

Right Heart Dysfunction in Patient with Acute Hypoxemic Respiratory Failure



전 경 만

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Hemodynamic Profile in Severe ARDS

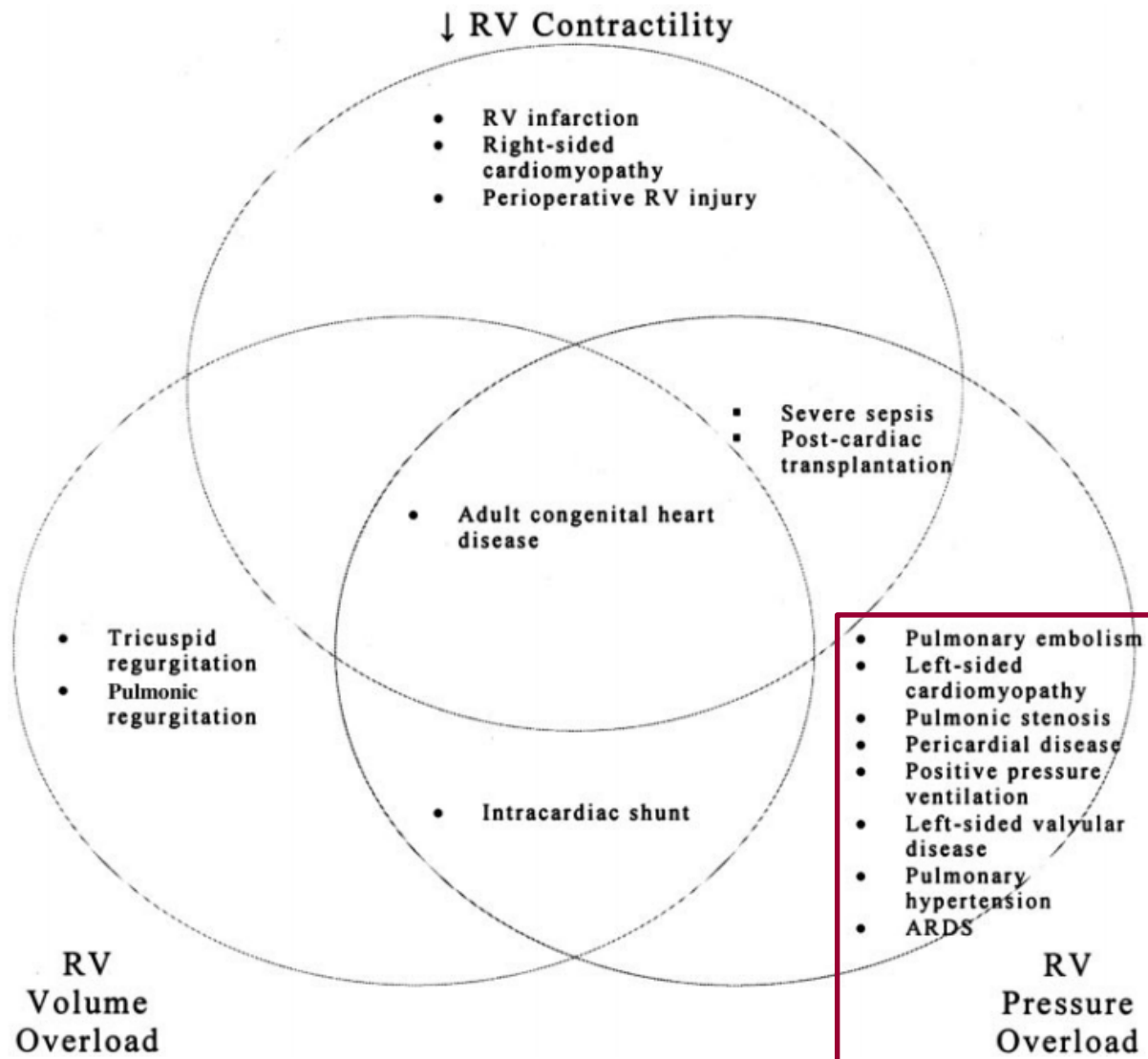
European Collaborative ARDS Study



	Initial Measurement	After 48 h
Number of patients	586	526
HR (beats · min ⁻¹)	115 ± 23	107 ± 22
Pra (mmHg)	10.0 ± 4.8	10.4 ± 5.0
PAOP (mmHg)	11.7 ± 4.5	12.3 ± 4.4
Mean PAP (mmHg)	26.1 ± 8.5	26.7 ± 8.1
Mean SAP (mmHg)	80.9 ± 18.2	84.7 ± 18.0
CI (l · mn ⁻¹ · m ⁻²)	4.18 ± 1.46	4.17 ± 1.39
PVR (dyne · s · cm ⁻⁵ · m ⁻²)	257 ± 140	265 ± 140
SVR (dyne · s · cm ⁻⁵ · m ⁻²)	1404 ± 663	1450 ± 660
RVSWI (g · m · m ⁻²)	8.5 ± 5.1	9.2 ± 5.2
LVSWI (g · m · m ⁻²)	36.8 ± 16.8	41.1 ± 20.1
RVSW/LVSW (%)	25 ± 15	24 ± 13

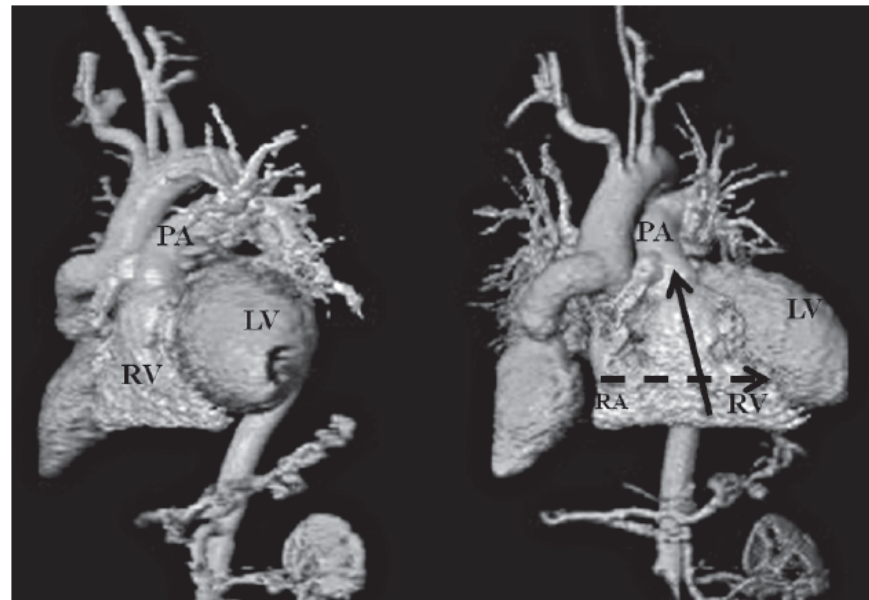
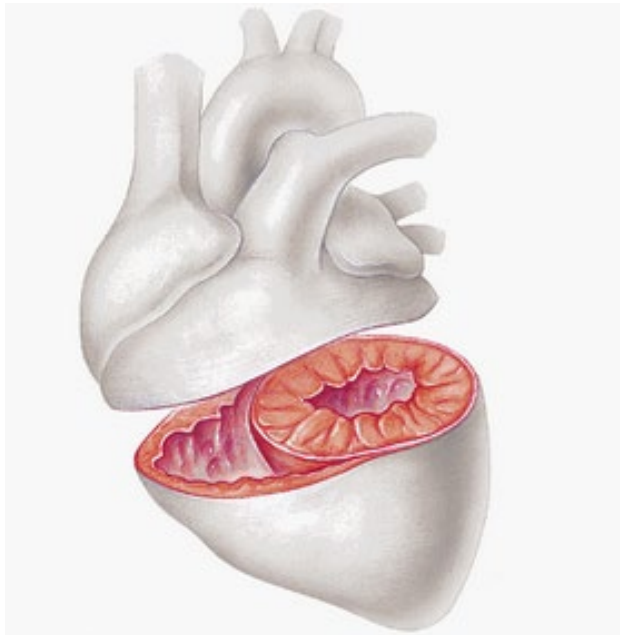
Acutely Decompensated Right Ventricle

Categorized by Initial Pathophysiology



RV Characteristics

- Two chambers wrapping the left ventricle
 - The filling chamber is in a posterior-anterior axis and has a **triangular shape**
 - The outflow chamber looks like a **crescent** in an inferior-superior axis
 - ▶ **Low-resistance and high-compliance system: very sensitive to any slight increase in pulmonary vascular resistance**



Various Definitions of RV Dysfunction/Failure

- There are **various definitions** for RV dysfunction/failure in the literature, with the terms being used interchangeably at times.
 - **RV dysfunction:** the parameters to quantify **RV function are less than the lower value of the normal range**
 - Tricuspid annular plane systolic excursion (TAPSE) < 17 mm
 - Pulsed Doppler S wave < 9.5 cm/s
 - RV fractional area change (RVFAC) < 35%
 - RV ejection fraction < 45%

American Society of Echocardiography and the European Association of Cardiovascular Imaging
J Am Soc Echocardiogr 2015;28:1
 - **RV failure:** **the inability of the RV to provide adequate blood flow** through the pulmonary circulation at a normal CVP

Crit Care Med 2008;36:S57

Acute Cor Pulmonale

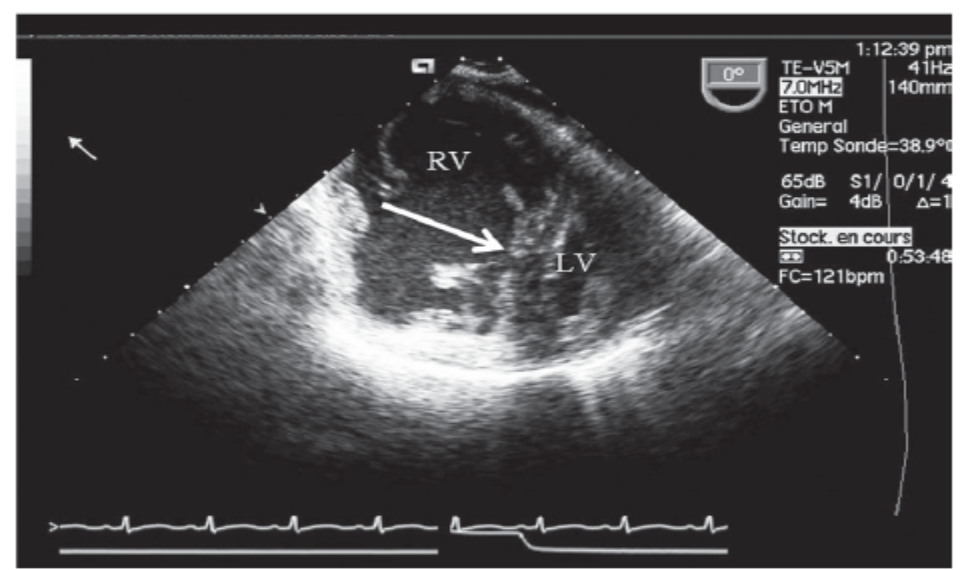
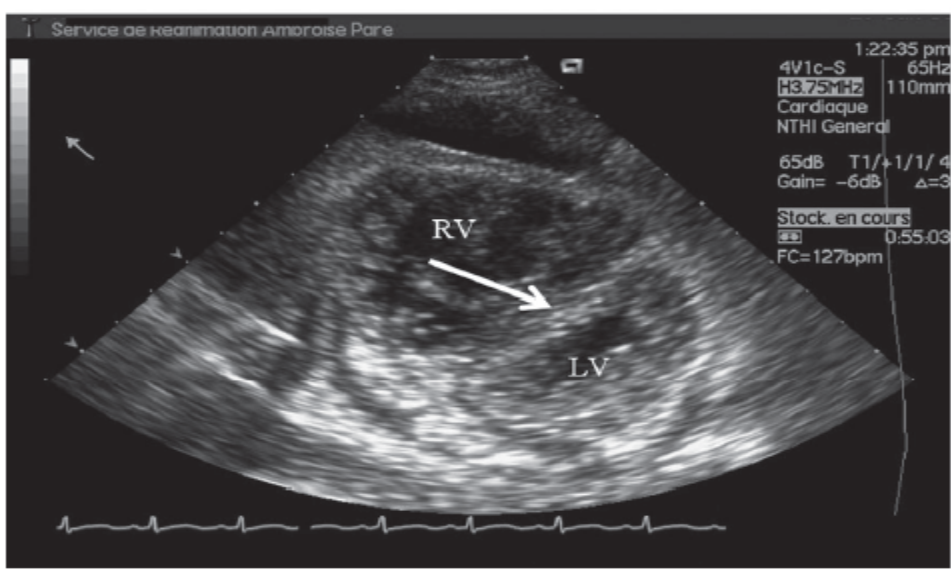
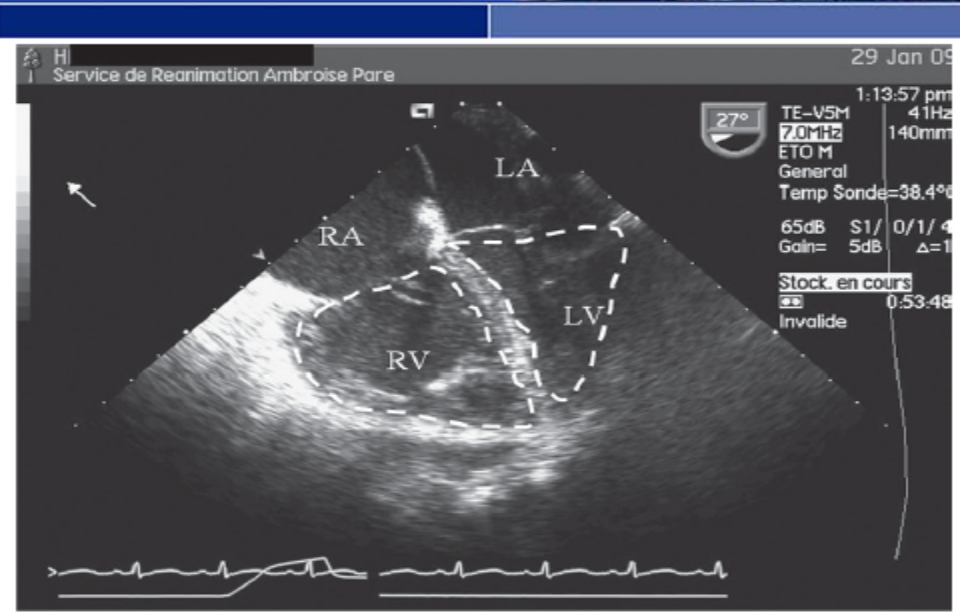
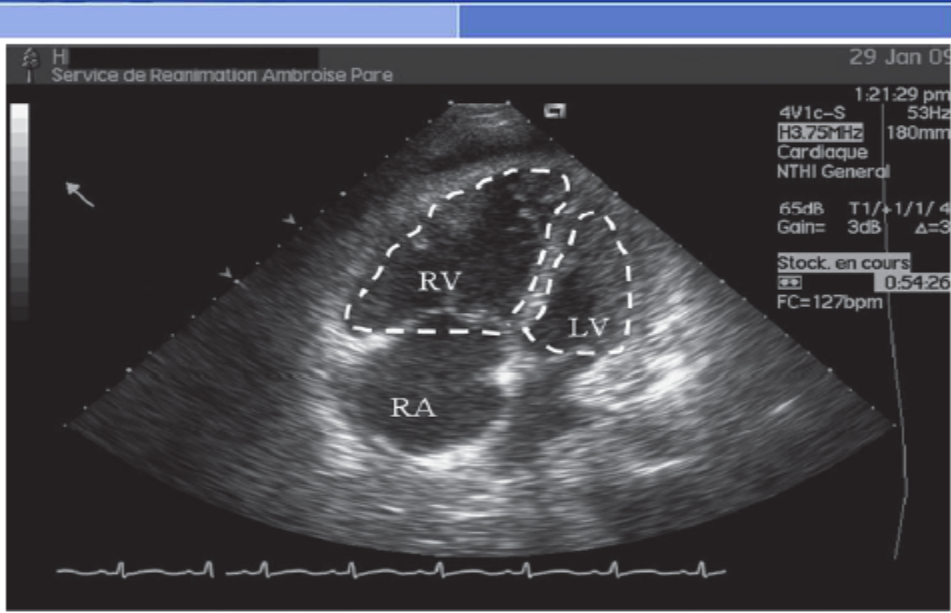


- Acute cor pulmonale (ACP): acute dilatation or dysfunction (or both) of the RV in the context of acute lung disease (eg, ARDS) and associated pulmonary vascular dysfunction
 - Form of RV dysfunction that is due to an acute increase in RV afterload that may lead to RVF
 - Defined echocardiographically as **septal dyskinesia with a ratio of RV end-diastolic area (RVEDA) to LV end-diastolic area (LVEDA) > 0.6**

Chest 1997;111:209



Echocardiographic Findings of ACP



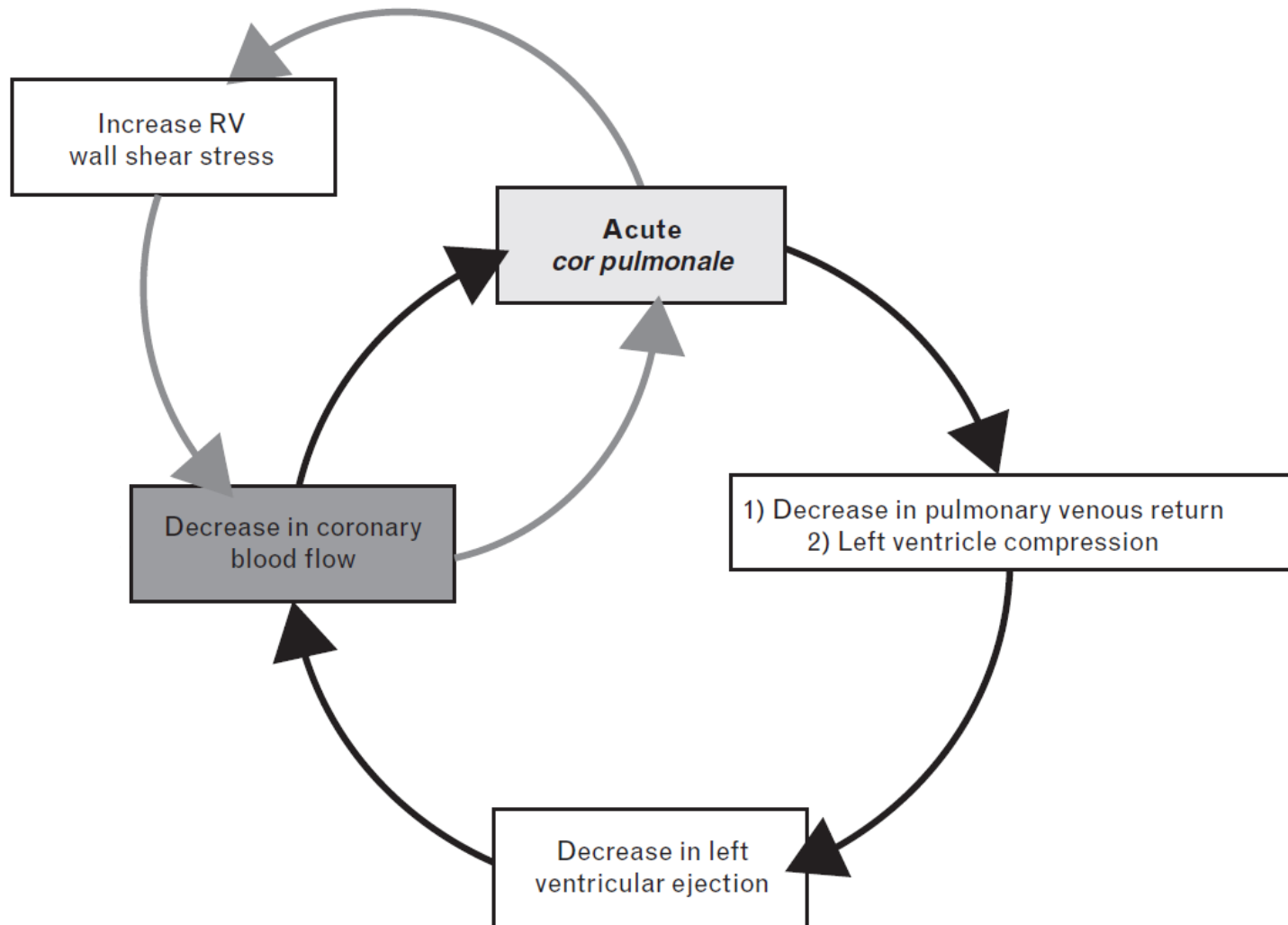
Acute Cor Pulmonale in ARDS

In the Past



Study	Year	No.	Diagnosis	ACP prevalence	Outcome
Jardin et al	1985	23	TTE	22%	NA
Vieillard-Baron et al	2001	75	TEE	25%	RVF reversible in survivors
Cepkova et al	2007	42	TTE	7%	Not predictive of increased mortality
Jardin et al	2007	196	TTE	13%	Not contribute to increased mortality
Osman et al	2009	145	PAC	9.6%	Not predictive of mortality
Mekontso et al	2011	203	TEE	22%	NA
Boissier et al	2013	226	TTE	22%	Not predictive of increased mortality
Lhéritier et al	2013	201	TTE/TEE	22.5%	Not contribute to increased mortality

Ischemic Vicious Circles of Acute Cor Pulmonale



Impact of Acute Cor Pulmonale on Outcome

Recent Reports on ACP in ARDS

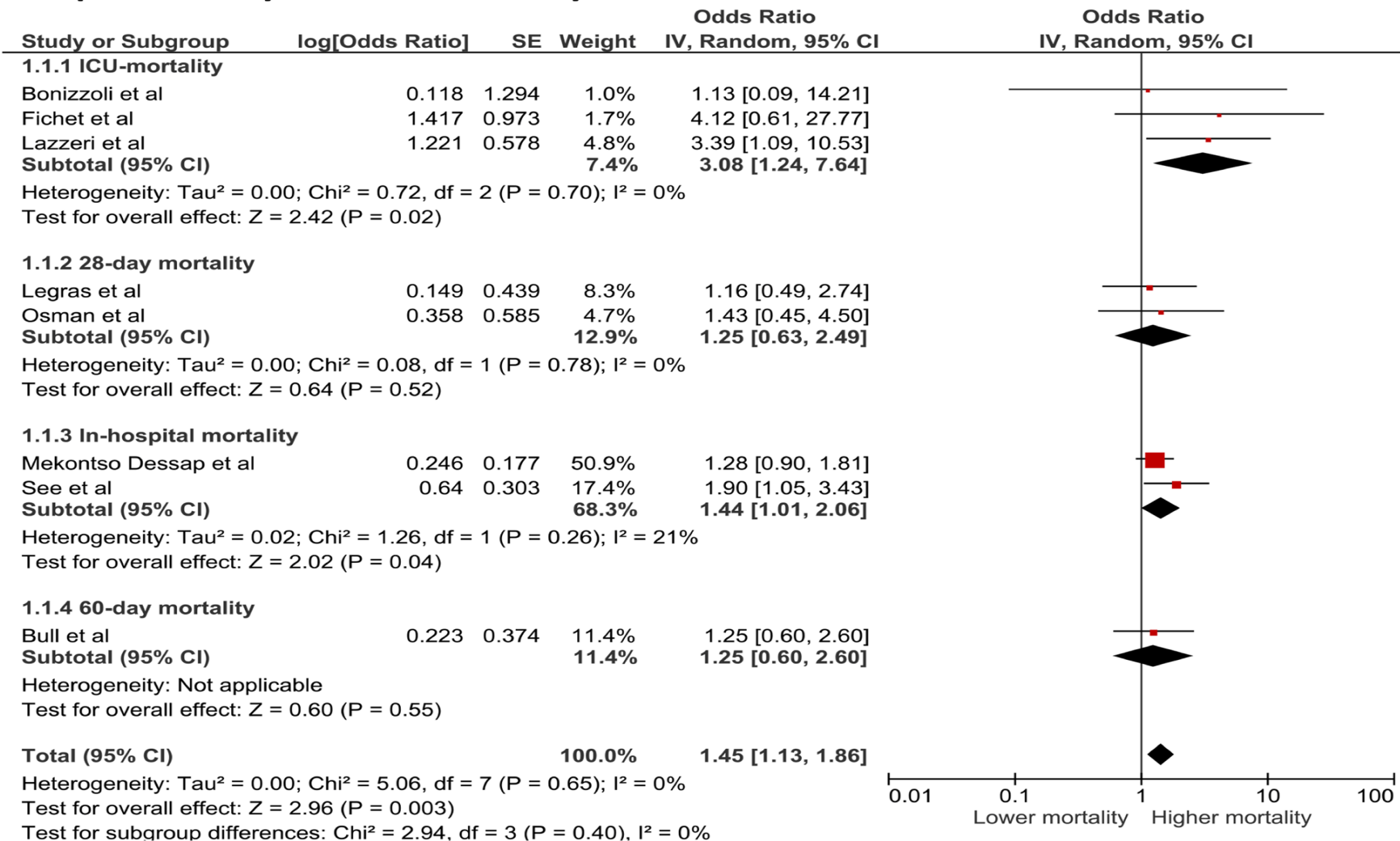
Study	Year	No.	Diagnosis	ACP prevalence	Outcome
Bull et al	2010	501	PAC	12%	Increase mortality
Guervilly et al	2012	16	TEE	56%	Increase mortality
Lazzeri et al	2016	21	TTE/TEE	47.6%	Increase mortality
Mekontso Dessap et al	2016	752	TEE	22%	Increase mortality
Shah et al	2016	38	TTE	55%	Increase mortality
Wadia et al	2016	14	TTE	42.9%	Increase mortality
See et al	2017	234	TTE	28.2%	Increase mortality
Bonizzoli et al	2018	28	TTE	89%	Increase mortality
Zelton et al	2018	45	TTE	22.2%	Increase mortality

Impact of RV Injury on Outcome

Systematic Review in ARDS



The pooled analysis for the mortality



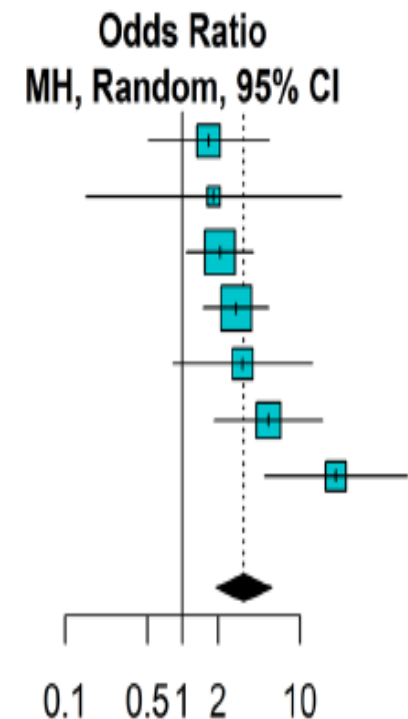
Impact of RV Injury on Outcome

Systematic Review in COVID-19



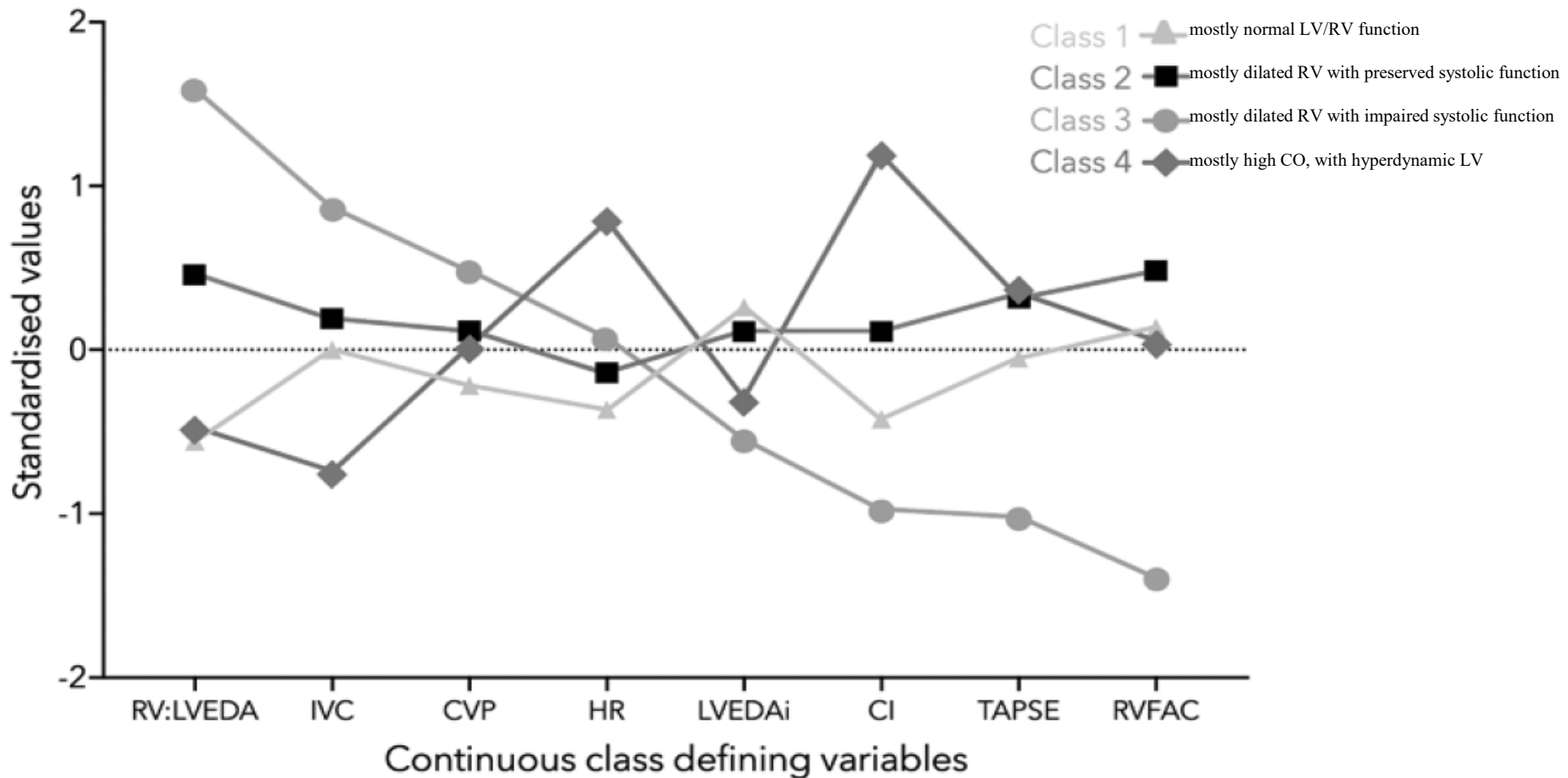
Study	RVD		No RVD		Weight	Odds Ratio	
	Events	Total	Events	Total		MH, Random, 95% CI	
Pagnesi 2020	4	29	15	171	13.1%	1.66	[0.51; 5.42]
Calderon-Esquivel 2020	1	4	4	26	4.1%	1.83	[0.15; 22.37]
Moody 2020	30	58	36	106	23.1%	2.08	[1.08; 4.00]
Chotalia 2021	46	87	24	85	23.6%	2.85	[1.51; 5.37]
Rath 2020	4	17	7	81	10.8%	3.25	[0.83; 12.71]
Li Y 2021	12	27	8	62	14.8%	5.40	[1.87; 15.62]
D'alto 2020	12	15	13	79	10.4%	20.31	[5.02; 82.18]
Total (95% CI)		237		610	100.0%	3.32	[1.94; 5.70]

Heterogeneity: $\tau^2 = 0.2162$; $\chi^2 = 10.70$, $df = 6$ ($P = 0.10$); $I^2 = 44\%$



Cardiovascular Subphenotypes in ARDS

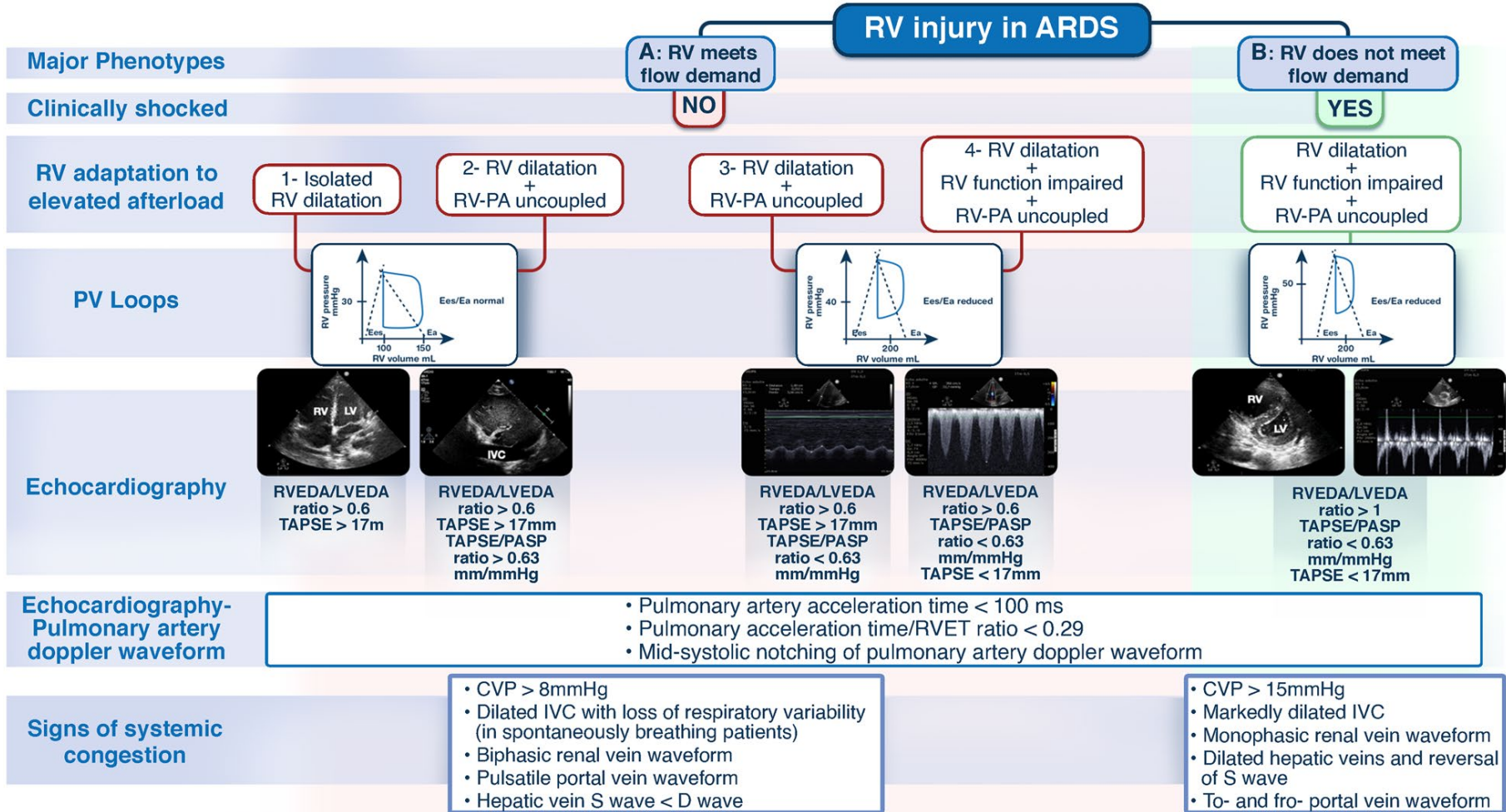
LCA of TTE/Hemodynamic Parameters



► The four subphenotypes differed in their characteristics and outcomes, with 90-day mortality rates of 19%, 40%, 78%, and 59% in classes 1–4.

RV Injury Phenotype of ARDS

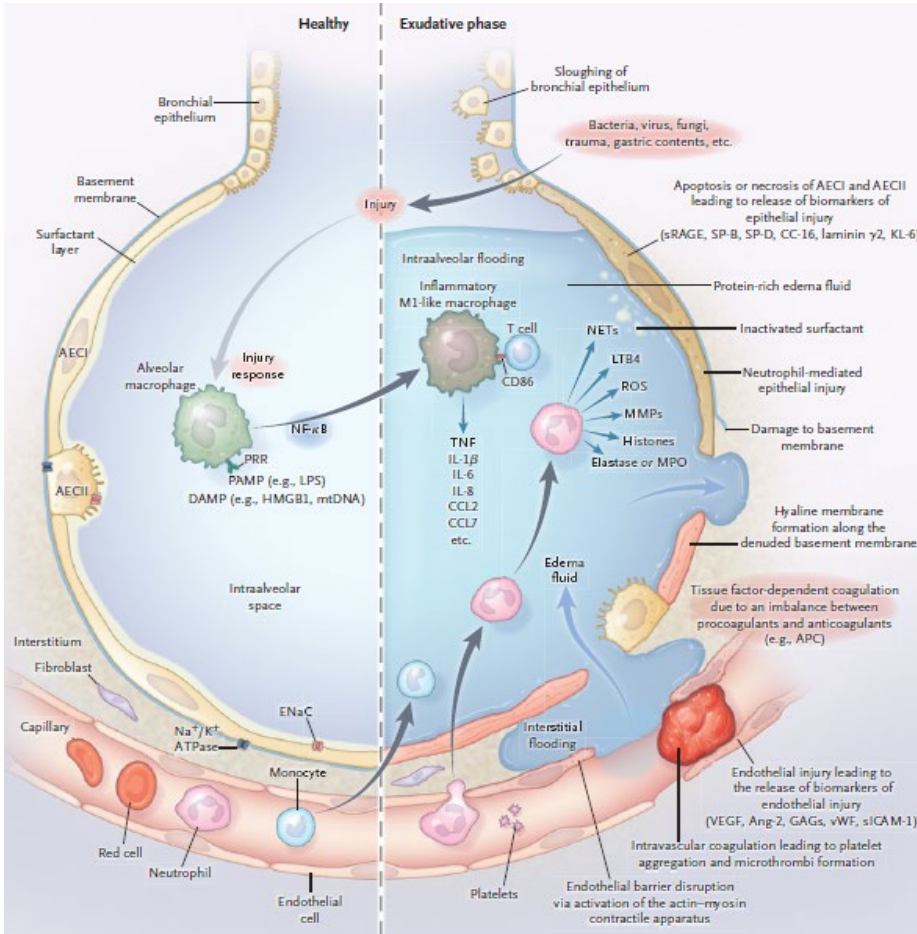
Protecting the Right Ventricle Network (PRORVnet)



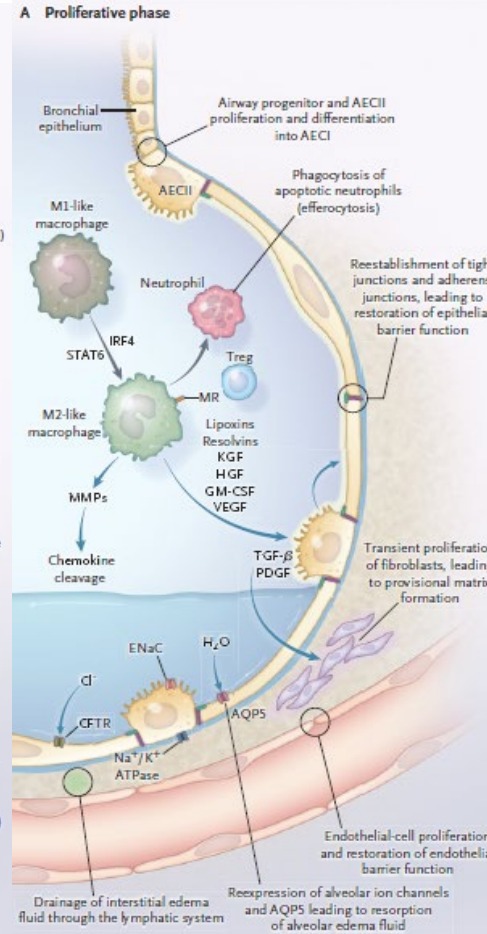
Pathophysiologic Changes of ARDS



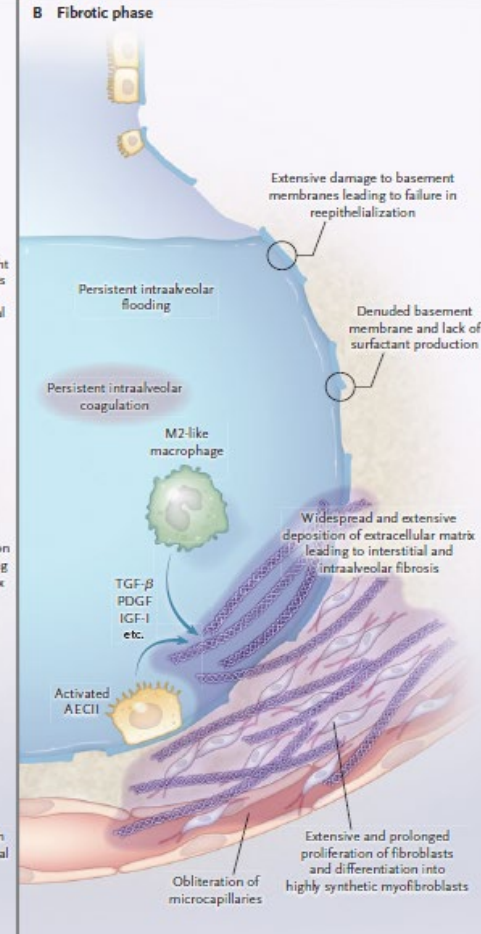
Exudative phase



Proliferative phase



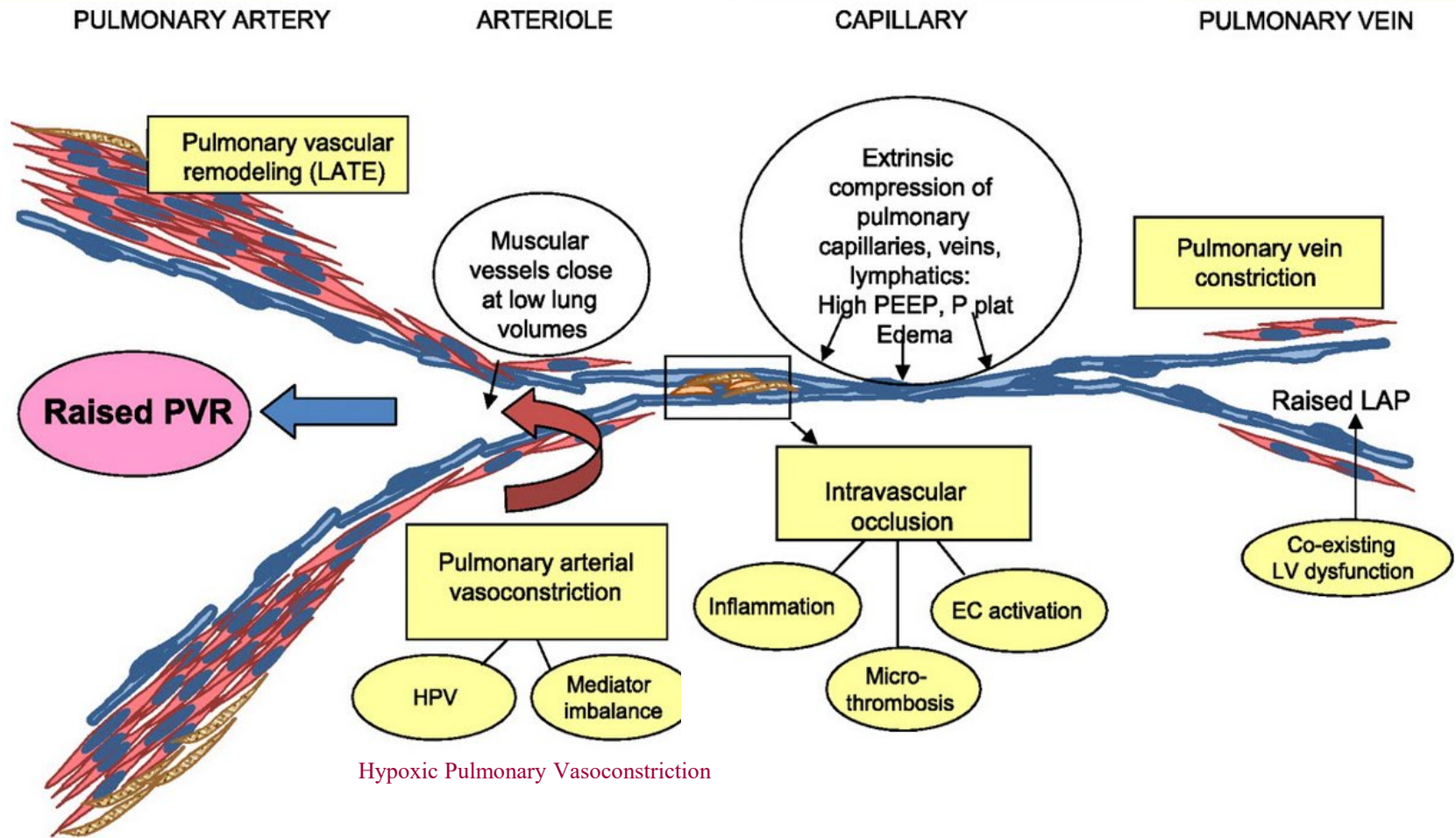
Fibrotic phase



Fibroproliferative phase of ARDS are often accompanied by persistent hypoxemia, low lung compliance, high dead space, and sometimes by **progressive pulmonary hypertension**.

Pathophysiology of ACP in ARDS

1. Increased Pulmonary Vascular Resistance (PVR)

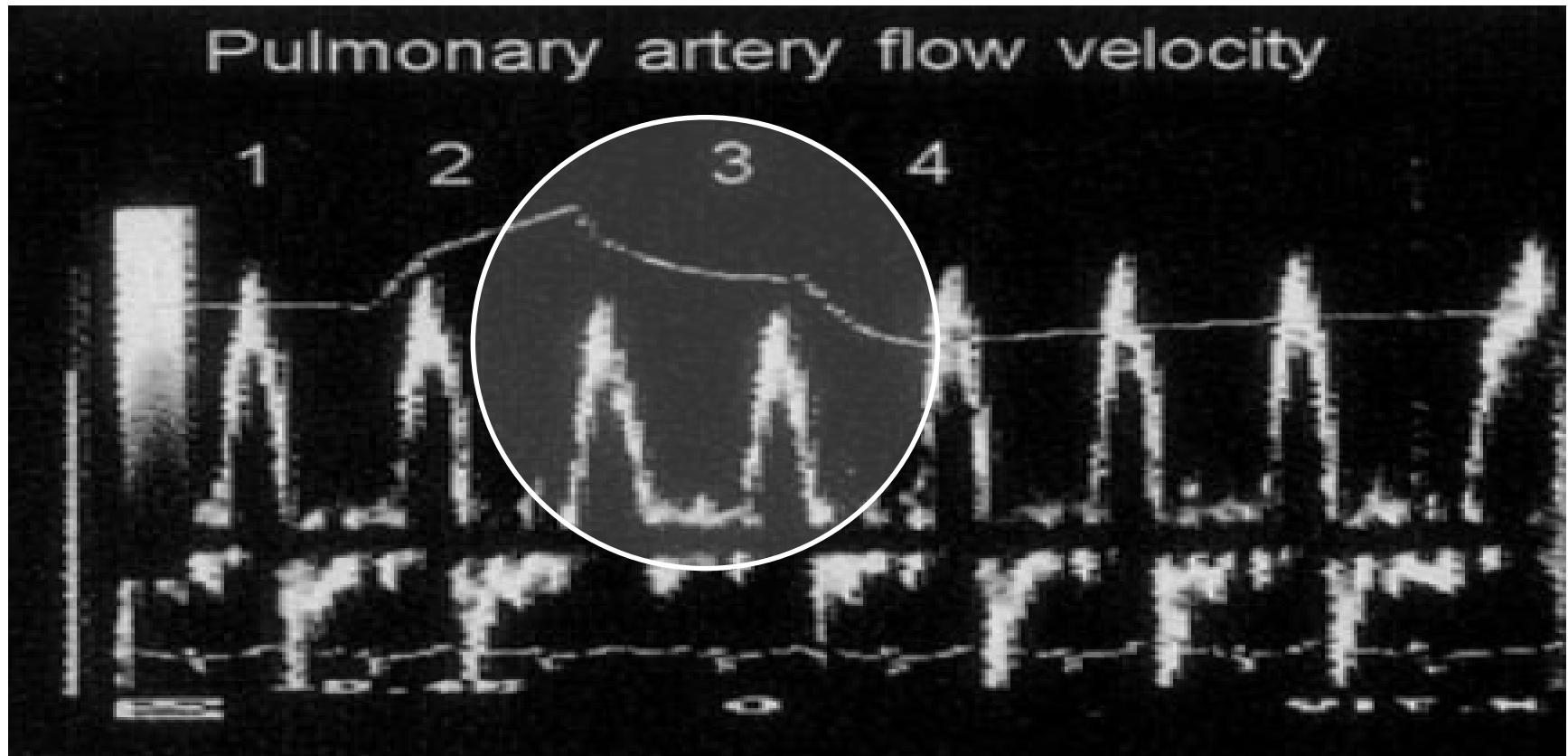


► Pathophysiological changes occurring within the pulmonary vasculature in ARDS

Am J Physiol Lung Cell Mol Physiol 2012;302: L803

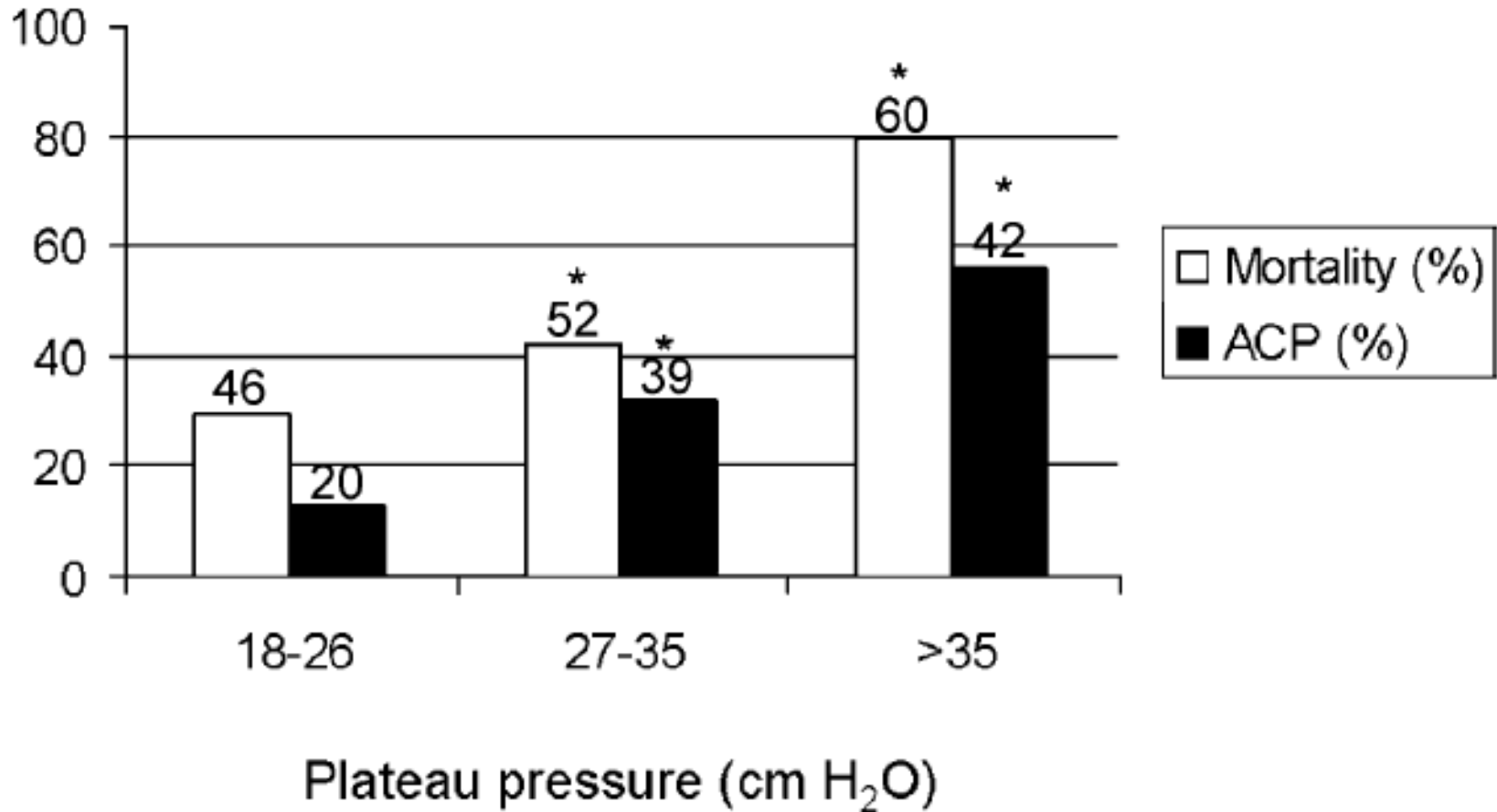
Effect of MV on RV Outflow

Increase in RV Outflow Impedance



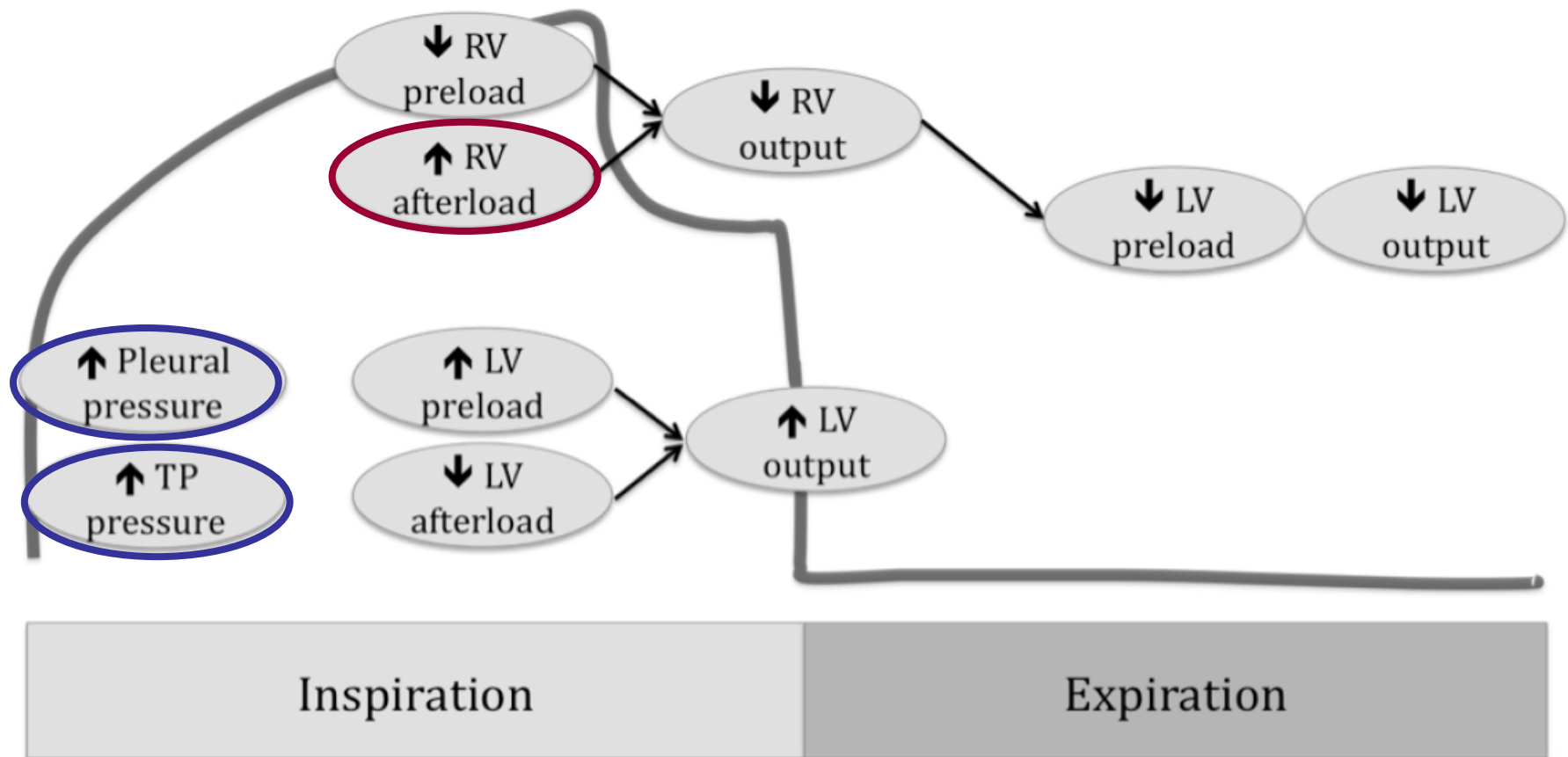
► Lung inflation during the inspiratory phase of MV produces a drop in pulmonary artery flow at end inspiration. This drop occurs without reduction in right atrial diameter or in RV diastolic dimensions.

Development of ACP by Plateau Pressure



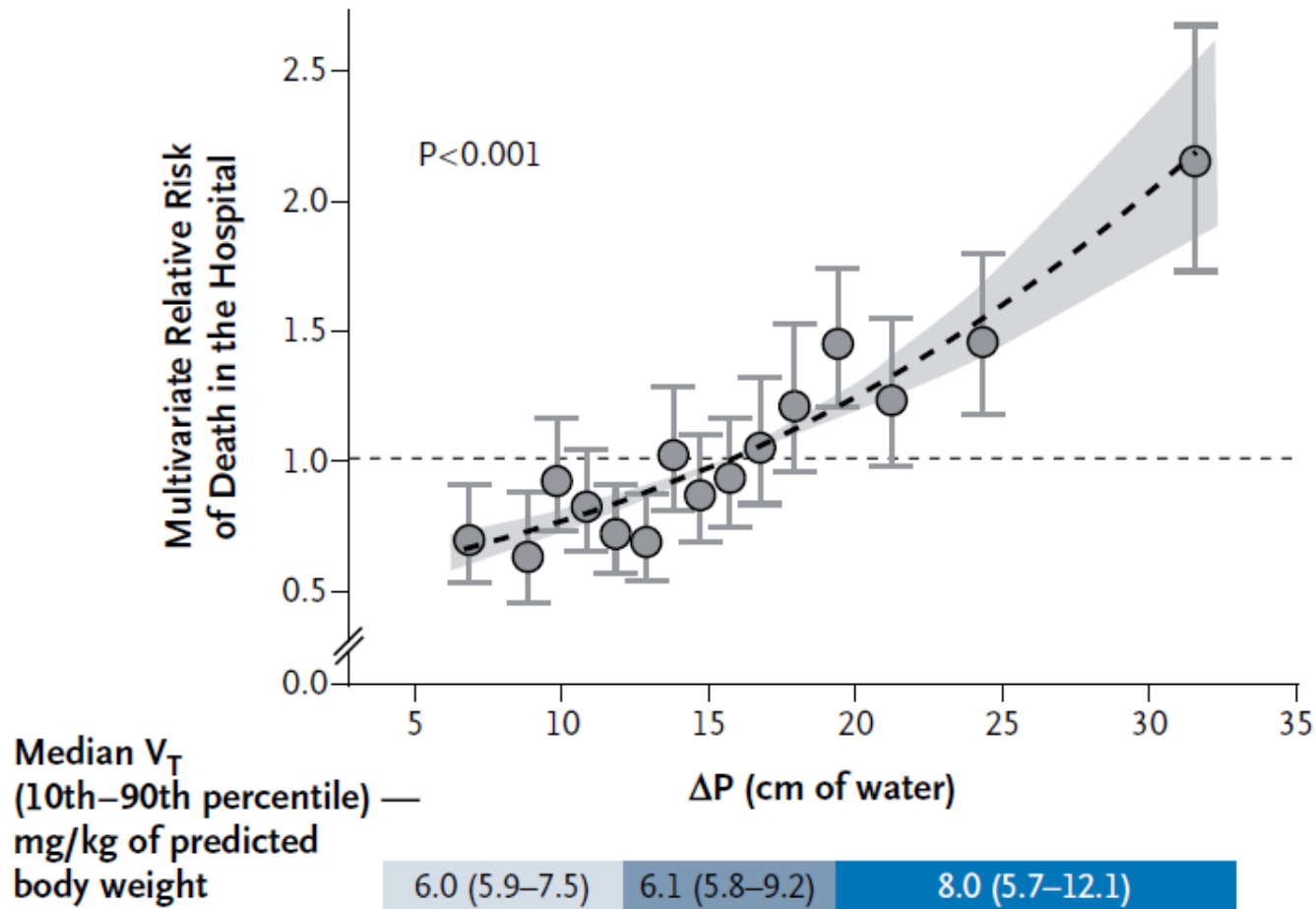
Pathophysiology of ACP in ARDS

2. Positive Pressure Ventilation (Driving Pressure)



► Positive-pressure MV causes an increase in driving or transpulmonary pressure, which acts as a back pressure for pulmonary venous return and may increase RV afterload.

Driving Pressure on Mortality in ARDS



► Decreases in ΔP owing to changes in ventilator settings were **strongly associated with increased survival**.

LPV with Permissive Hypercapnia



- Limitation of tidal volumes and airway pressure is now used as a lung protective strategy during MV in patients with ARDS.
 - This strategy can sometimes result in high PaCO₂.

Low mortality associated with low volume pressure limited ventilation with permissive hypercapnia in severe adult respiratory distress syndrome

K.G. Hickling, S. J. Henderson and R. Jackson

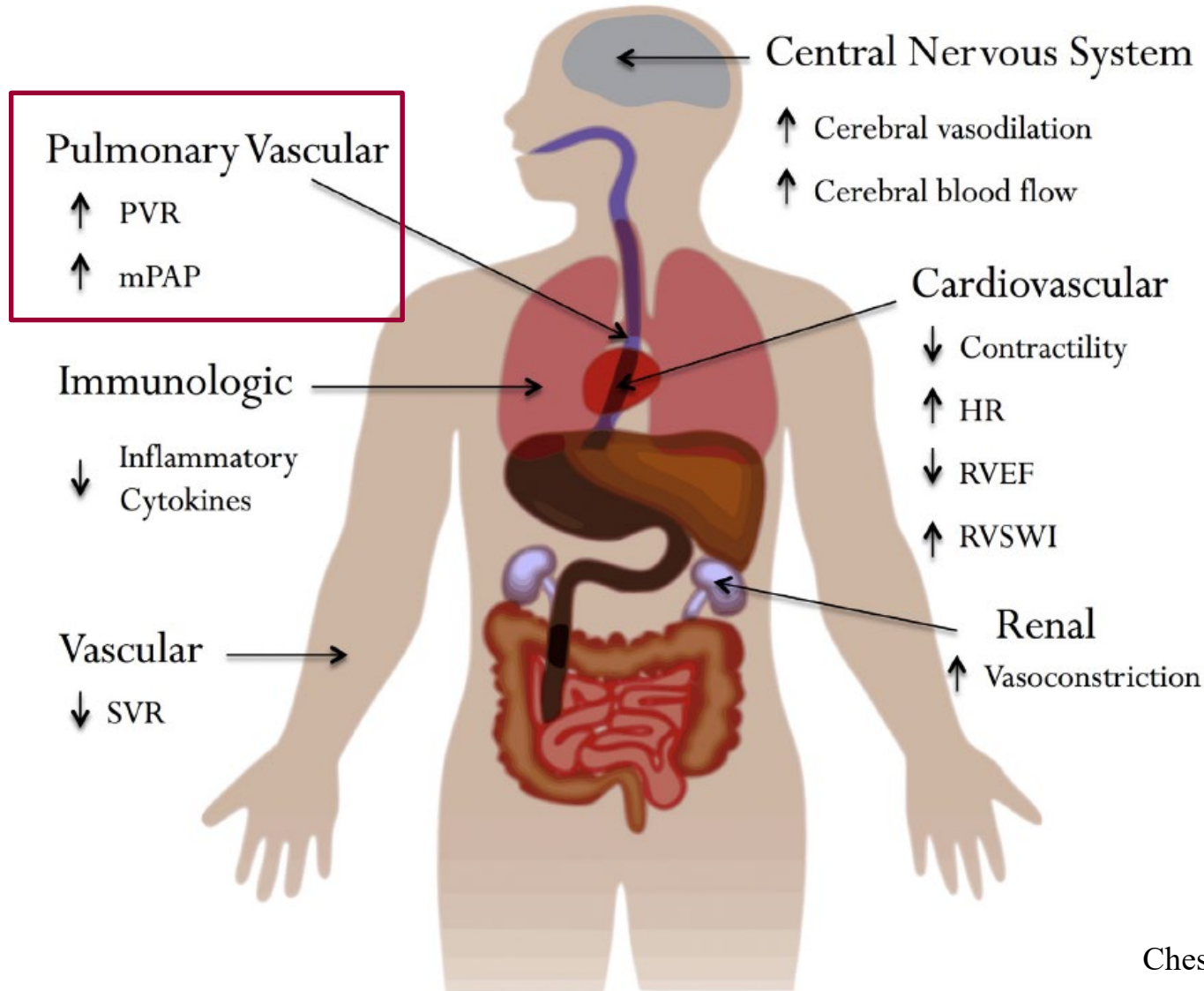
Departments of Intensive Care and Radiology, Christchurch Hospital, Christchurch, New Zealand

Intensive Care Med 1990;16:372

- In the early 1990s, the concept of permissive hypercapnia was proposed for patients with ARDS, to facilitate low-tidal volume ventilation.
- It was even suggested that “therapeutic hypercapnia” might be beneficial.
- ▶ However, more recent studies have reported that hypercapnia has harmful effects.

Intensive Care Med 2017;43:200

Hypercapnia Induces Physiological Changes In Pulmonary and Systemic Circulations



Association of Hypercapnia with ACP

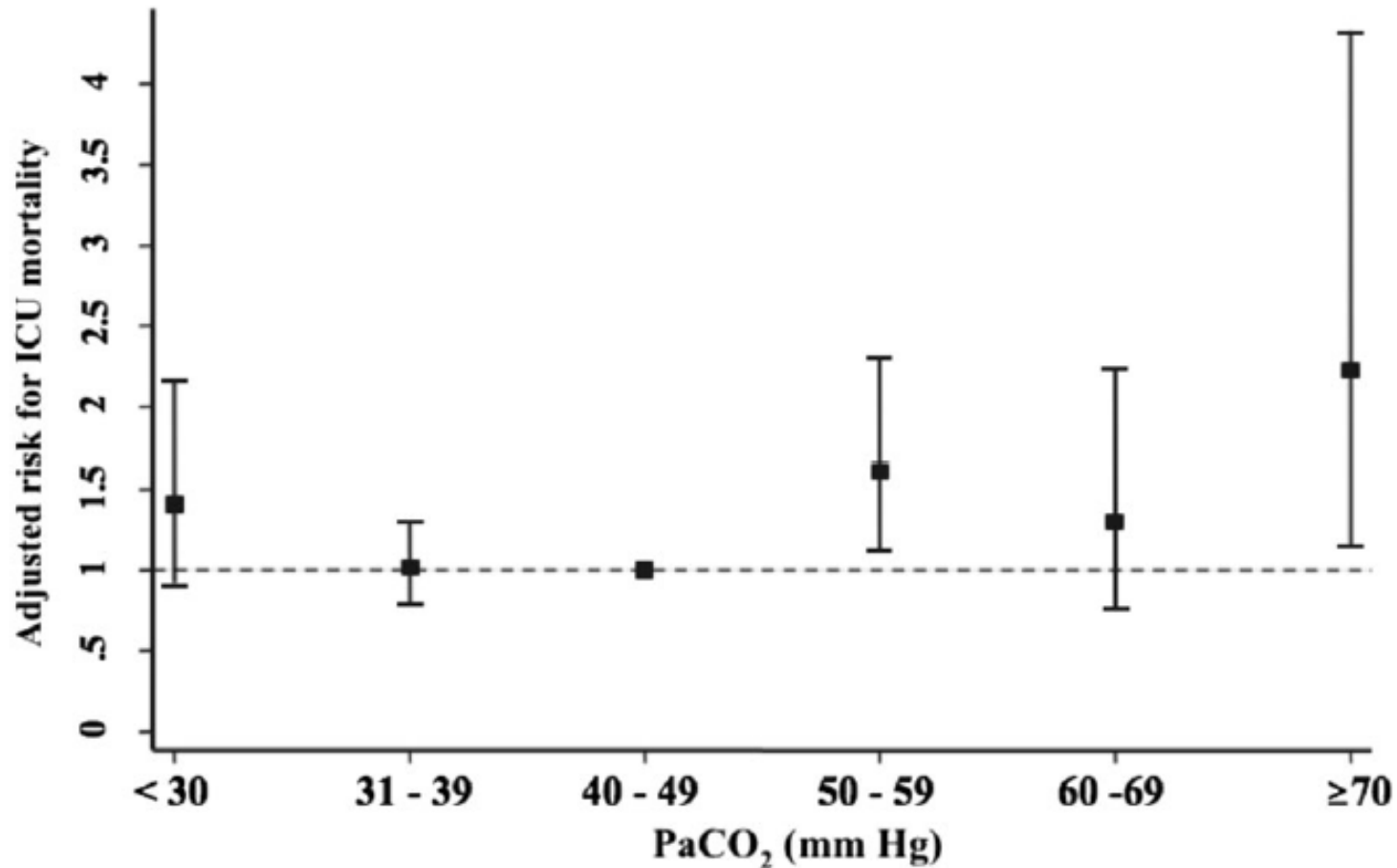


Study	Design	Results
Vieillard-Baron et al, 2001	Prospective single center	Multivariate regression analysis: PaCO ₂ independently associated with ACP; OR, 1.15 (95% CI, 1.05-1.25)
Lheritier et al, 2013	Prospective multicenter	Multivariate regression analysis: PaCO ₂ > 60 mmHg strongly associated with ACP; OR, 3.70 (95% CI, 1.32-10.38)
Mekontso Dessap et al, 2016	Prospective multicenter	PaCO ₂ > 48 mm Hg associated with ACP; OR, 2.39 (95% CI, 1.62-3.52);

Crit Care Med 2001;29:1551
Intensive Care Med 2013;39:1734
Intensive Care Med 2016;42:862

Severe Hypercapnia and Outcome

1,899 Patients with ARDS, VENTILA Study



► Severe hypercapnia appears to be **independently associated with higher ICU mortality** in patients with ARDS

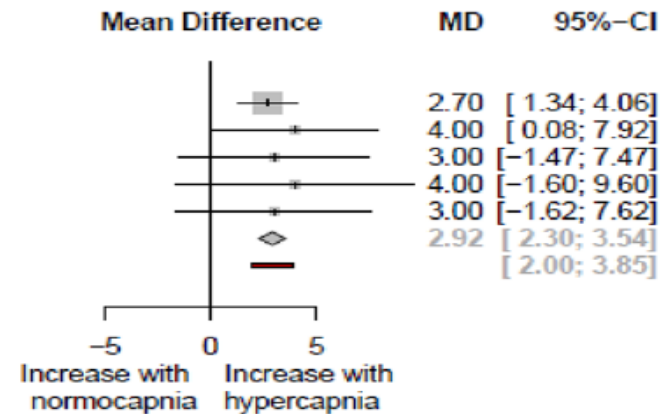
Role of Hypercapnia in ARDS

Systematic Review on Pulmonary Hemodynamics



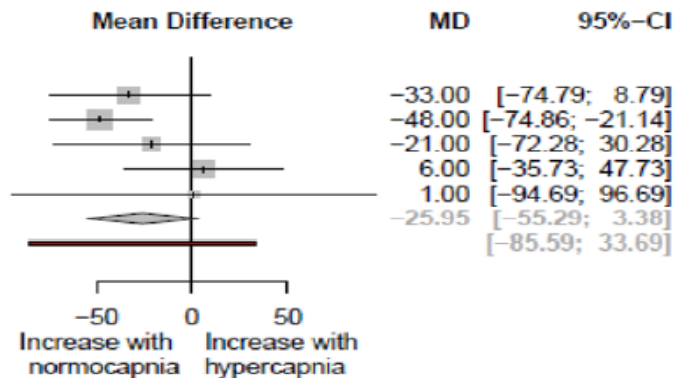
(B) Pulmonary artery pressure, mean (mmHg)

Study	PAPm, Hypercapnia			Normocapnia		
	Total	Mean	SD	Total	Mean	SD
Group = permissive						
Amato 1995	15	30.10	1.3000	13	27.40	2.2000
Feihl 2000	8	32.00	4.0000	8	28.00	4.0000
Pfeiffer 2002 (without shock)	10	31.00	4.0000	10	28.00	6.0000
Pfeiffer 2002 (with shock)	12	32.00	7.0000	12	28.00	7.0000
Thorens 1996	11	32.00	6.0000	11	29.00	5.0000
Random effects model	56			54		
Prediction interval	-			-		
Heterogeneity: $I^2 = 0\%$, $\tau^2 = 0.0351$, $p = 0.97$						



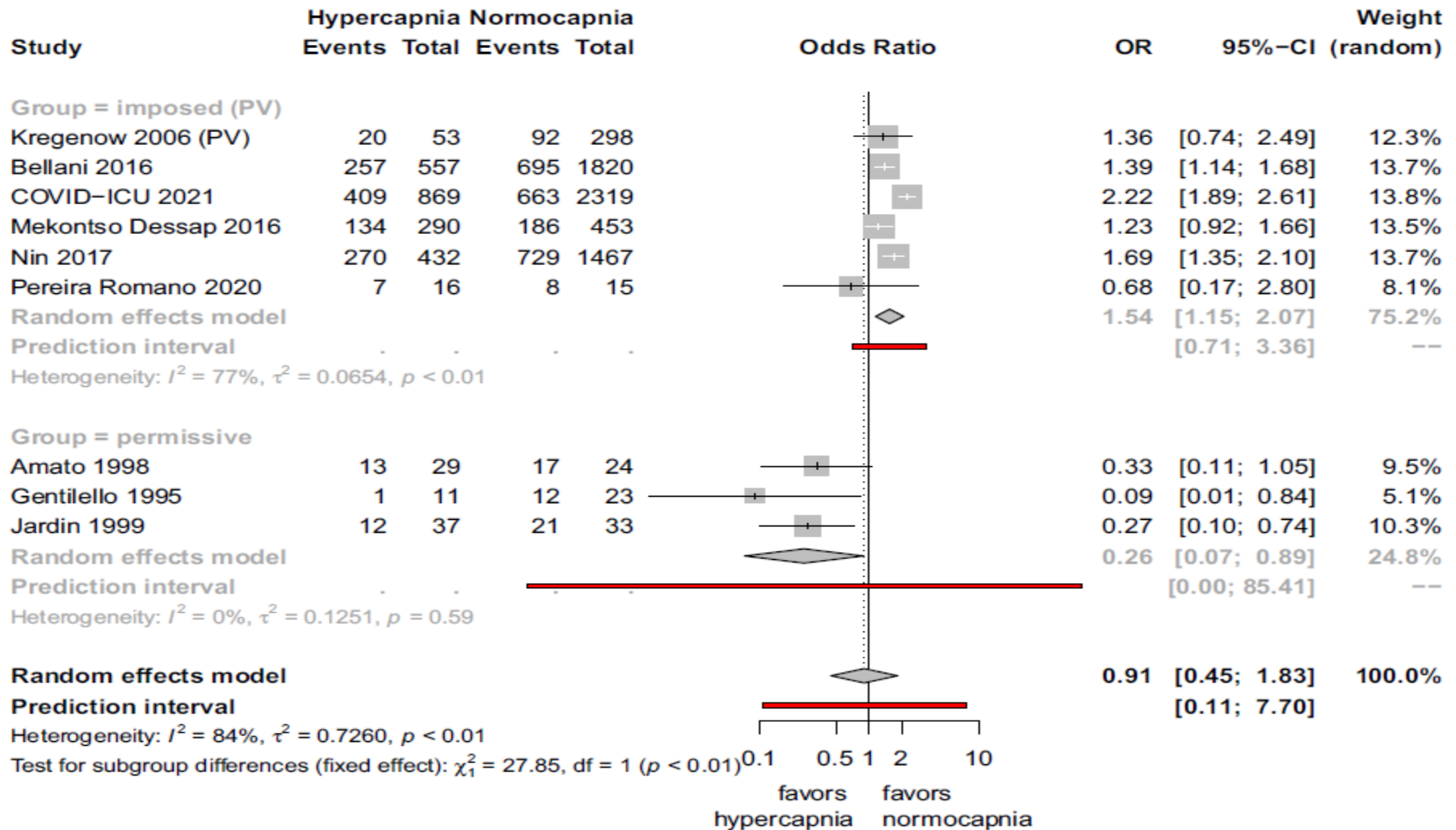
(C) Pulmonary vascular resistance, mean (dynes.s.cm⁻⁵)

Study	PVR, Hypercapnia			Normocapnia		
	Total	Mean	SD	Total	Mean	SD
Group = permissive						
Feihl 2000	8	311.00	46.0000	8	344.00	39.0000
McIntyre 1994	15	228.00	36.0000	15	276.00	39.0000
Pfeiffer 2002 (without shock)	10	171.00	59.0000	10	192.00	58.0000
Pfeiffer 2002 (with shock)	12	139.00	48.0000	12	133.00	56.0000
Thorens 1996	11	209.00	114.0000	11	208.00	115.0000
Random effects model	56			56		
Prediction interval	-			-		
Heterogeneity: $I^2 = 22\%$, $\tau^2 = 239.5472$, $p = 0.27$						



Role of Hypercapnia in ARDS

Systematic Review on Mortality

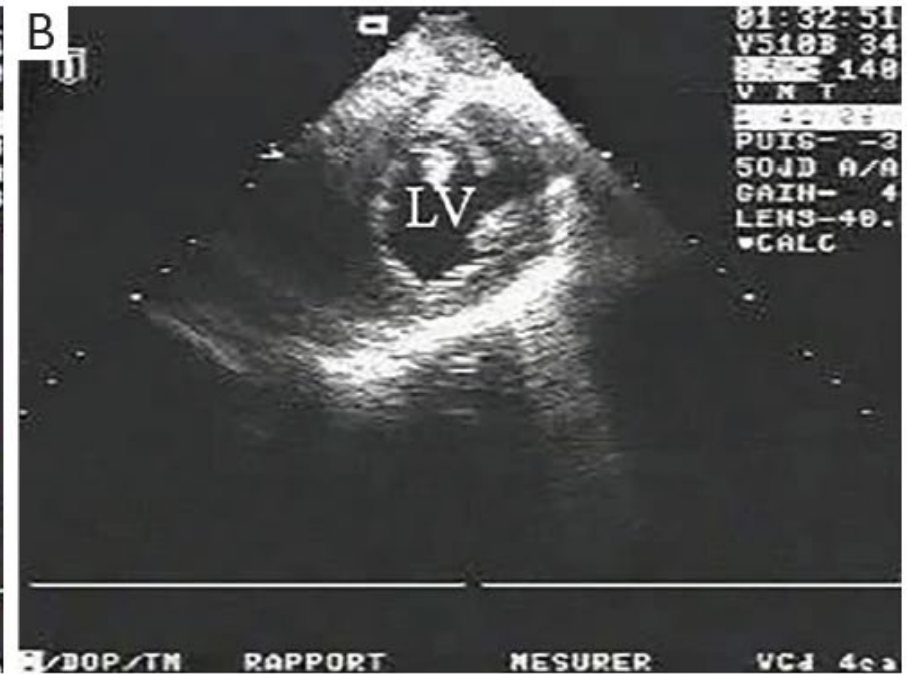


Pathophysiology of ACP in ARDS

3. Hypercapnic Increase in PVR



Pplat 22 cmH₂O
PaCO₂ 71 mmHg
P/F 103 mmHg



Pplat 23 cmH₂O
PaCO₂ 52 mmHg
P/F 88 mmHg

► Effect of a fast change in PaCO₂ (90 minutes) on the right ventricle in a patient ventilated for severe ARDS.

Development of RV Dysfunction in ARDS

Prospective Observational Study (n = 752)



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

Intensive Care Med (2016) 42:862–870

Table 2 Factors associated with acute cor pulmonale in patients with acute respiratory distress syndrome

Variable	Odds ratio (95 % CI) by logistic regression	
	Univariate	Multivariable ^a
Pneumonia as cause of ARDS	2.54 (1.79–3.62), <i>p</i> < 0.01	2.73 (1.84–4.05), <i>p</i> < 0.01
Respiratory settings on TEE day		
Tidal volume <7 mL/kg	1.70 (1.17–2.47), <i>p</i> < 0.01	I/NR
Respiratory rate ≥30 breaths/min	1.70 (1.11–2.60), <i>p</i> = 0.02	I/NR
Plateau pressure ≥27 cmH ₂ O	1.91 (1.33–2.73), <i>p</i> < 0.01	I/NR
Compliance <30 ml/cmH ₂ O	1.91 (1.33–2.73), <i>p</i> < 0.01	I/NR
Driving pressure ≥18 cmH ₂ O ^b	2.16 (1.51–3.10), <i>p</i> < 0.01	2.28 (1.53–3.38), <i>p</i> < 0.01
Arterial blood gases on TEE day		
PaO ₂ /FiO ₂ ratio <150 mmHg	2.41 (1.49–3.92), <i>p</i> < 0.01	2.60 (1.50–4.52), <i>p</i> < 0.01
PaCO ₂ ≥48 mmHg	2.95 (2.06–4.21), <i>p</i> < 0.01	2.39 (1.62–3.52), <i>p</i> < 0.01

► Lack of data that illustrate a sequential relationship between any of the four parameters listed and the severity of ACP

ACP Risk Score



Table 3 The acute cor pulmonale risk score

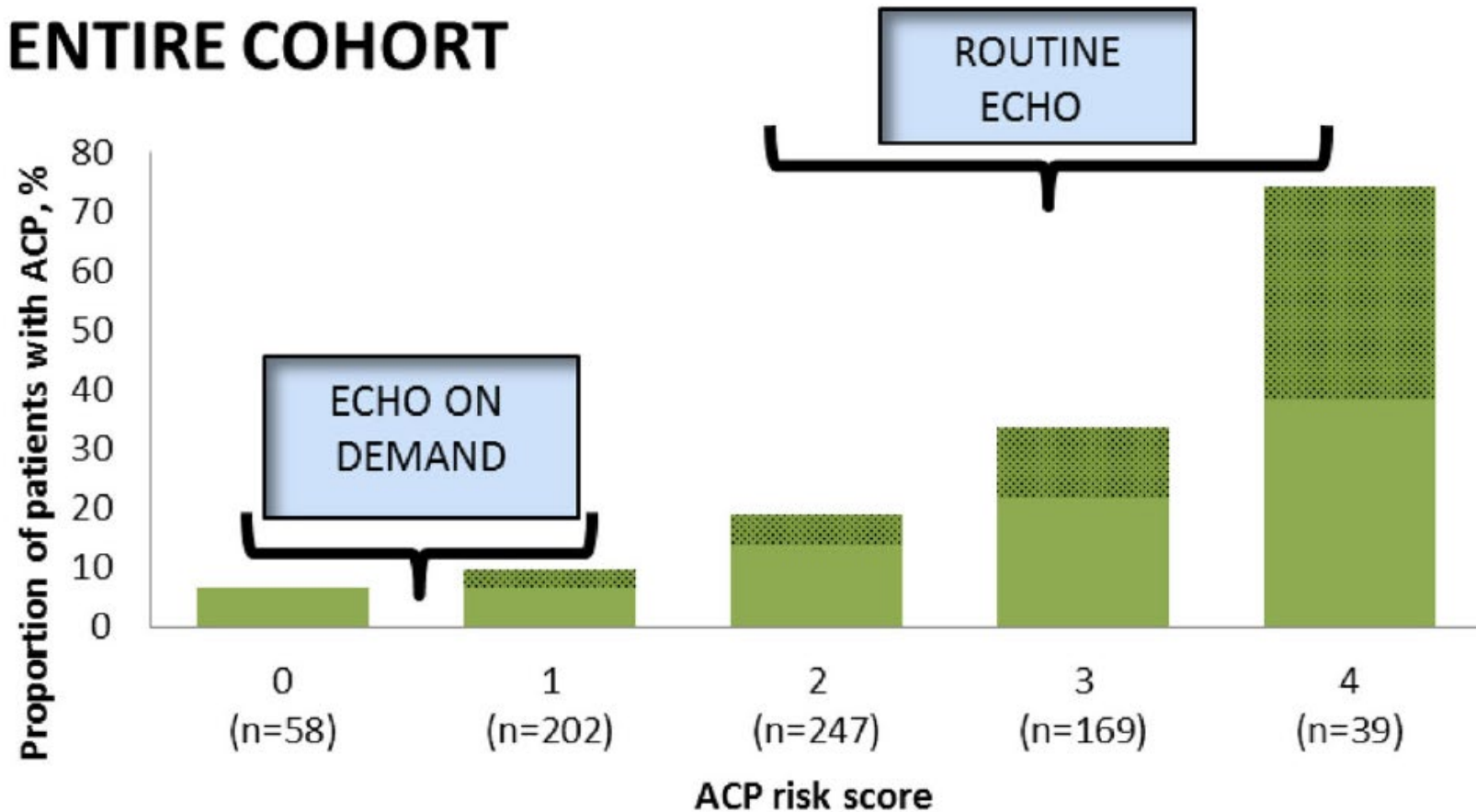
Parameter	Score
Pneumonia as cause of ARDS	1
Driving pressure ≥ 18 cmH ₂ O ^a	1
PaO ₂ /FiO ₂ ratio <150 mmHg	1
PaCO ₂ ≥ 48 mmHg	1
Total score	0–4

ARDS Acute respiratory distress syndrome

^a Driving pressure is defined as the difference between plateau pressure and total end-expiratory positive pressure. Because the relative contribution of all β parameters was close to each other, equivalent weights were generated for all items of the Score in keeping with parsimony [21]

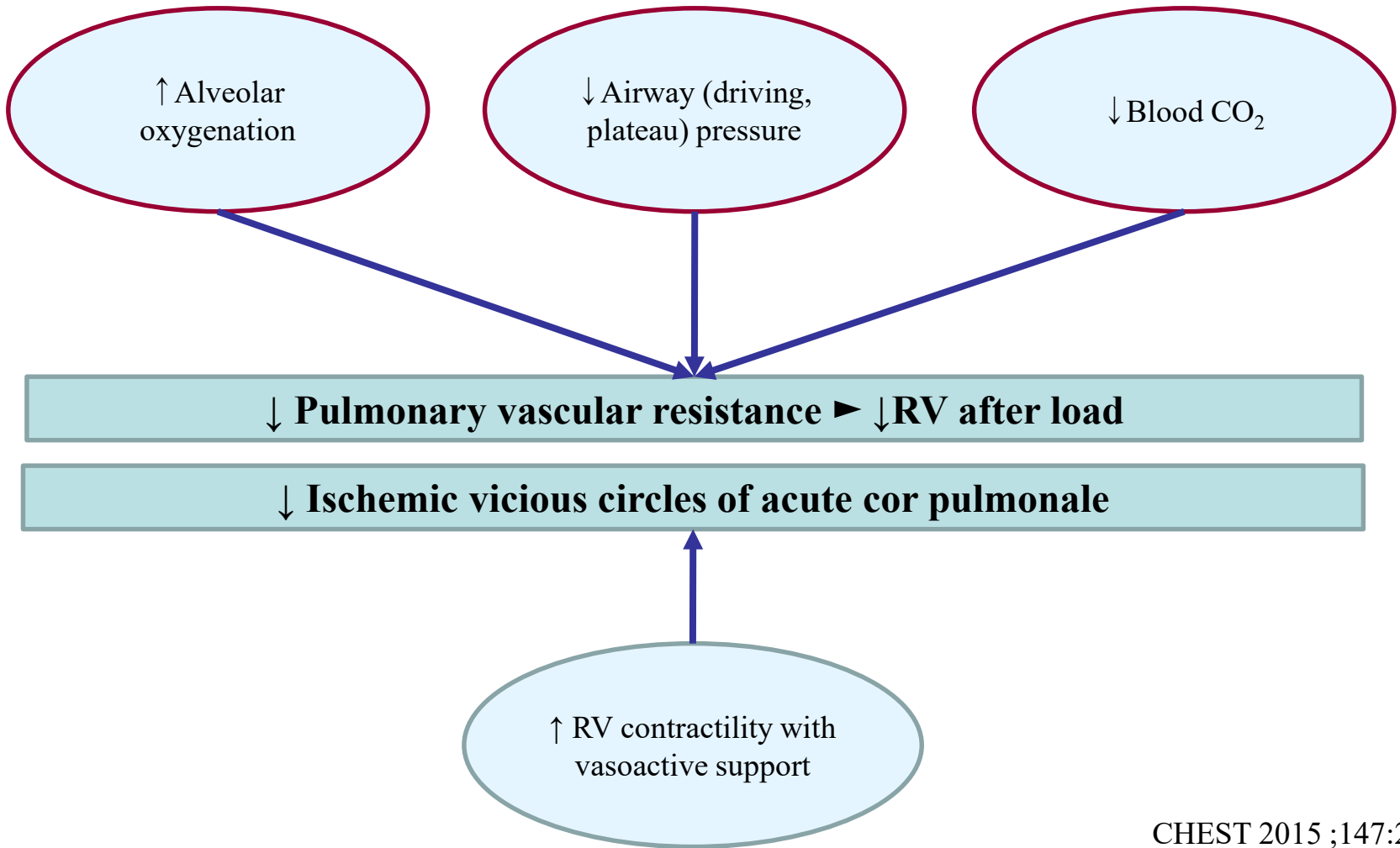
Proposal for Echocardiography Monitoring

ENTIRE COHORT

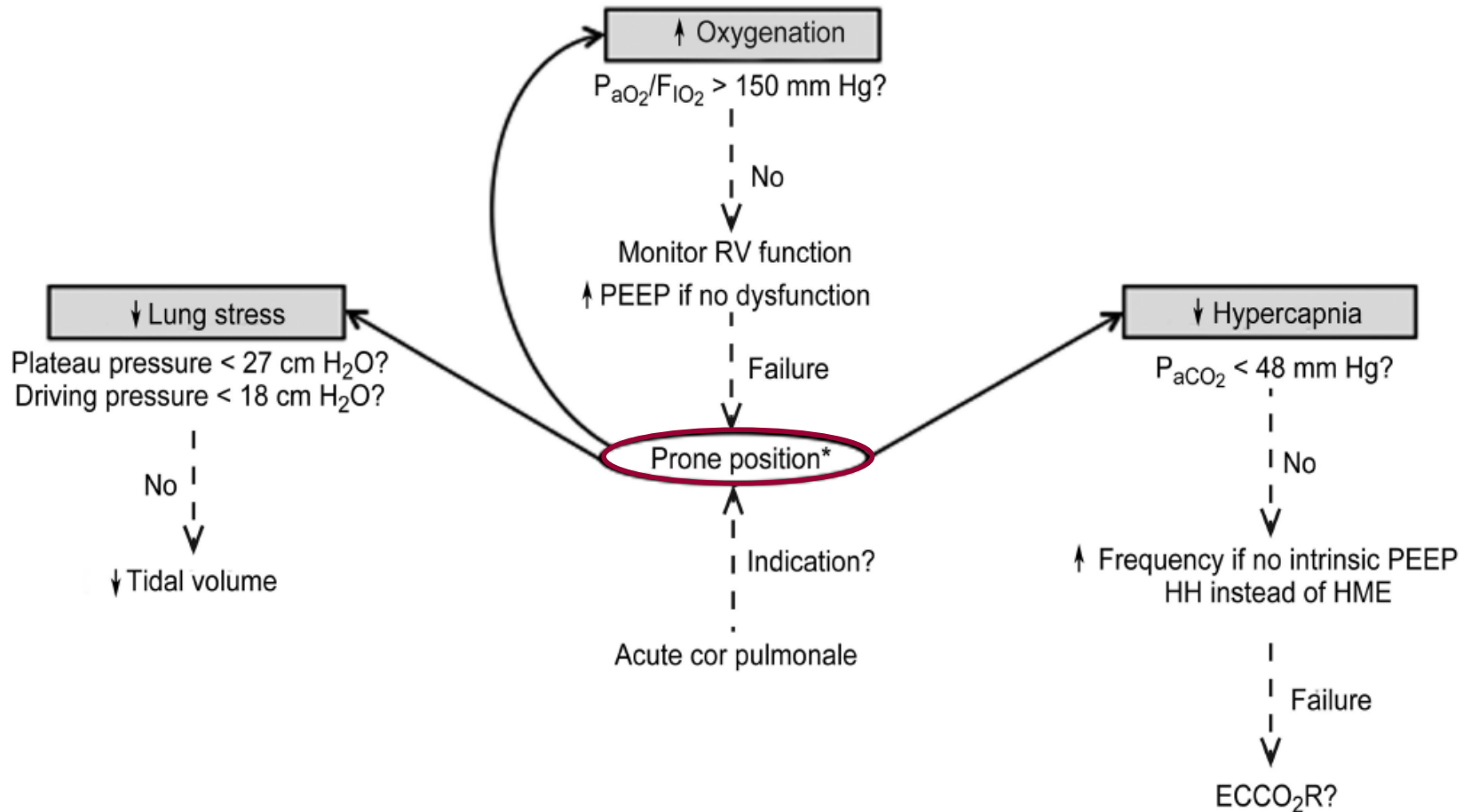


How to protect the RV?

RV Protective Strategy

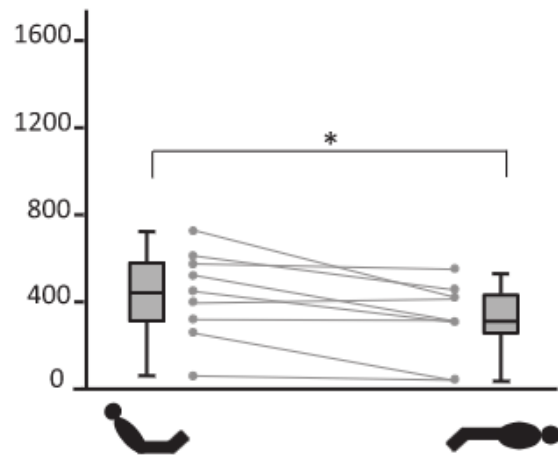


RV Protective Ventilation with Prone Position

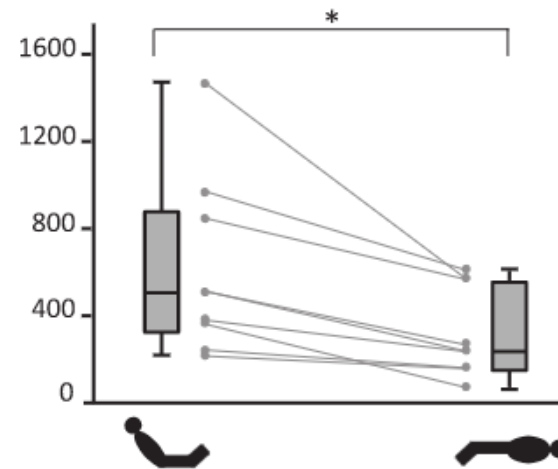


Hemodynamic Effects of Prone Positioning

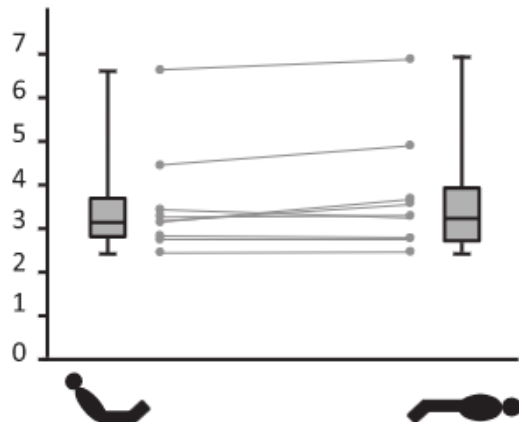
Pulmonary vascular resistance (dynes·s/cm⁵/m²)



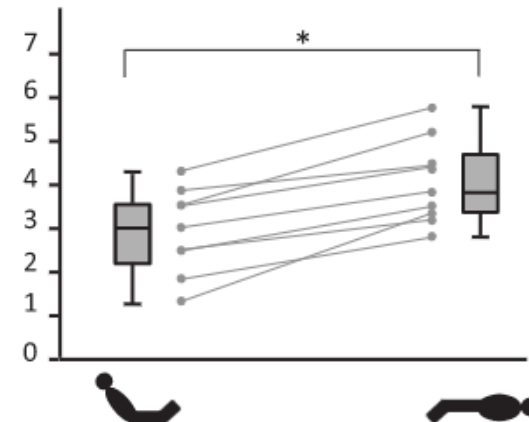
Pulmonary vascular resistance (dynes·s/cm⁵/m²)



Cardiac index (L/min/m²)



Cardiac index (L/min/m²)



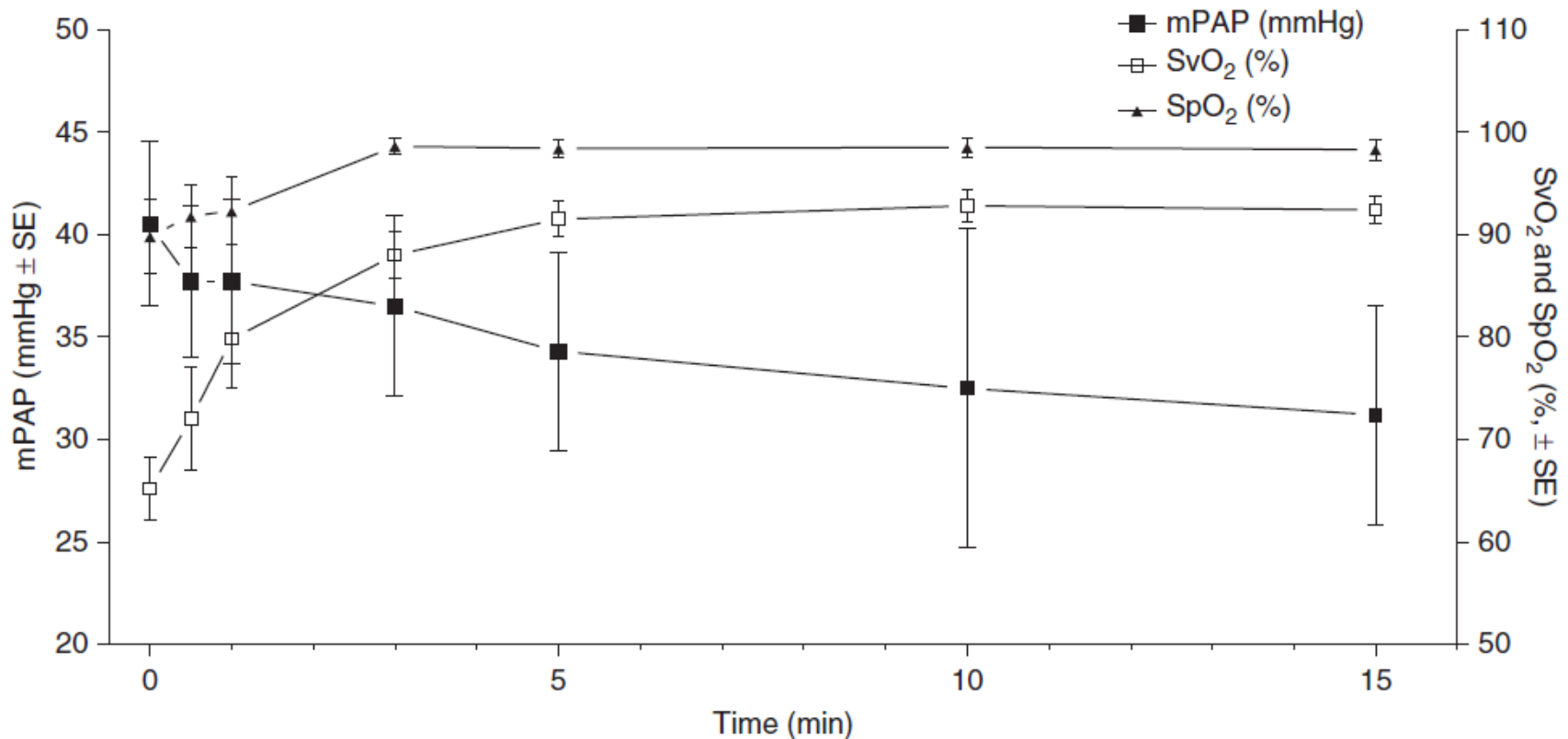
Prone Positioning for RV Protection

Rationale from PROSEVA Study

	Day 3		Day 5		Day 7	
	SG	PG	SG	PG	SG	PG
Tidal volume (ml)	415±117 (n=201)	411±95 (n=218)	425±115 (n=188)	440±124 (n=197)	440±117 (n=156)	431±102 (n=155)
Tidal volume (ml.kg ⁻¹ PBW)	6.6±1.6 (n=201)	6.5±1.4 (n=218)	6.9±1.8 (n=188)	6.9±1.8 (n=197)	7.0±1.9 (n=156)	6.8±1.4 (n=155)
Respiratory frequency (breaths.min ⁻¹)	28±6 (n=202)	27±6 (n=218)	27±6 (n=190)	27±7 (n=201)	27±7 (n=157)	27±7 (n=160)
PEEP (cm H ₂ O)	9.3±3.3 (n=205)	8.6±2.6* (n=222)	8.9±3.5 (n=191)	8.1±3.0* (n=205)	8.5±3.5 (n=159)	8.1±3.9 (n=165)
F _I O ₂	0.58±0.18 (n=203)	0.53±0.14** (n=223)	0.58±0.19 (n=192)	0.51±0.14** (n=206)	0.56±0.19 (n=160)	0.51±0.13 (n=168)
PaO ₂ (mm Hg)	83±25 (n=204)	86±26 (n=219)	82±21 (n=190)	84±24 (n=206)	85±27 (n=160)	84±25 (n=173)
PaO ₂ / F _I O ₂ (mm Hg)	157±64 (n=200)	172±64* (n=219)	157±68 (n=189)	179±100** (n=203)	170±80 (n=158)	173±62 (n=167)
PaCO ₂ (mm Hg)	47±14 (n=204)	45±9 (n=219)	47±13 (n=190)	45±10 (n=206)	47±13 (n=160)	44±10 (n=173)
Arterial pH	7.39±0.08 (n=204)	7.40±0.18 (n=219)	7.40±0.09 (n=190)	7.42±0.07 (n=206)	7.41±0.08 (n=160)	7.43±0.07 (n=173)
Pplat, RS (cm H ₂ O)	24±5 (n=133)	22±4* (n=135)	24±5 (n=105)	22±5* (n=91)	24±5 (n=73)	22±4** (n=71)
Cst,RS (ml.cmH ₂ O ⁻¹)	36±18 (n=133)	38±17 (n=132)	35±16 (n=103)	36±18 (n=89)	35±16 (n=73)	31±17 (n=71)

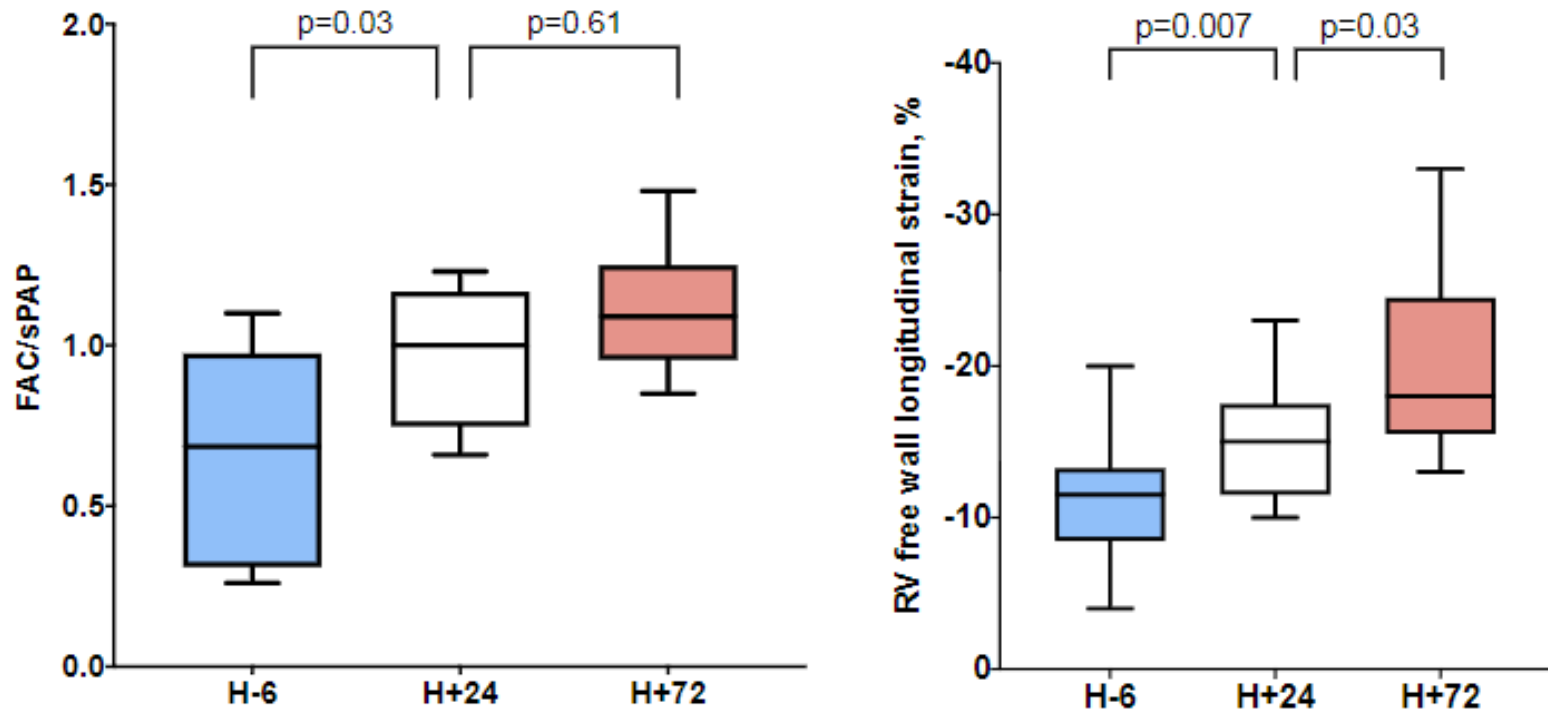
► Improving oxygenation without increasing PEEP; decreasing PaCO₂ by rendering lung ventilation more homogenous; and decreasing driving pressure due to the recruitment of the dependent dorsal regions

RV Unloading Following VV ECMO



► Initiation of VV ECMO in respiratory failure is associated with **immediate RV unloading** associated with an increase in SvO₂ and a decrease in PaCO₂

Reversal of RV Dysfunction with VV ECMO COVID-19 Pneumonia



FAC/sPAP, fractional area change of right ventricle/systolic pulmonary artery pressure

Eligible for VV ECMO in Severe ARDS Based on RV Function in Addition to EOLIA Criteria

Petit et al. *Crit Care* (2021) 25:220
<https://doi.org/10.1186/s13054-021-03646-x>


Critical Care

RESEARCH LETTER

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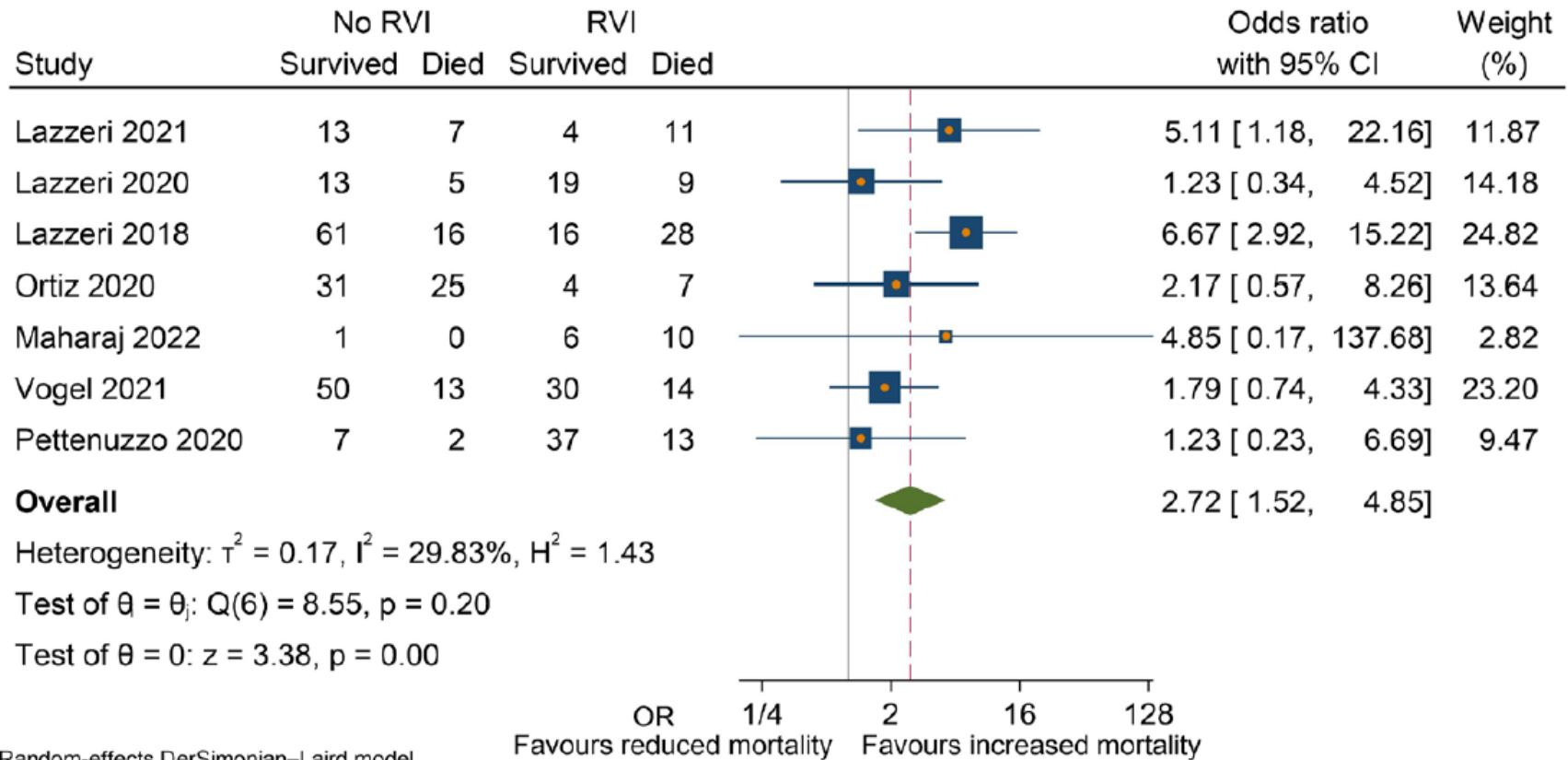


Evaluation of right ventricular function and driving pressure with blood gas analysis could better select patients eligible for VV ECMO in severe ARDS

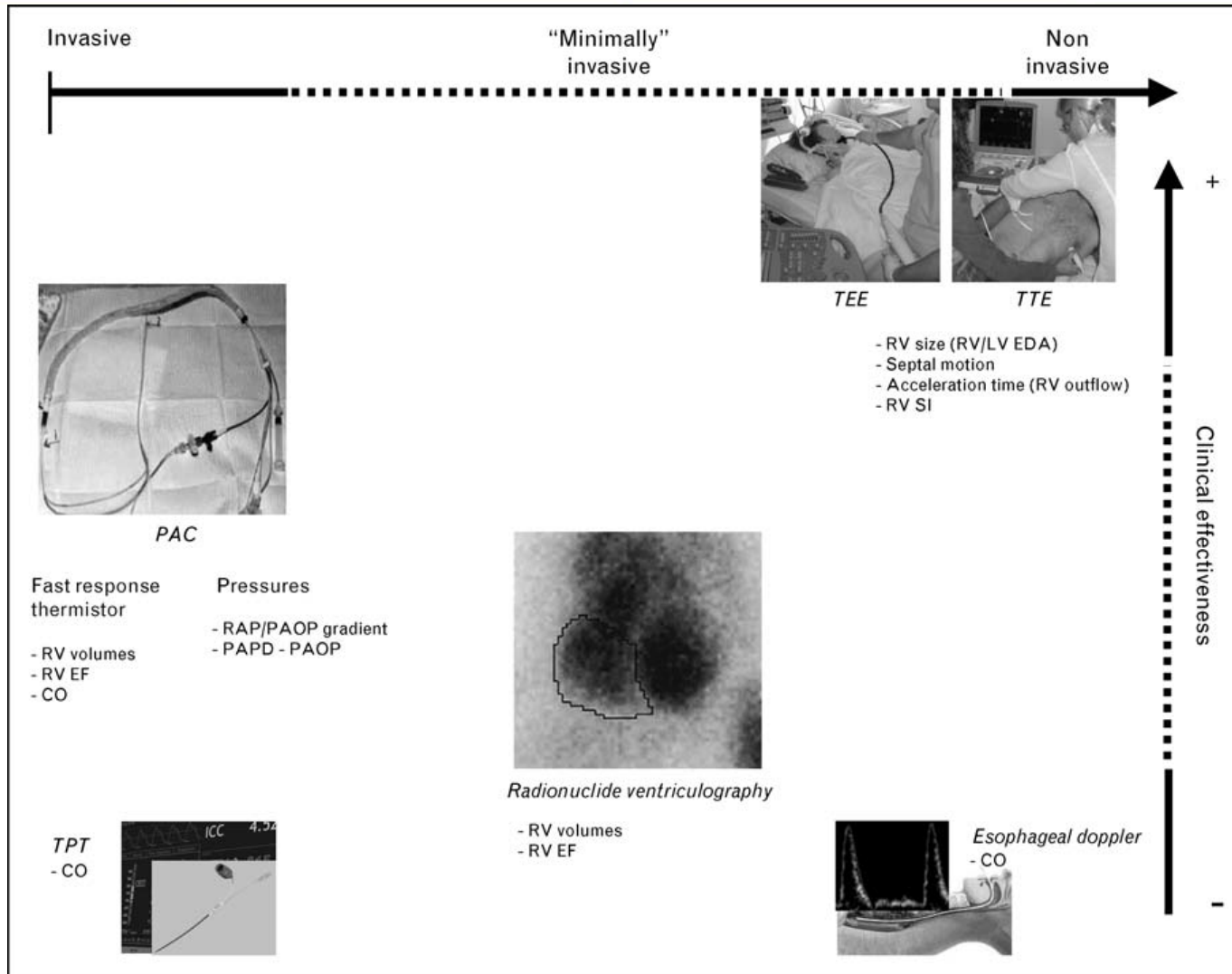
Matthieu Petit^{1,2*} , Armand Mekontso-Dessap^{3,4,5}, Paul Masi^{3,4}, Annick Legras⁷, Philippe Vignon⁶ and Antoine Vieillard-Baron^{1,2}

RV Injury and Mortality of ARDS on VV ECMO

Systematic Review



Monitoring of RV Failure



Echocardiographic Findings of RV Failure

- RV dilatation and hypokinesis
- RV hypertrophy
- Change to a more concentric RV morphology
- Paradoxical septal motion
- Impaired LV diastolic function
- Right atrial enlargement
- Tricuspid regurgitation
- Pulmonary artery hypertension as estimated by the modified Bernoulli equation
- Pulmonary artery dilatation
- Lack of inspiratory collapse of the inferior vena cava
- Pericardial effusions

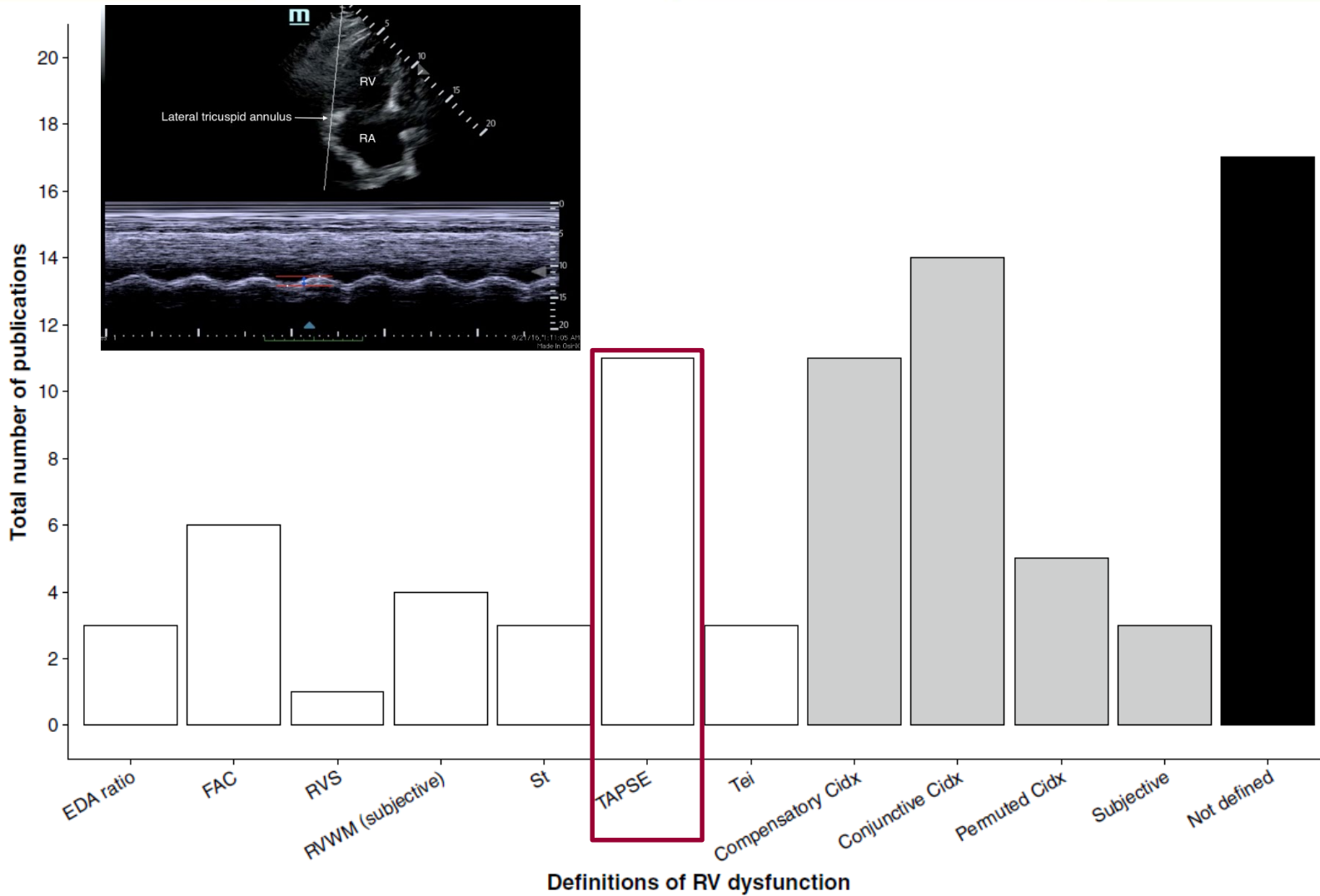
Echocardiographic Indices for RV Function

Index	Description	Advantages	Disadvantages (limitations)
Longitudinal function index			
TAPSE	A single dimensional measurement of the longitudinal motion of the tricuspid annular plane Measured at lateral free wall	Easy to perform Quick Minimal training required Less dependent on image quality Averaging is easy to perform Good intra- and interoperator reproducibility	Angle-dependent Maybe misleading if regional wall motion abnormalities are present Subject to LV motion and translational artefact
S_t	A single dimensional measurement of the peak longitudinal systolic velocity of the tricuspid annulus Measured at lateral free wall	Easy to perform Quick Less subject to 2D image quality Less dependent on image quality Averaging is easy to perform Good intra- and interoperator reproducibility	Angle-dependent Maybe misleading if regional wall motion abnormalities are present Subject to LV motion and translational artefact
RVS	A single dimensional measurement of the percentage change in longitudinal length Measured at lateral free wall	Not angle-dependent Yields regional wall motion information Not subject to translational artefact	Requires good image quality Relatively time-consuming Requires off-line analysis Requires extra and expensive software Special training required Poor interoperator variabilities
Global function index			
FAC	A two dimensional measurement of the change in RV area Usually measured in the longitudinal view but some use the cross-sectional view Similar to and correlates with ejection fraction	Not angle-dependent Not subject to regional wall motion information Not subject to translational artefact Fair interoperator reproducibility	Requires good image quality Relatively time-consuming Some training required RVOT not included in assessment Does not necessarily correlate with PASP
Tei index ^a	A Doppler (or tissue Doppler) measurement of the ratio of sum of isovolumic times to ejection time Reflects both systolic and diastolic function (combined)	Not subject to regional wall motion abnormality Not subject to translational artefact Sensitive to loading conditions Less subject to image quality	Angle-dependent Depends on good Doppler signal Not recommended in irregular heart beats Moderate intra- and interoperator variabilities
EDA ratio	A two dimensional measurement of the ratio of RV end-diastolic to LV end-diastolic ratio A measure of how severe the RV is dilated compared to LV Severely dilated RV usually connotes RV dysfunction Usually used in conjunction with paradoxical septal motion in defining cor pulmonale	Not angle-dependent Not subject to regional wall motion information Not subject to translational artefact Sensitive to loading conditions Good intra- and interoperator variabilities	A mild increase does not imply RV dysfunction Requires good image quality Relatively time-consuming Some training required

TAPSE tricuspid annular plane systolic excursion, S_t tissue Doppler of the tricuspid annular systolic velocity, RVS right ventricular strain, FAC fractional area change, EDA ratio RV end-diastolic area to LV end-diastolic area ratio

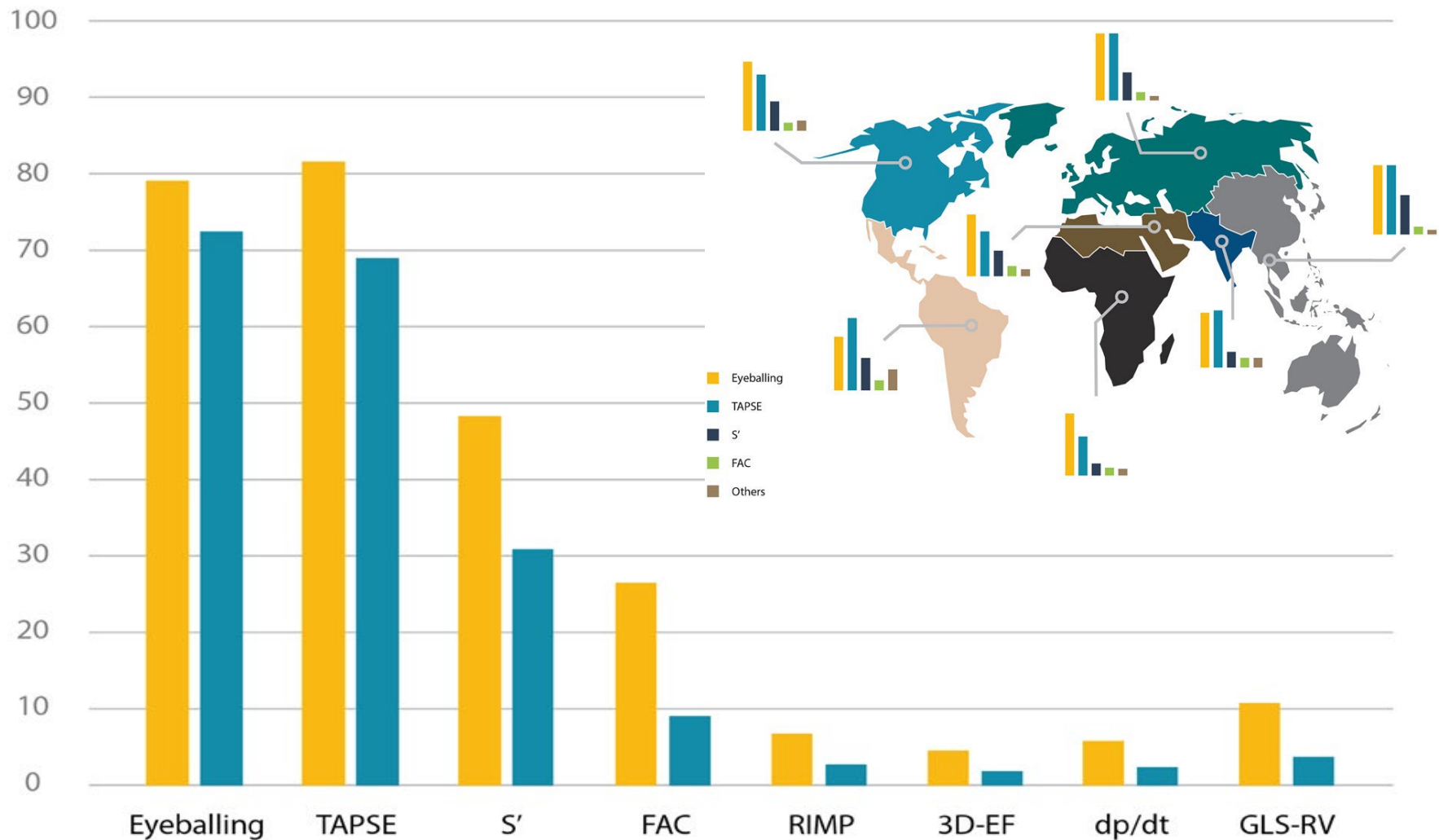
TAPSE: Most Popular Index

Systematic Review with 81 Studies



Echocardiographic Assessment of RV

Current Clinical Practice



Core Critical Care US Competencies

ESICM Recommendations, 2020



Agreement

No agreement

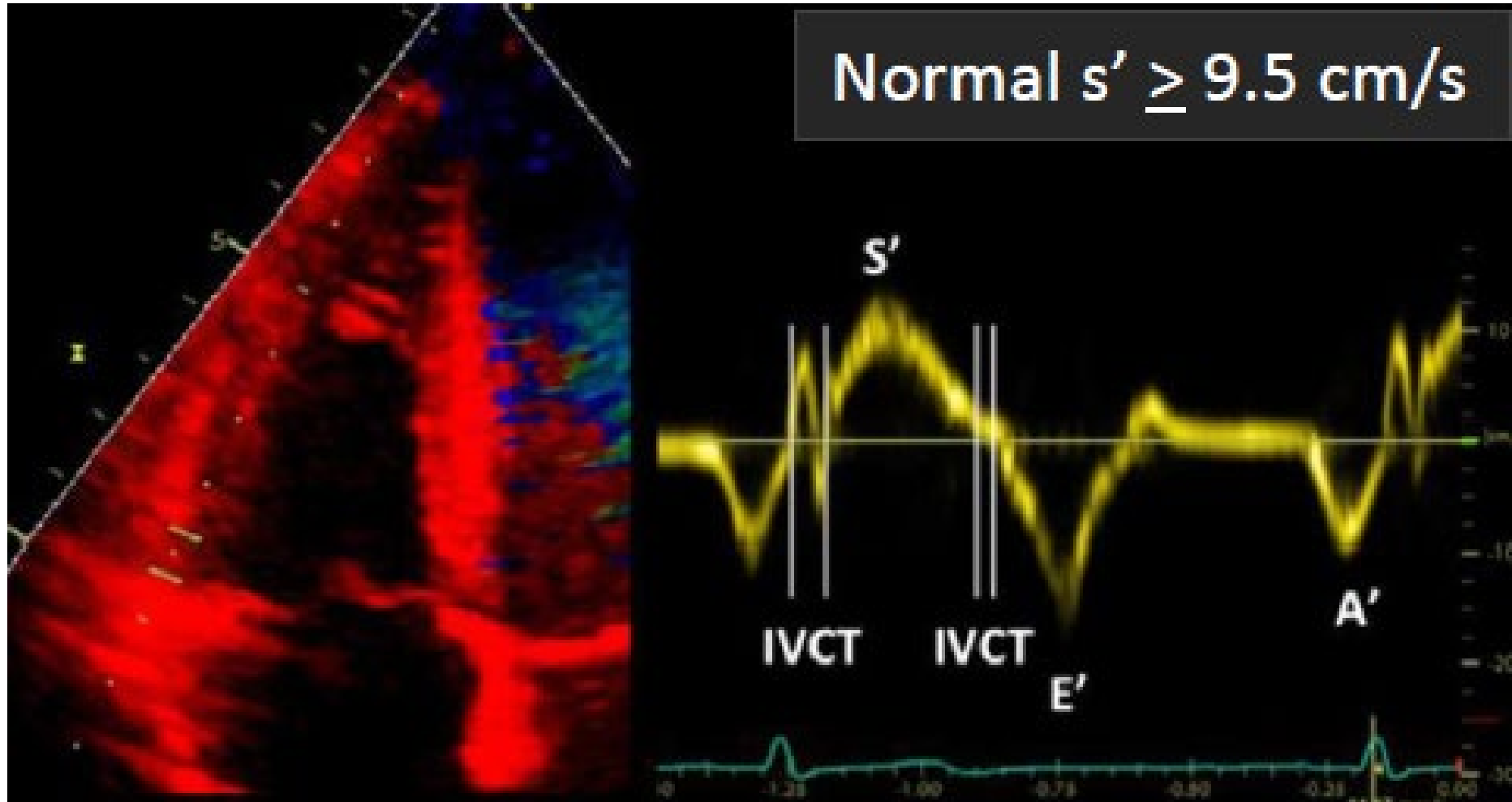
Include

Not to include

Echocardiography

Syndromes	Severe hypovolemia LV failure RV failure Tamponade Acute cor pulmonale Severe valvular abnormalities	Post-cardiac arrest management*	
Left ventricle	Size (qualitative) Systolic function (qualitative) Contraction pattern (qualitative) Valvular disease (qualitative: colour doppler)	Systolic function (quantitative: Simpson, Teicholz) Diastolic function (quantitative) Contraction pattern (quantitative) Valvular disease (quantitative)	Size (quantitative: diameter and wall thickness) Systolic function (quantitative: MAPSE, aortic VTI)
Right ventricle	Size (qualitative) Systolic function (quantitative: TAPSE, RV/LV ratio) Valvular disease (qualitative: colour doppler)	Size (quantitative) Valvular disease (quantitative)	
Inferior vena cava	Size (quantitative) Respiratory variation (quantitative)		
Procedures			Pericardiocentesis

RV Strain Measurements with TDI in Critically Ill SICS Study



Suggested Reading



VIDEOS IN CLINICAL MEDICINE SUMMARY POINTS

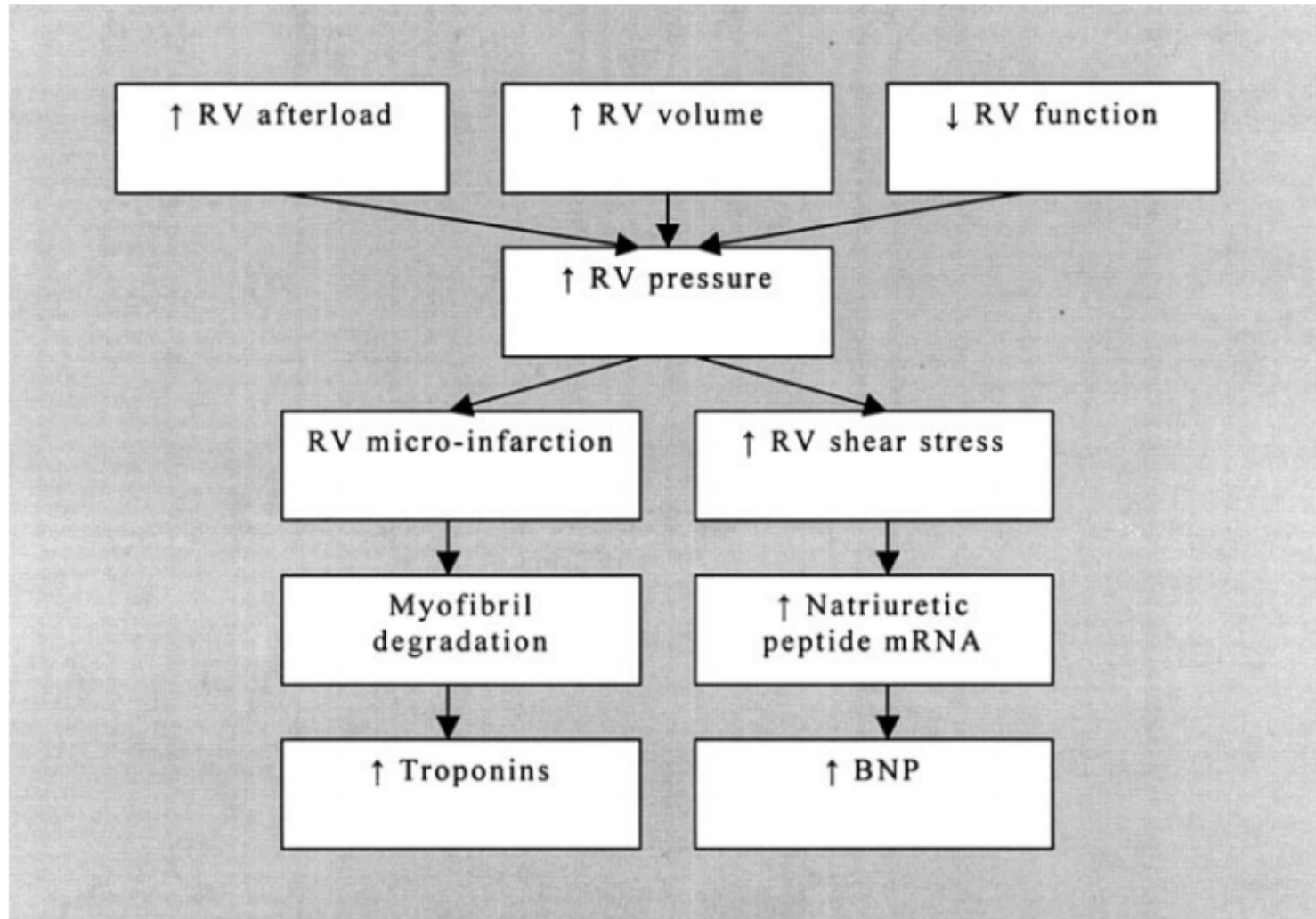
Julie R. Ingelfinger, M.D., *Editor*

Focused Cardiac Ultrasonography for Right Ventricular Size and Systolic Function

Gabriel Prada, M.D., Aliaksei Pustavoitau, M.D., M.H.S., Seth Koenig, M.D.,
Carol Mitchell, Ph.D., Raymond F. Stainback, M.D.,
and José L. Díaz-Gómez, M.D.

This video presents a practical method for conducting visual, semiquantitative assessment of right ventricular size and systolic function with focused cardiac ultrasonography.

Cardiac Biomarker Elevation in RV Failure



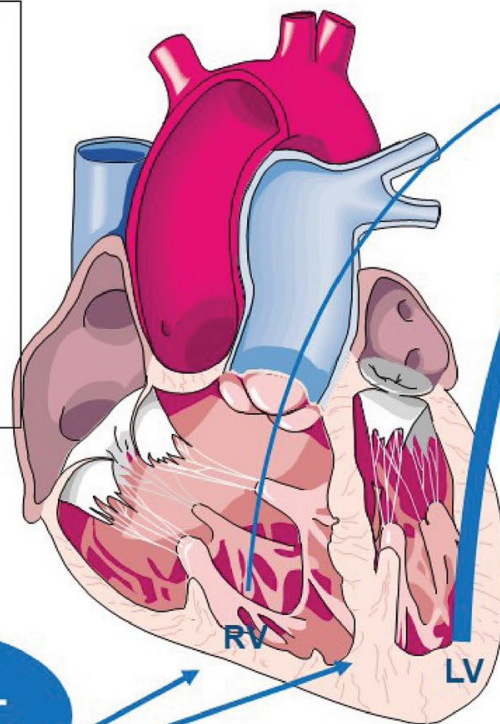
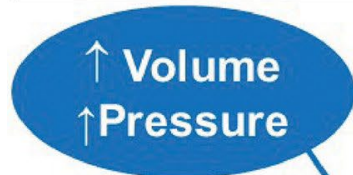
Overview of Natriuretic Peptides

NP Lower than Expected Despite HF:

- Obesity
- Flash pulmonary edema
- Upstream from LV (e.g. mitral stenosis)
- Pericardial constriction

NP Higher than Expected for Degree of HF:

- Advanced age
- Renal dysfunction
- Acute coronary syndrome/ischemia
- High output states
- Atrial fibrillation
- Left ventricular dysfunction
- Pulmonary disease
 - e.g. ARDS, COVID-19, lung disease with right heart failure
- Pulmonary embolism
- Neprilysin inhibitor (BNP only)



Pre-Pro-BNP

Pro-BNP

N-terminal
Pro-BNP

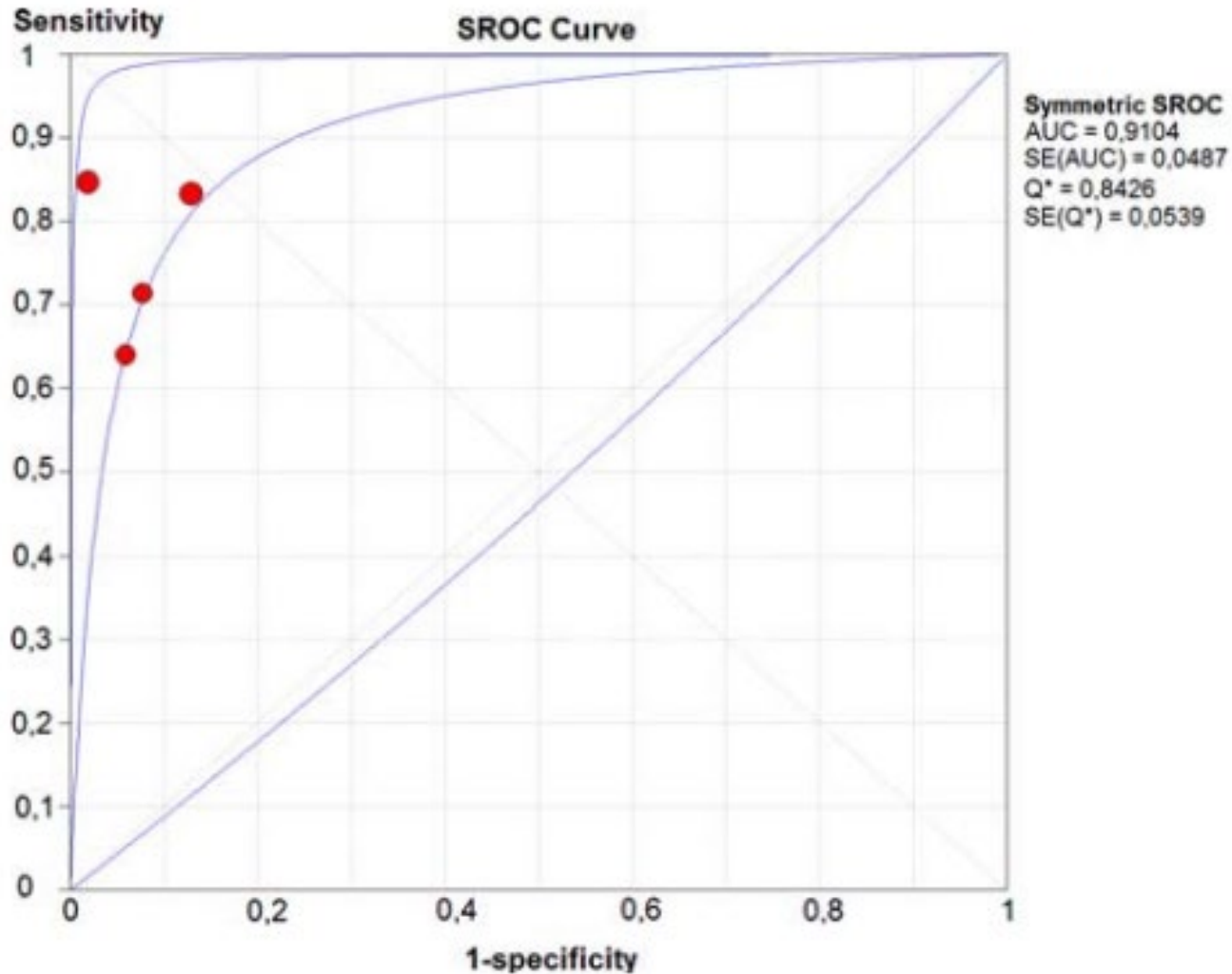
$t_{1/2} = 60-120 \text{ min}$

BNP

$t_{1/2} = \sim 20 \text{ min}$

- Natriuresis
- Vasodilatation
- Diuresis
- Myocardial relaxation
- ↓ myocardial fibrosis

Diagnostic Accuracy of BNP RV Dysfunction using Echocardiography



Cardiac Biomarker with Mortality in ARDS

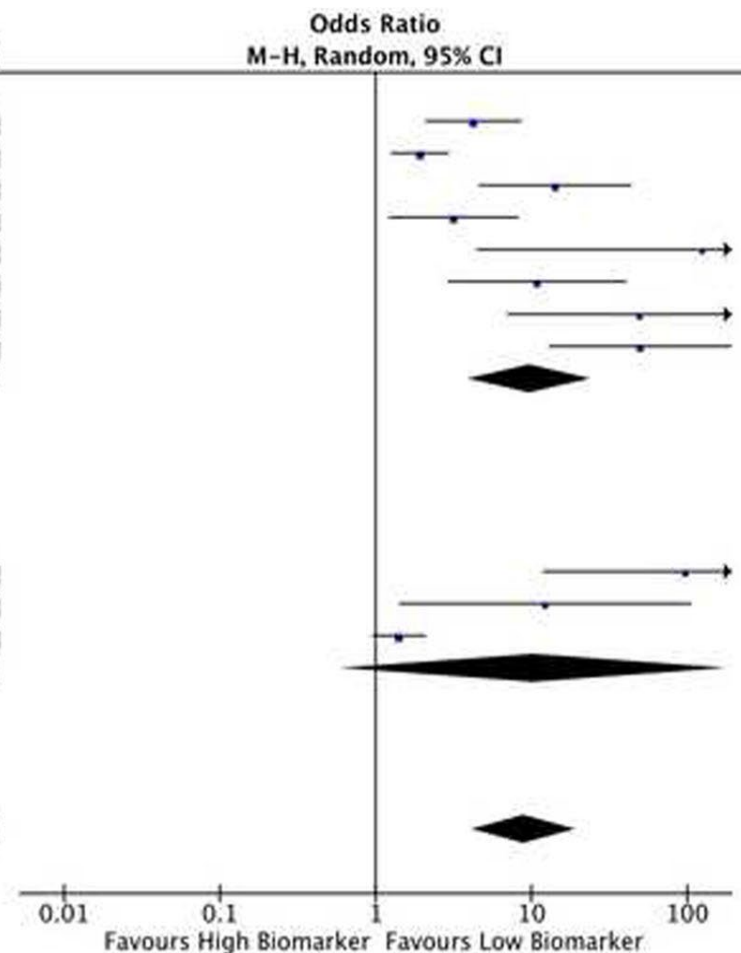
Systematic Review



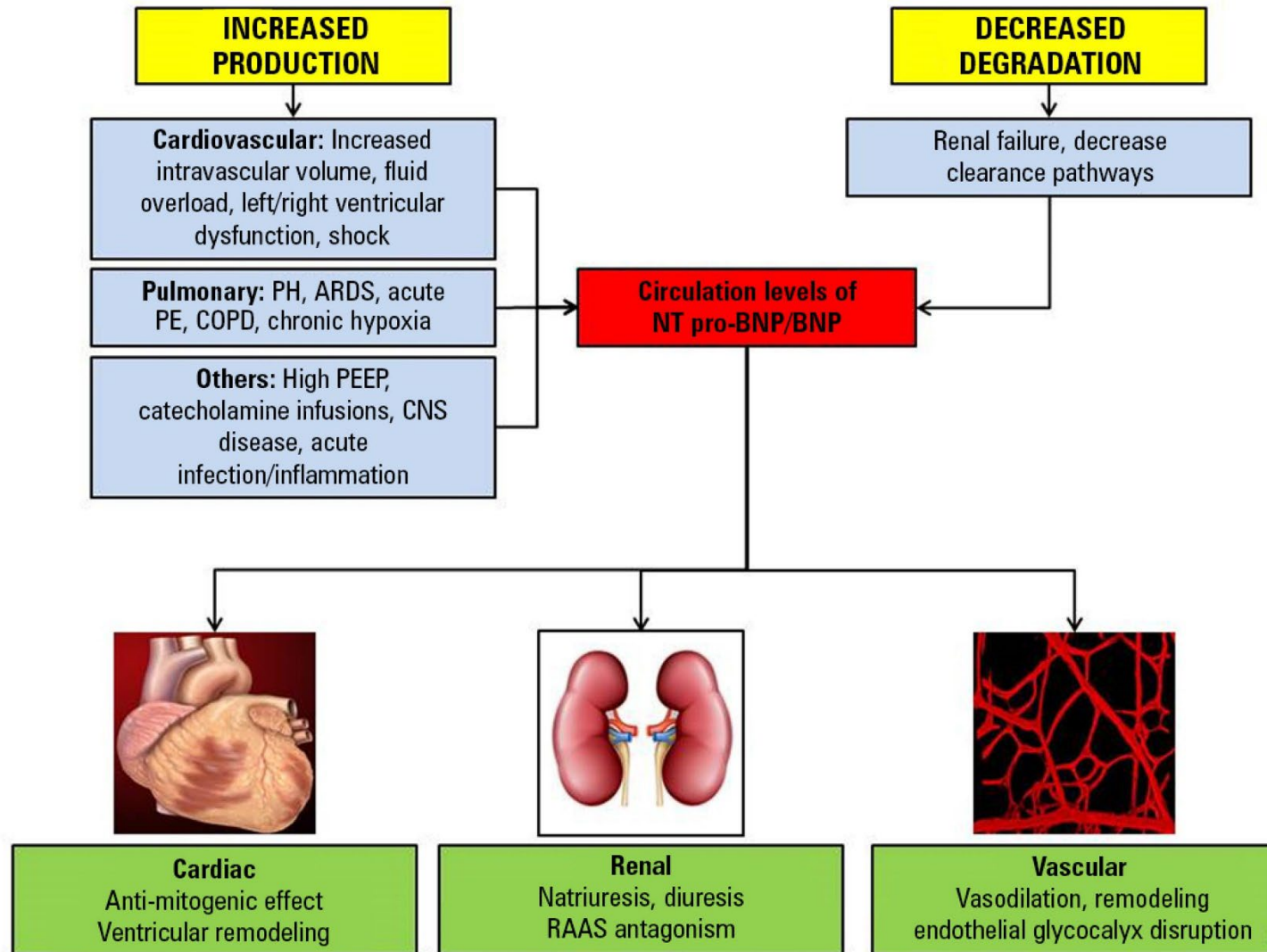
Study or Subgroup	High Biomarker		Low Biomarker		Weight	Odds Ratio M-H, Random, 95% CI
	Events	Total	Events	Total		
1.1.1 NT-proBNP						
Bajwa 2008	57	109	14	68	11.6%	4.23 [2.10, 8.49]
Ferris 2018	77	253	47	254	12.4%	1.93 [1.27, 2.92]
Ji 2016	24	35	6	45	10.1%	14.18 [4.64, 43.34]
Lin Q 2012	17	38	10	49	10.8%	3.16 [1.23, 8.12]
Nassar 2010	12	12	1	8	3.8%	125.00 [4.49, 3478.94]
Su 2018	19	26	5	25	9.4%	10.86 [2.93, 40.17]
Xu 2013	8	11	2	39	7.1%	49.33 [7.05, 345.21]
Zhou 2015	23	28	5	59	9.3%	49.68 [13.11, 188.25]
Subtotal (95% CI)		512		547	74.5%	9.68 [3.92, 23.91]
Total events	237		90			
Heterogeneity: $\tau^2 = 1.24$; $\chi^2 = 43.64$, $df = 7$ ($P < 0.00001$); $I^2 = 84\%$						
Test for overall effect: $Z = 4.92$ ($P < 0.00001$)						

1.1.2 BNP						
Lin Y 2010	42	43	13	43	6.6%	96.92 [12.02, 781.44]
Rhee 2007	13	14	17	33	6.5%	12.24 [1.43, 104.56]
Semler 2016	77	313	59	313	12.5%	1.40 [0.96, 2.06]
Subtotal (95% CI)		370		389	25.5%	10.41 [0.60, 181.40]
Total events	132		89			
Heterogeneity: $\tau^2 = 5.63$; $\chi^2 = 20.45$, $df = 2$ ($P < 0.0001$); $I^2 = 90\%$						
Test for overall effect: $Z = 1.61$ ($P = 0.11$)						

Total (95% CI)		882		936	100.0%	8.98 [4.15, 19.43]
Total events	369		179			
Heterogeneity: $\tau^2 = 1.21$; $\chi^2 = 74.41$, $df = 10$ ($P < 0.00001$); $I^2 = 87\%$						
Test for overall effect: $Z = 5.57$ ($P < 0.00001$)						
Test for subgroup differences: $\chi^2 = 0.00$, $df = 1$ ($P = 0.96$), $I^2 = 0\%$						

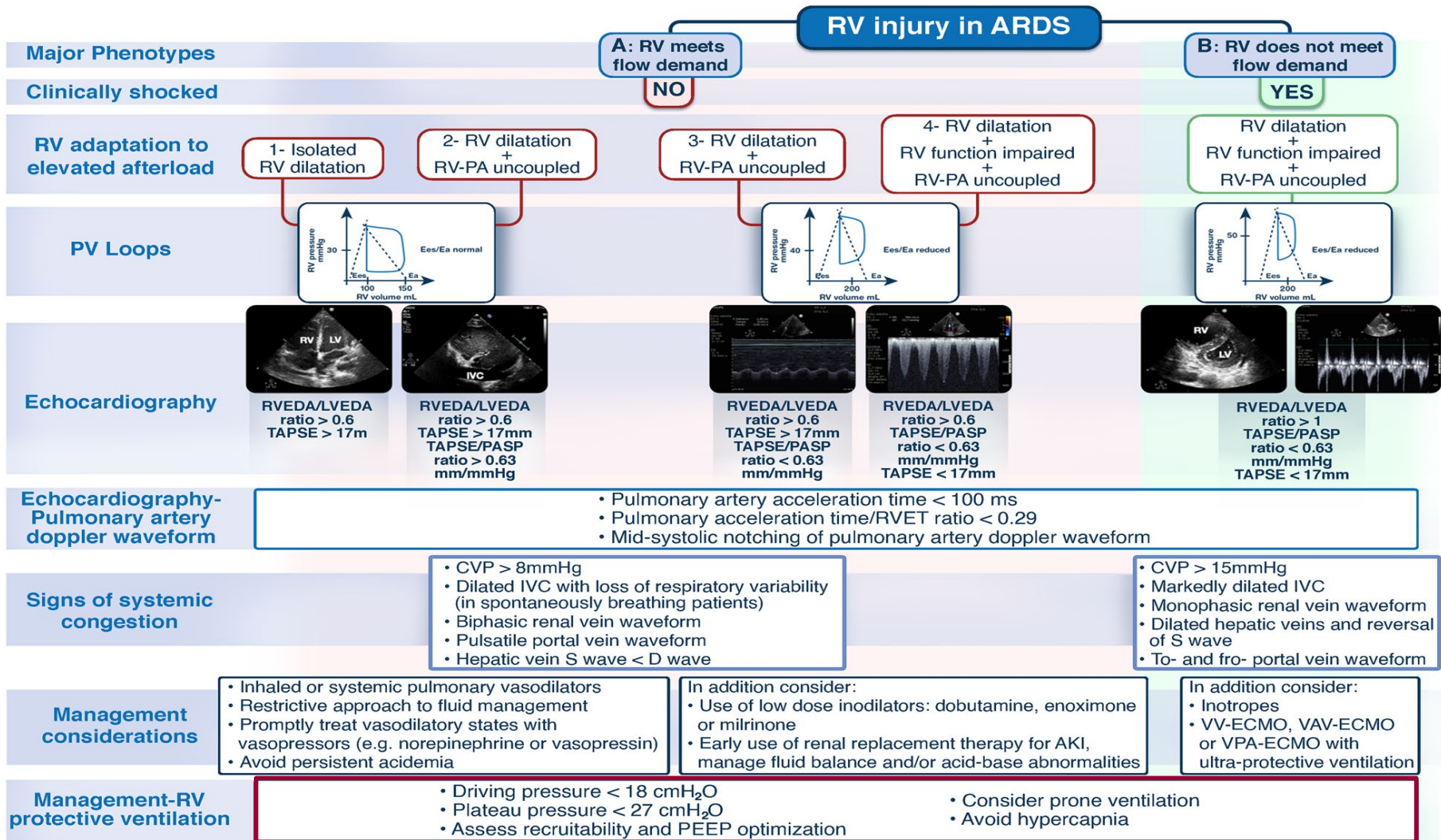


Limitation of Natriuretic Peptides



RV Protective Ventilation

Protecting the Right Ventricle Network (PRORVnet)



Change of Therapeutic Strategies in ARDS

From LPV to RV Protective Ventilation



VILI

1990 – 2000

High V_T

Normocapnia

▶ High mortality with VILI

LPV

2000 – 2020

LPV

Permissive hypercapnia

▶ Decreased mortality with LPV

RV Protective Ventilation

2020...

↓ Driving pressure

↑ Alveolar oxygenation

↓ Blood CO_2

▶ More decreased mortality ?

Need for RCTs