to pulmonary hypertension in the intensive care unit. CVP, central venous pressure; ECHO, echocardiogram; INO, inhaled nitric oxide; IV, intravenous; LVH, left ventricular hypertrophy; MAP, mean arterial pressure; PAC, pulmonary artery catheter; RV, right ventricle; RVH, right ventricular hypertrophy; Spo_2, oxygen saturation in the blood; TV, tidal volume. (From Tsapenko MV: Arterial pulmonary hypertension in noncardiac intensive care unit. Vasc Health Risk Manage 2008;4:1043-1060.)


Ischemia
Sepsis
acidosis
Fluid overload
Shunt (ASD)
Embolism
LV failure
Mechanical ventilation
Contractility ↓
Preload ↑
Afterload ↑
RV distension

Pulmonary Hypertension in **acute pulmonary embolism**



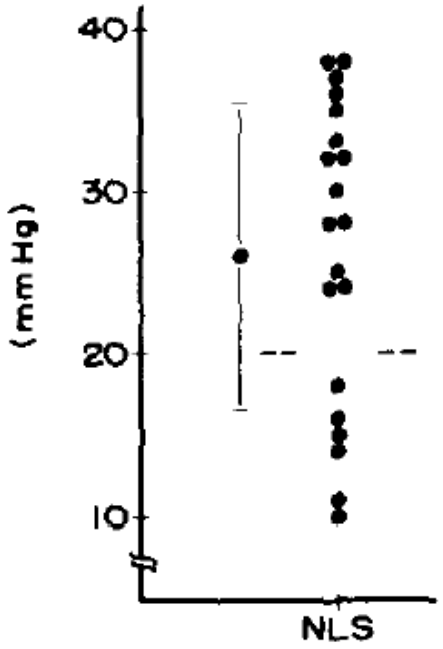
- Angiographic obstruction of PA **>50%** → PAP ↑

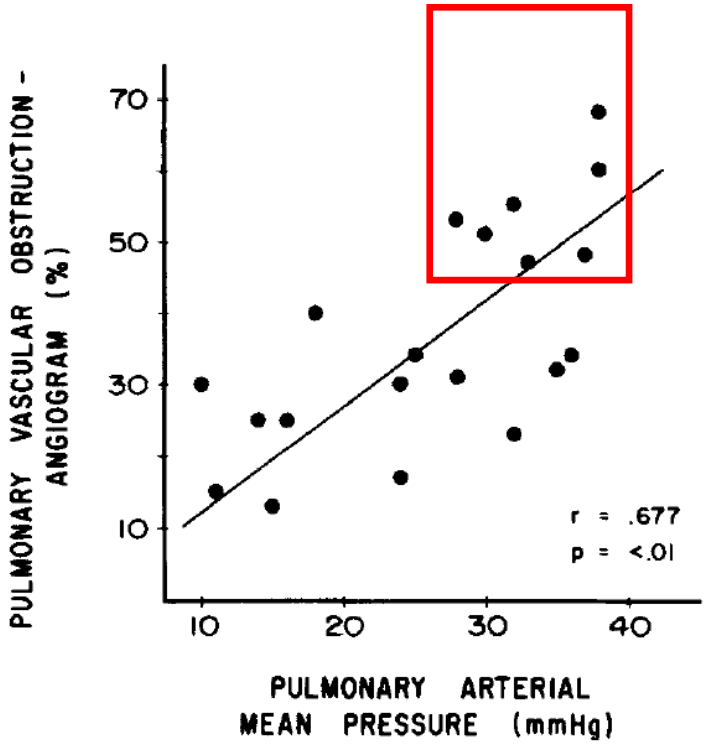
- **"Acute PE never resulted in mean PAP > 40 mm Hg in previously healthy patients"**

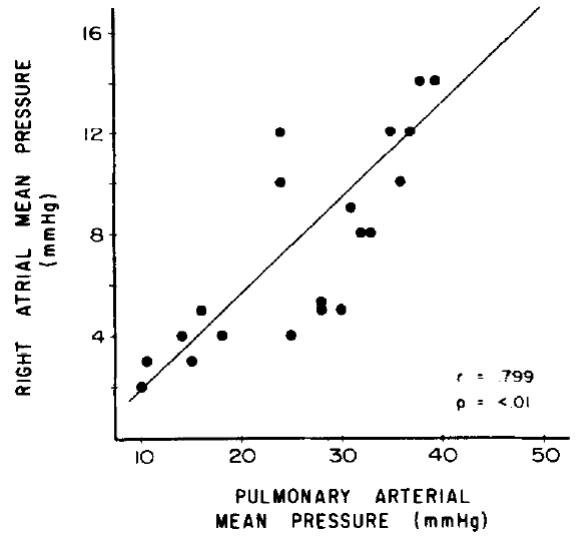
- maximum upper limit that a non-adapted right ventricle can generate when exposed to an acutely increased afterload.

Hemodynamic response to pulmonary embolism

- Included 20 patients previously healthy



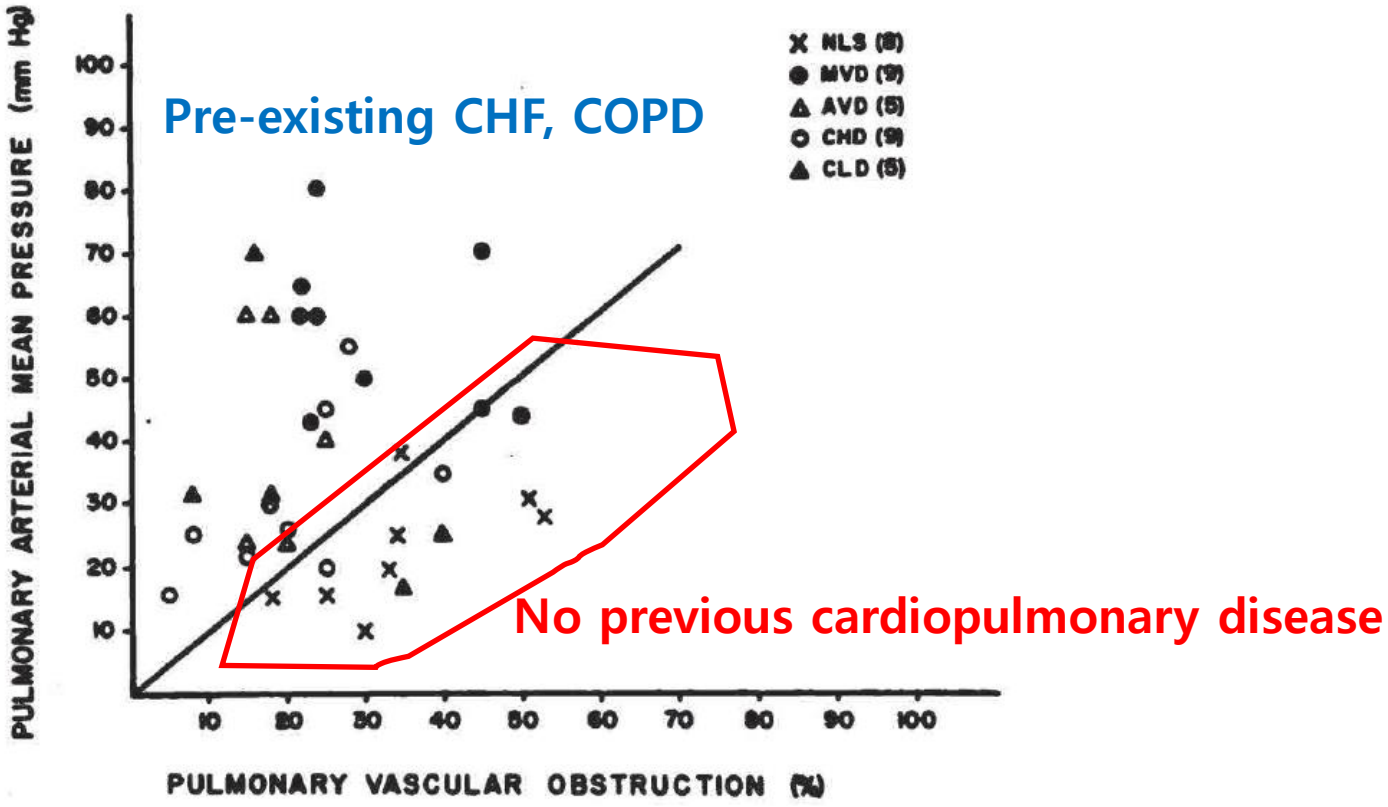




McIntyre KM. et al The hemodynamic response to pulmonary embolism in patients without prior cardiopulmonary disease. Am J Cardiol 1971;28:288–294

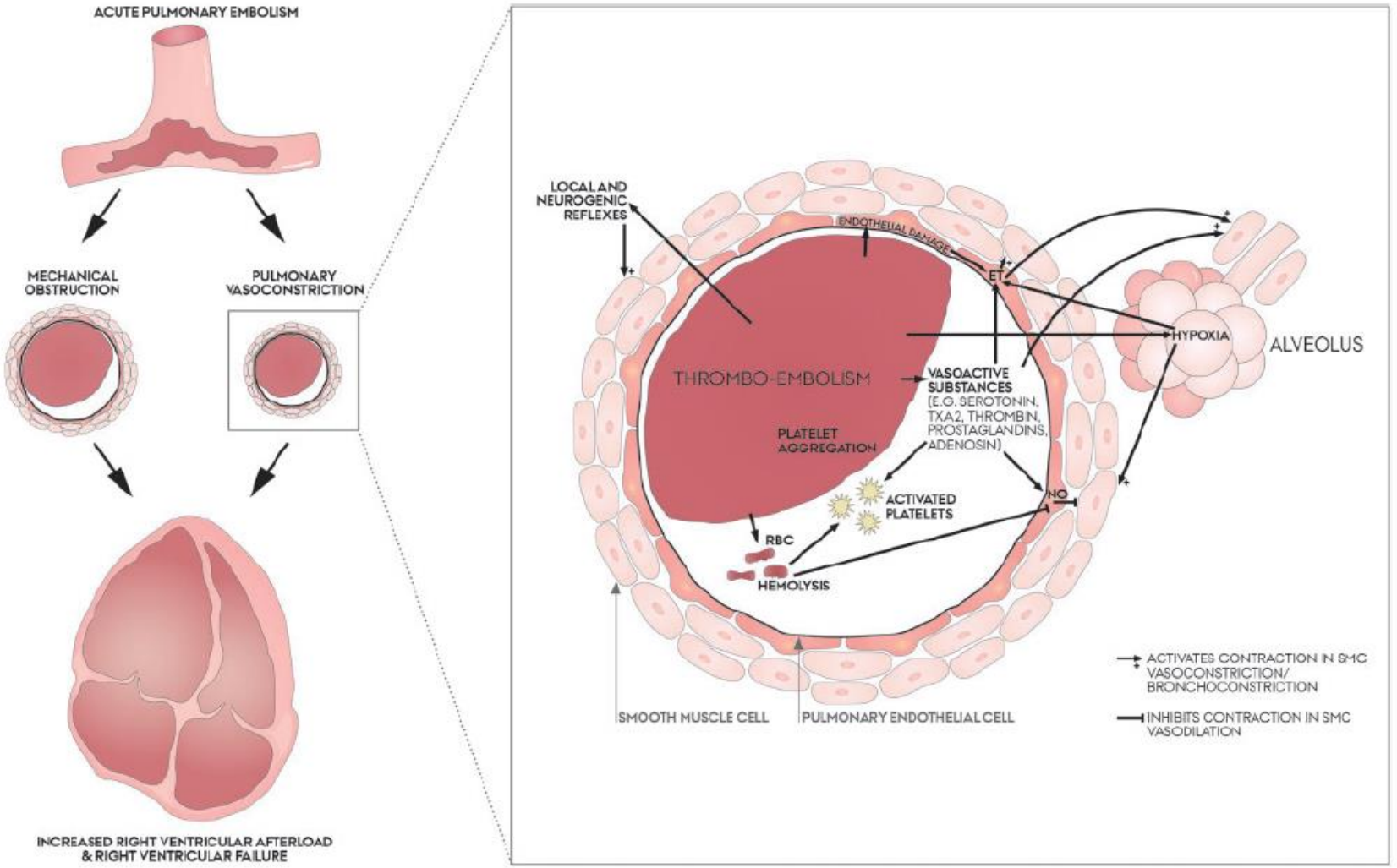
The ratio of PAP to pulmonary vascular obstruction

: With or without previous cardio-pulmonary diseases



McINTYRE, SASAHARA, CHEST, 71: 6, JUNE, 1977

Pulmonary Hypertension in **acute pulmonary embolism**



Lyhne et al, Pulmonary vasodilation in acute pulmonary embolismPulm Circ. 2020 Mar 4;10(1)

Pulmonary vasodilation in acute pulmonary embolism systemic review

- **Inhaled Nitric oxide** → may improve the hemodynamic status

Summary of Outcomes From Analyzed Patients			
Improvement in MAP/CO	**Improvement in PAP/PVR**	**Improvement in PaO^2/ SpO^2**	**Survival From ICU**
14/14 who reported (100%)	6/7 who reported (86%)	16/18 who reported (89%)	14/18 (78%)

CO, cardiac output; ICU, intensive care unit; MAP, mean arterial pressure; PaO^2: partial pressure of oxygen; PAP, pulmonary arterial pressure; PVR, pulmonary vascular resistance; SpO^2: percutaneous oxygen saturation.

- PDE-5 inhibitors
- sCG stimulators/activators
- Prostacycline
- ERA

No recommendation