Pulmonary Vascular Disease

Anaesthetic implications and strategies

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Outline

- Case study
- Background
- RV physiology
- Implications for anaesthetists, cardiologists and surgeons
- Management

Case study

- Young female in her 20's
- Previously corrected CHD now with moderate-severe pulmonary hypertension and arrhythmias
- Presenting for generator change under local + sedation…
  - IVDU (still occasional use)
  - 40mg methadone daily (plus benzos, oxycodone, smoker…)
  - Severe anxiety and chronic pain fearful of being awake

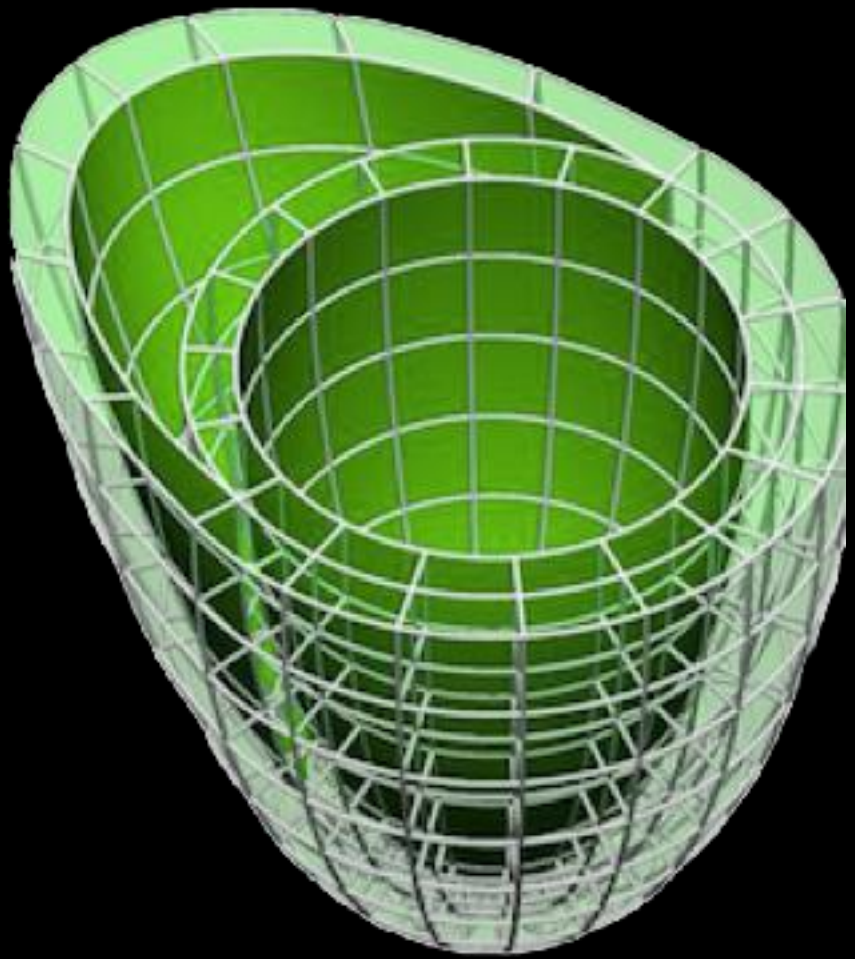
Case study

- Supplemental oxygen via mask
- Sedation with midazolam and small doses of ketamine
- Adequate plane of sedation and tolerated LA well
- With deeper dissection well became tachycardic requiring more sedation…..
  - Suddenly apnoeic
  - Rapidly hypoxic
  - Severe systemic hypotension

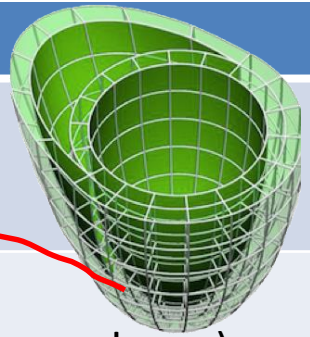
Background

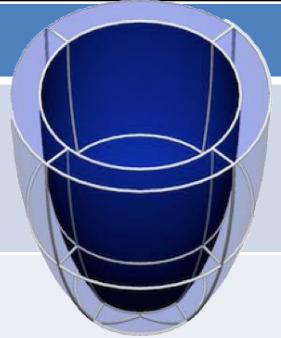
- Severe pre-op PHT significant independent mortality risk factor in both cardiac and non-cardiac surgery
  - (Reich 1999) 145 patients for non-cardiac surgery with avg. sPAP 68 mmHg
    - 11% - CCF
    - 3.5% - died from RV failure
  - (Lai 2007) 62 patients for non-caridac surgery with avg. sPAP 79 mmHg
    - 9.7% cardiac mortality vs 0% in matched controls

RV PHYSIOLOGY



	RV	LV
Wall	Thin (<5mm)	Thick (7-11mm)
Contraction	Bellows like Traction by LV (interdependence)	Twisting rotational
EF	Lower (40-45%) Same SV (large SA:vol ratio)	Higher (50-55%)
Afterload (dyne•s•cm^{-5})	Low PVR 70 (20-130)	High SVR 1100 (700-1600)
CBF	Lower CBF (0.4-0.7ml/min/g) Lower oxygen extraction (50%) Normally in both systole and diastole	Higher CBF Higher Oxygen extraction (75%) Occurs mostly in diastole
Stroke work	Lower stroke ~ 1/4th LV	Higher stroke work





RV

PRELOAD

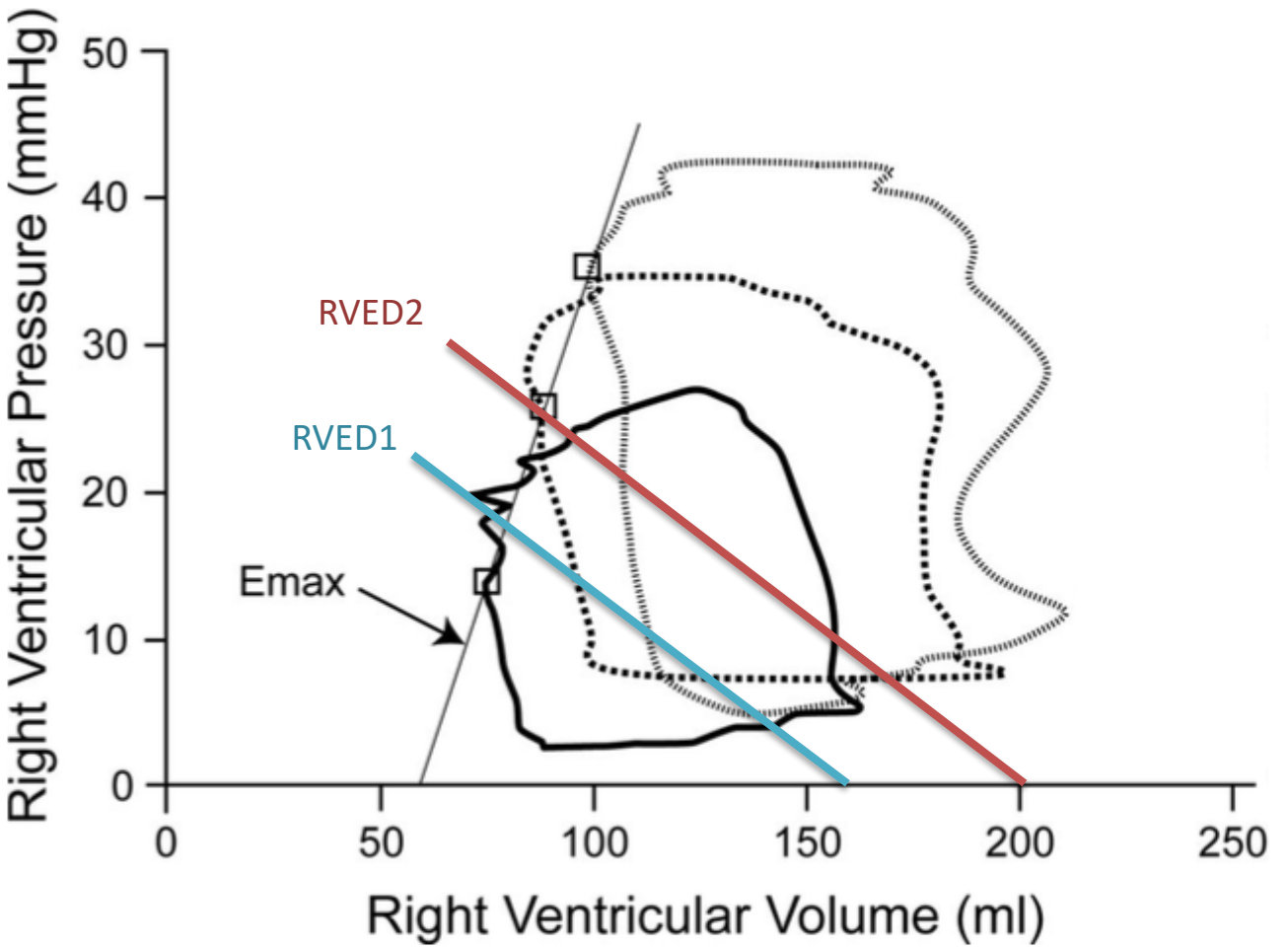
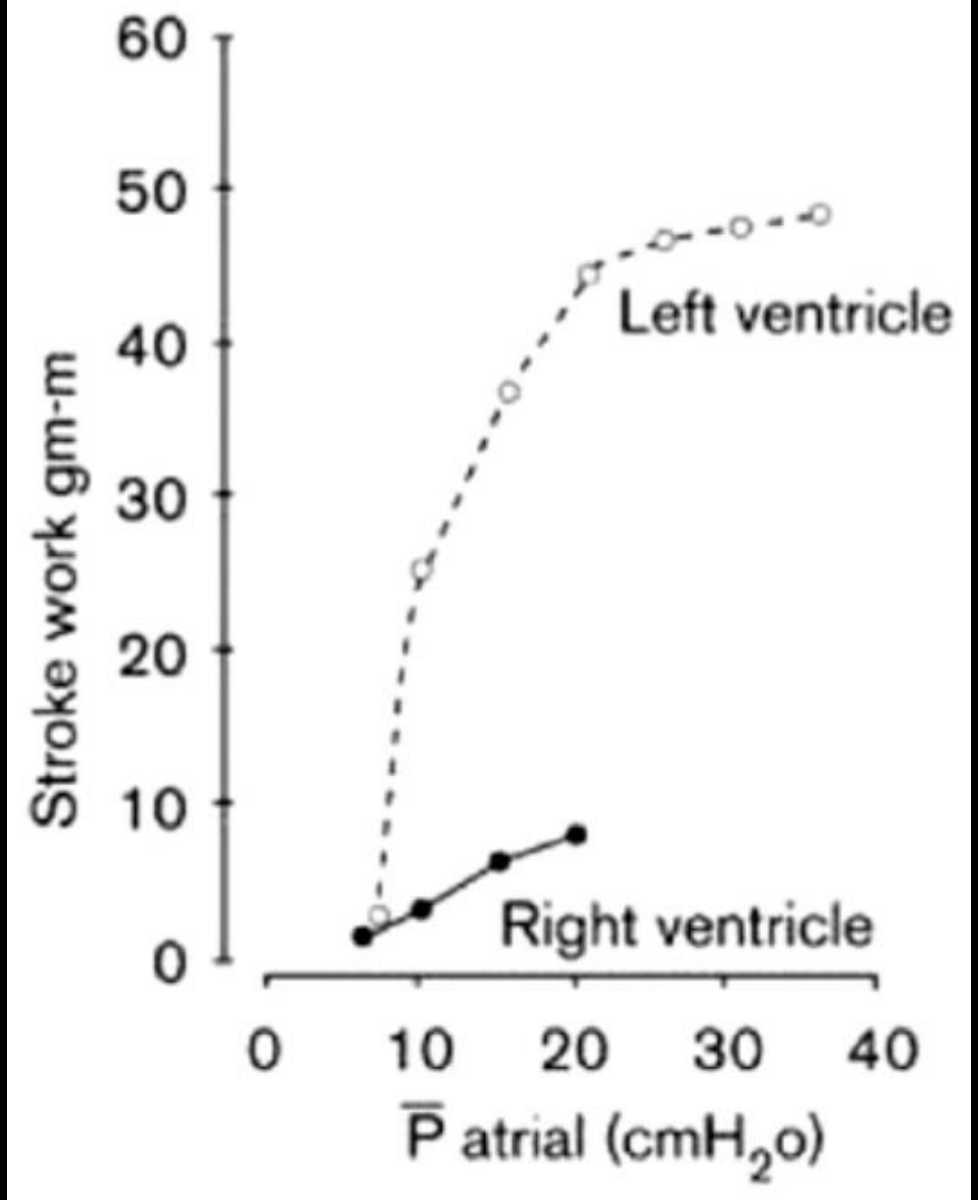


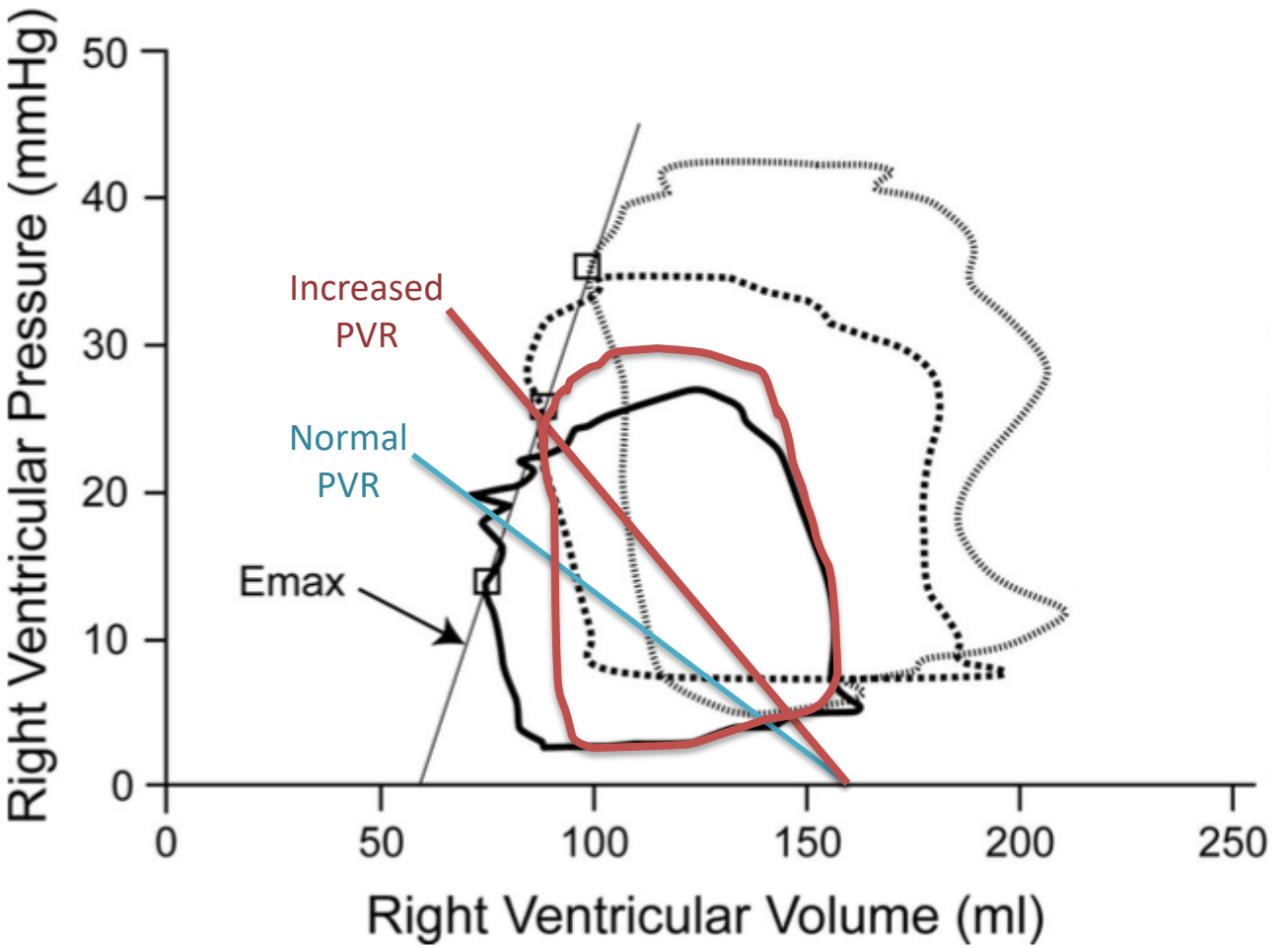
Figure 2. Pressure-volume loops of the right ventricle under different loading conditions. The slope of maximum time-varying elastance (E_{max}) is displayed on the graph. Adapted from Dell'Italia et al.[16]



RV adapts to ↑ ↑ preload well with only a modest increase in stroke work

RV

AFTERLOAD (PVR)



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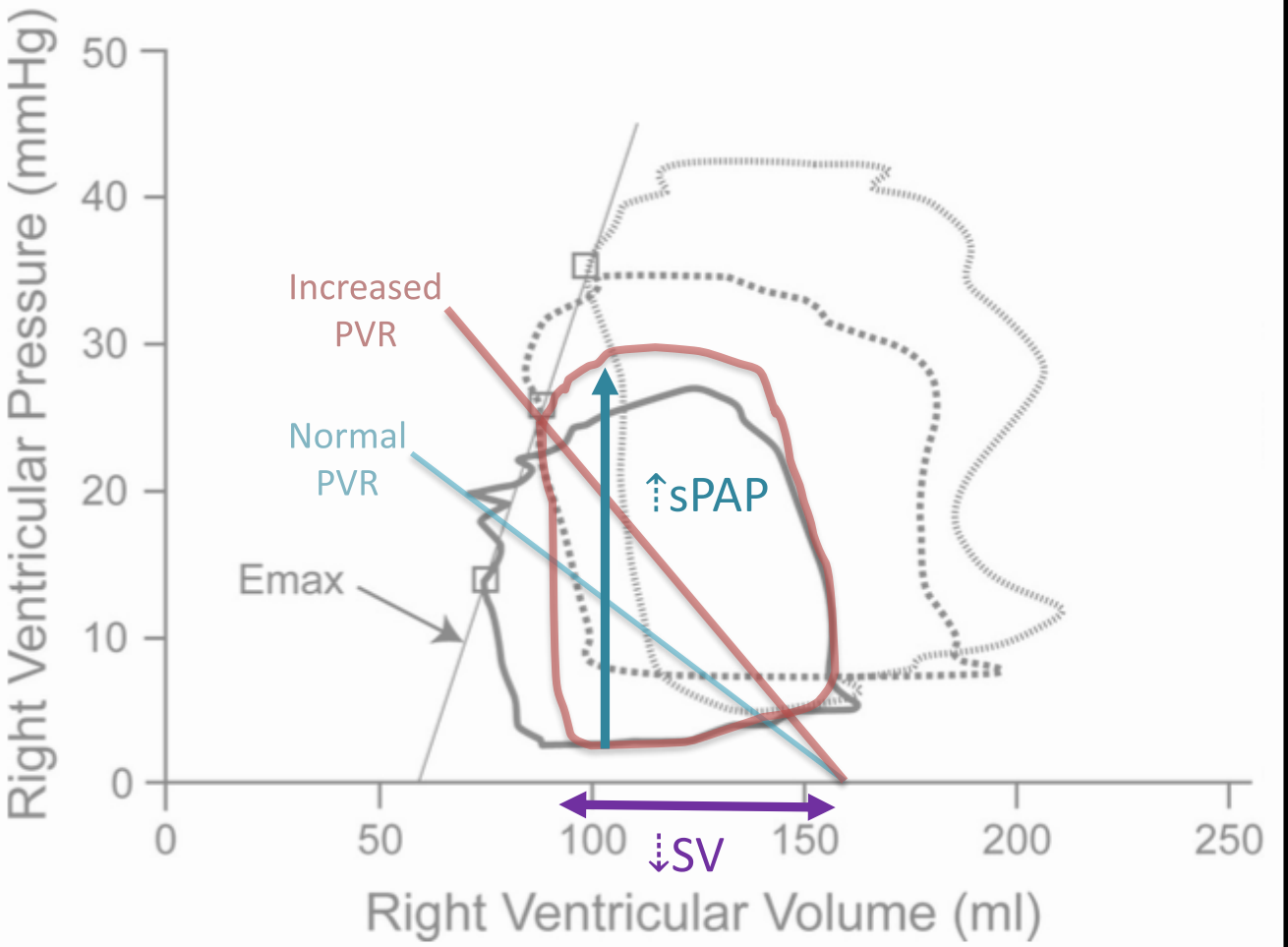

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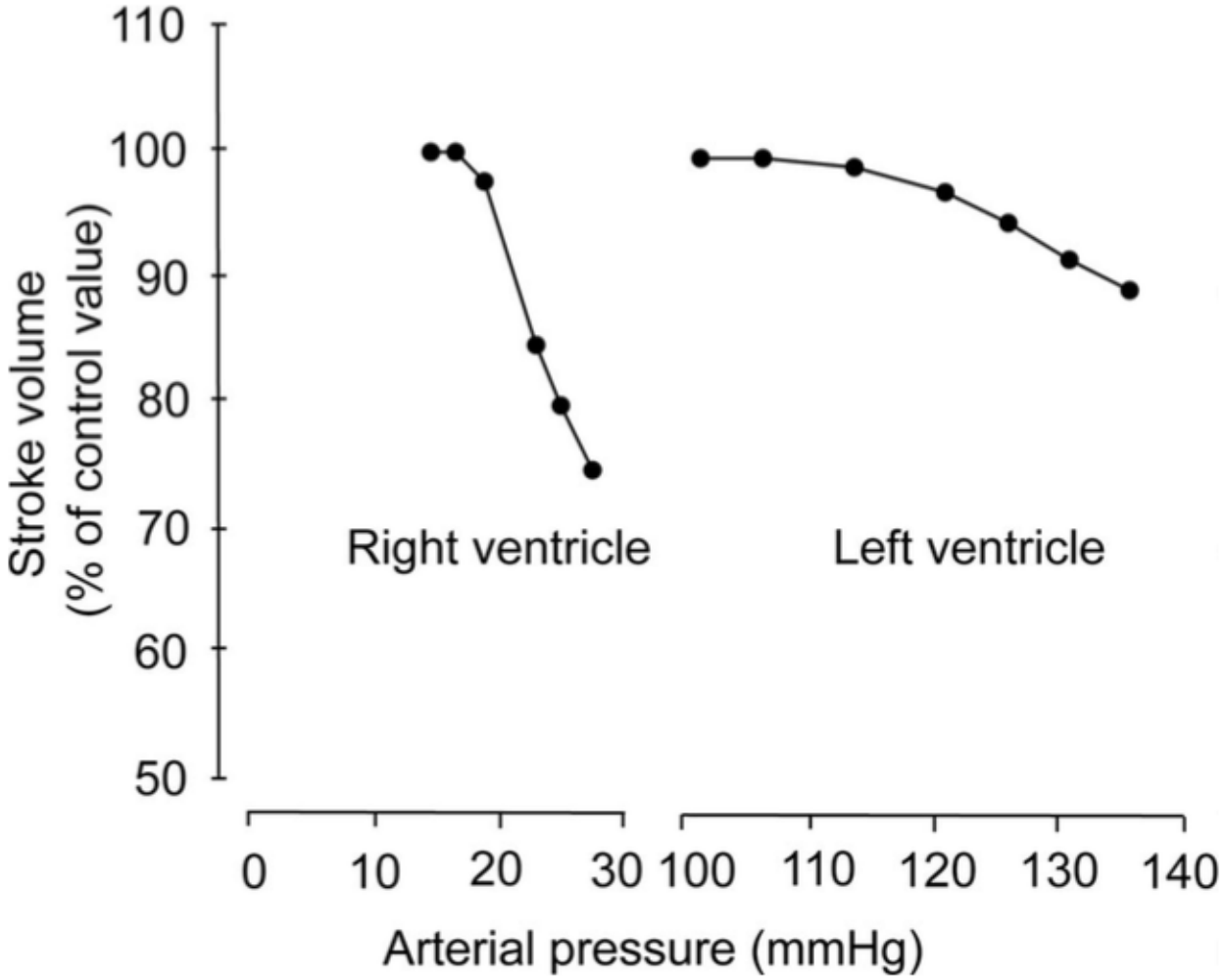


Figure 3. The response of the right and left ventricle to experimental increase in pressure or afterload. Adapted from MacNee et al.[18]

RV tolerates increased afterload (PVR) poorly with ↓↓ in SV

RV

LUNG VOLUME

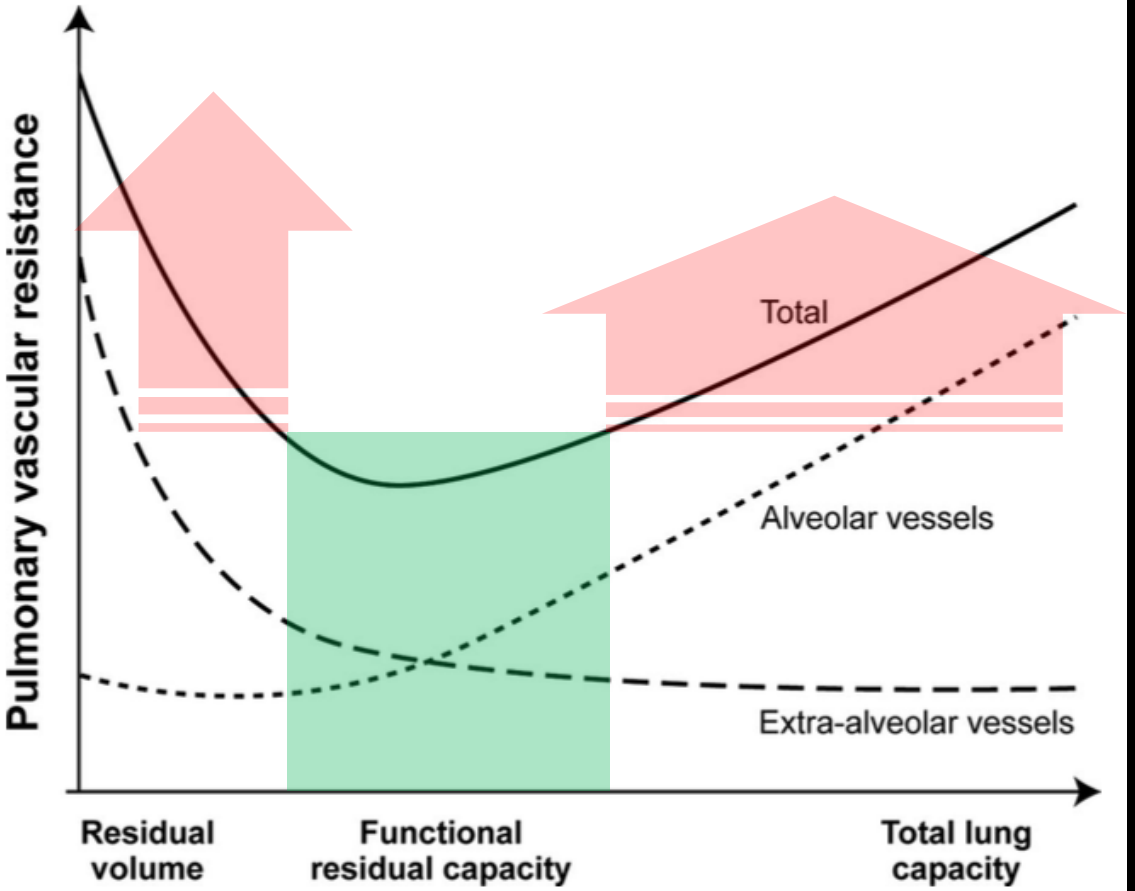
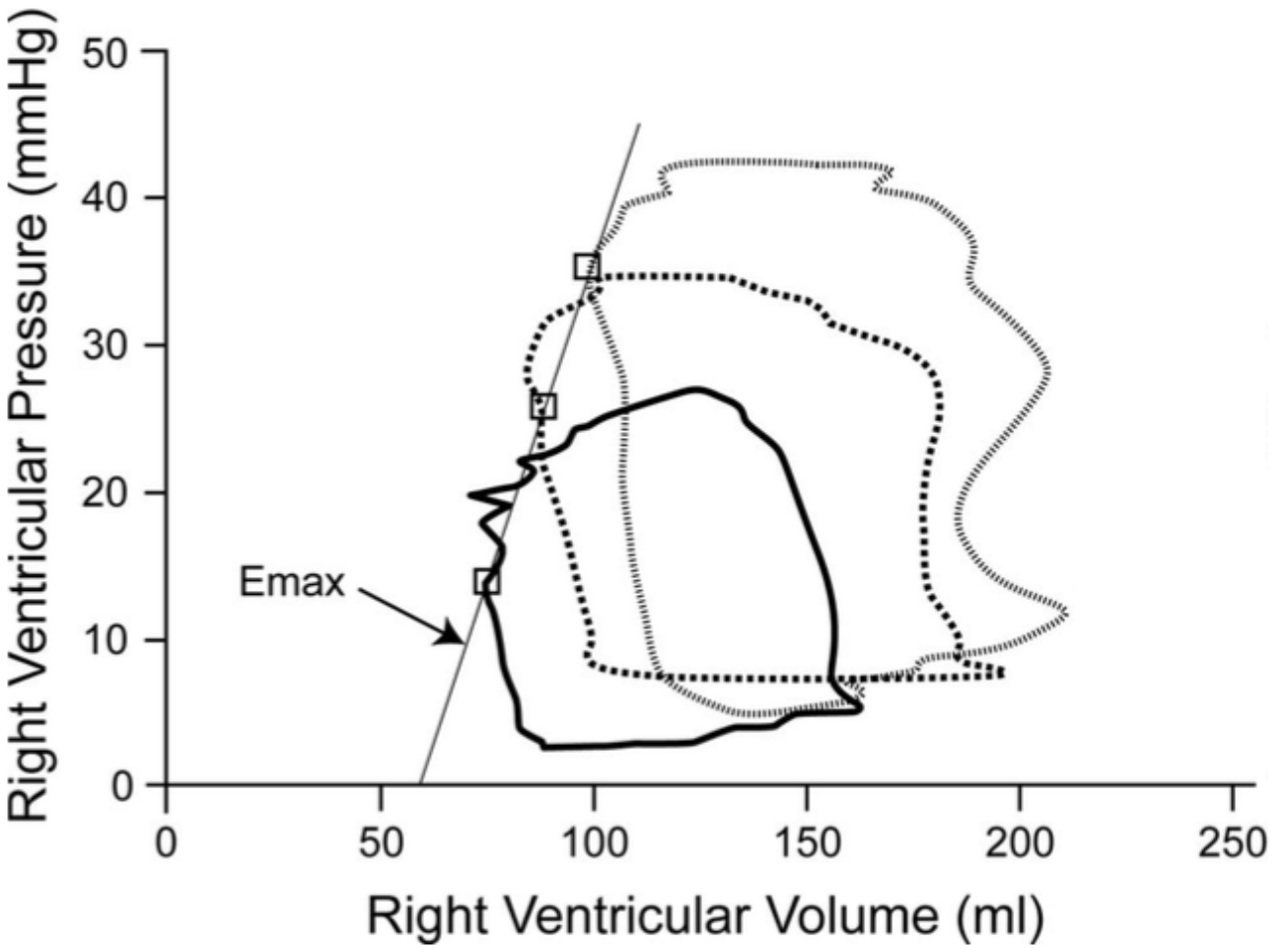


Figure 4. Relationship between lung volume and pulmonary vascular resistance (PVR). As lung volume is reduced or increased, the increase in PVR result from compression of the alveolar and extraalveolar vessels. RV = residual volume; FRC = functional residual capacity; TLC = total lung capacity. Adapted from Fischer et al.[20]

RV

CONTRACTILITY



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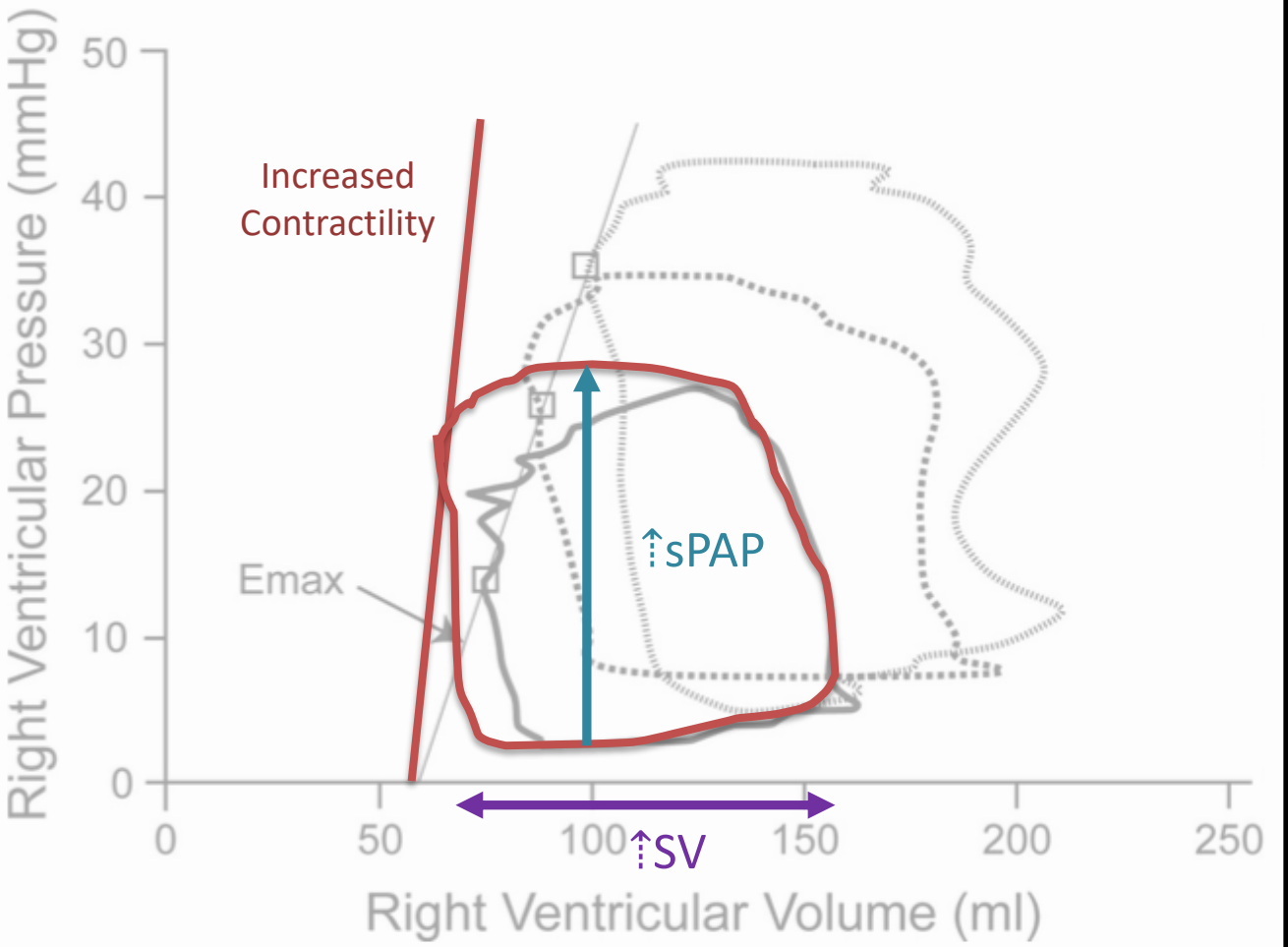

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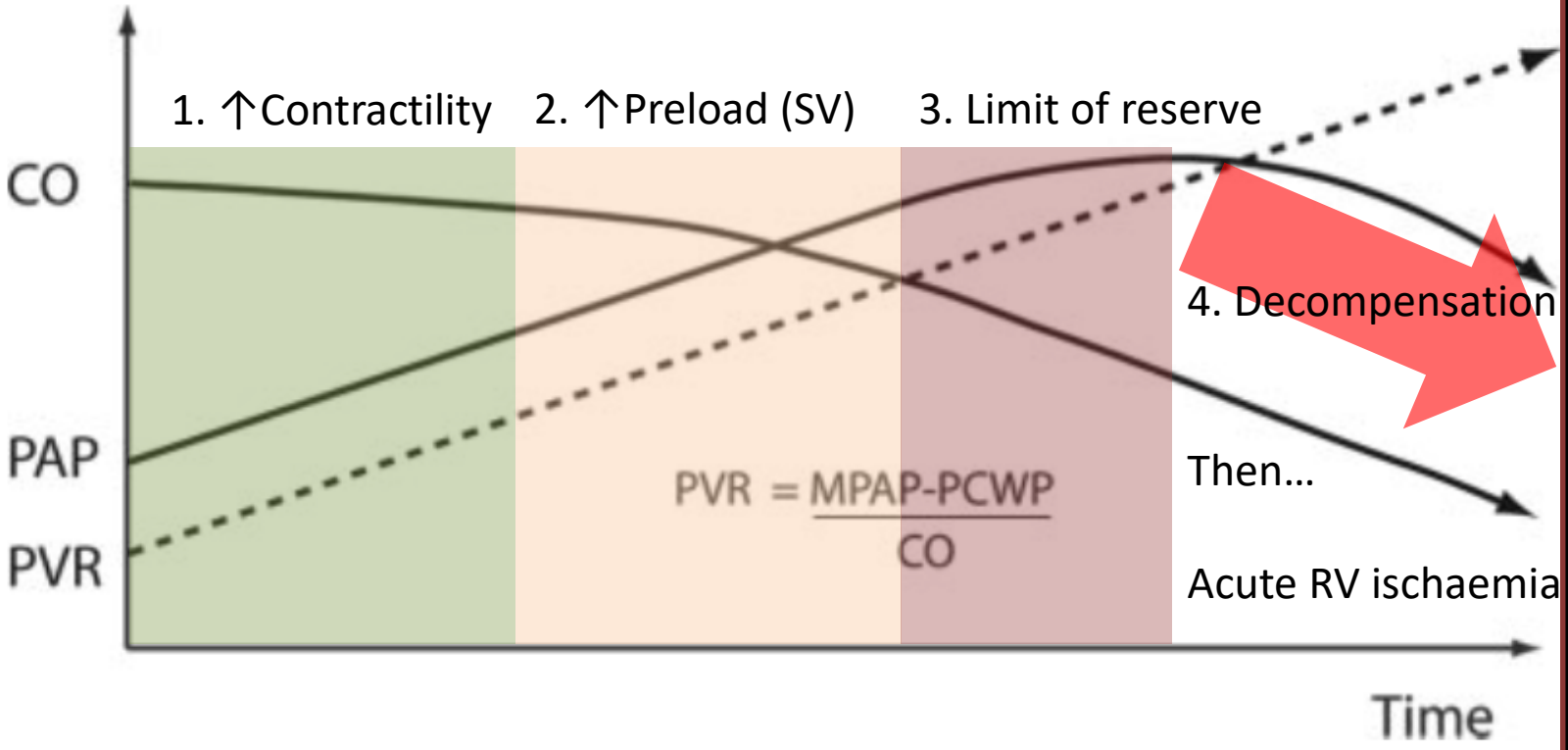


Figure 4. Hemodynamics in progressive pulmonary vascular disease. A decrease in pulmonary arterial pressure (PAP) in patients with PH may be a sign of low cardiac output (CO) and severe RV failure. PVR indicates pulmonary vascular resistance; PCWP, pulmonary artery capillary wedge pressure; and MPAP, mean PAP.

ANAESTHETIC IMPLICATIONS

RV versus LV

RV

- Less prone to ischaemia

EXCEPT when chronic pressure overload results in RV hypertrophy

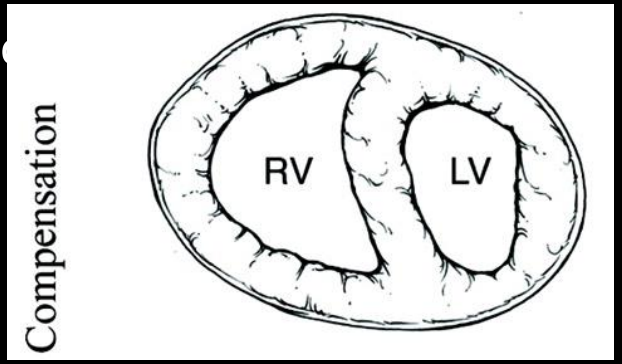
- Tolerates volume overload better

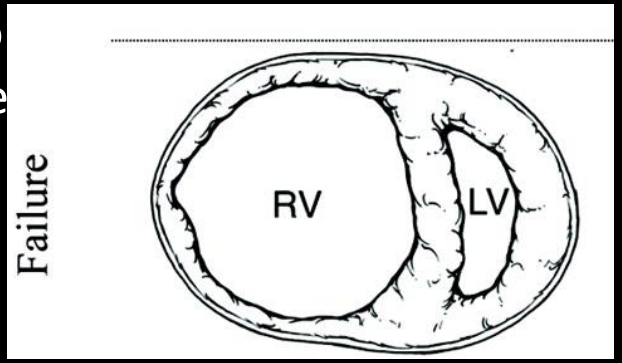
EXCEPT when dilatation of RV (+/- LV) affects geometry

LV

- M

- To
be





PAP

PAP: chronic > acute
- RV hypertrophy
- CO preserved

PAP alone does not predict the functional state of the RV!

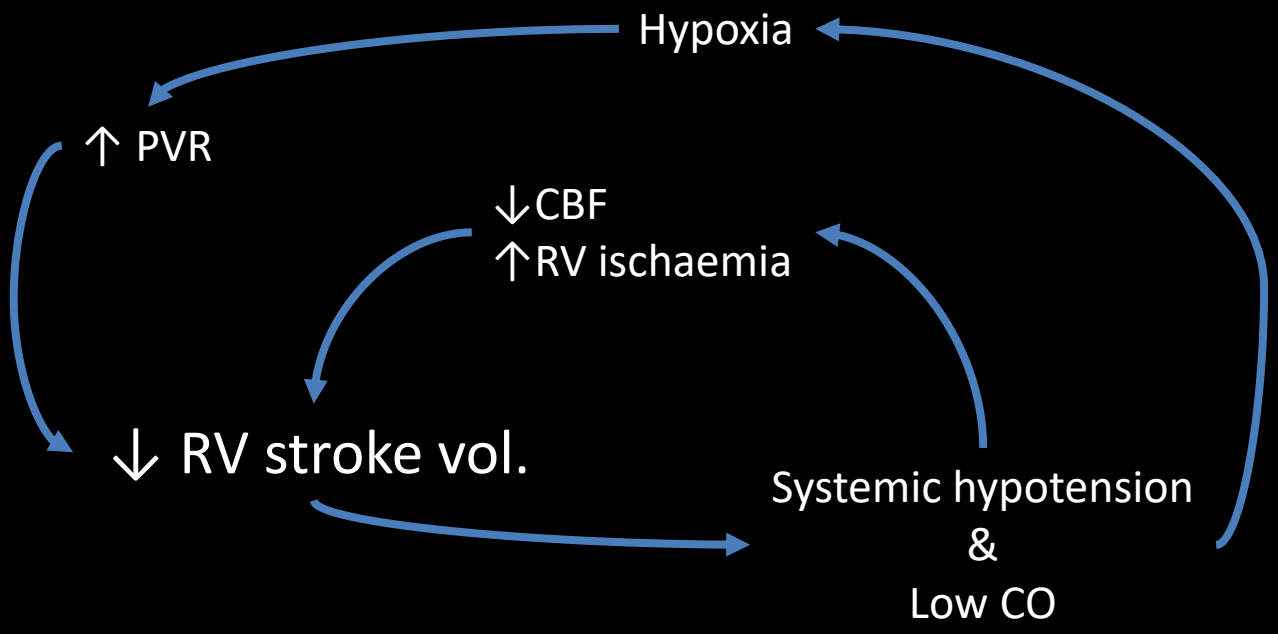
- ↑CO + fixed PVR will ↑PAP
- ↓CO (failing RV) may pseudo-normalise the PAP

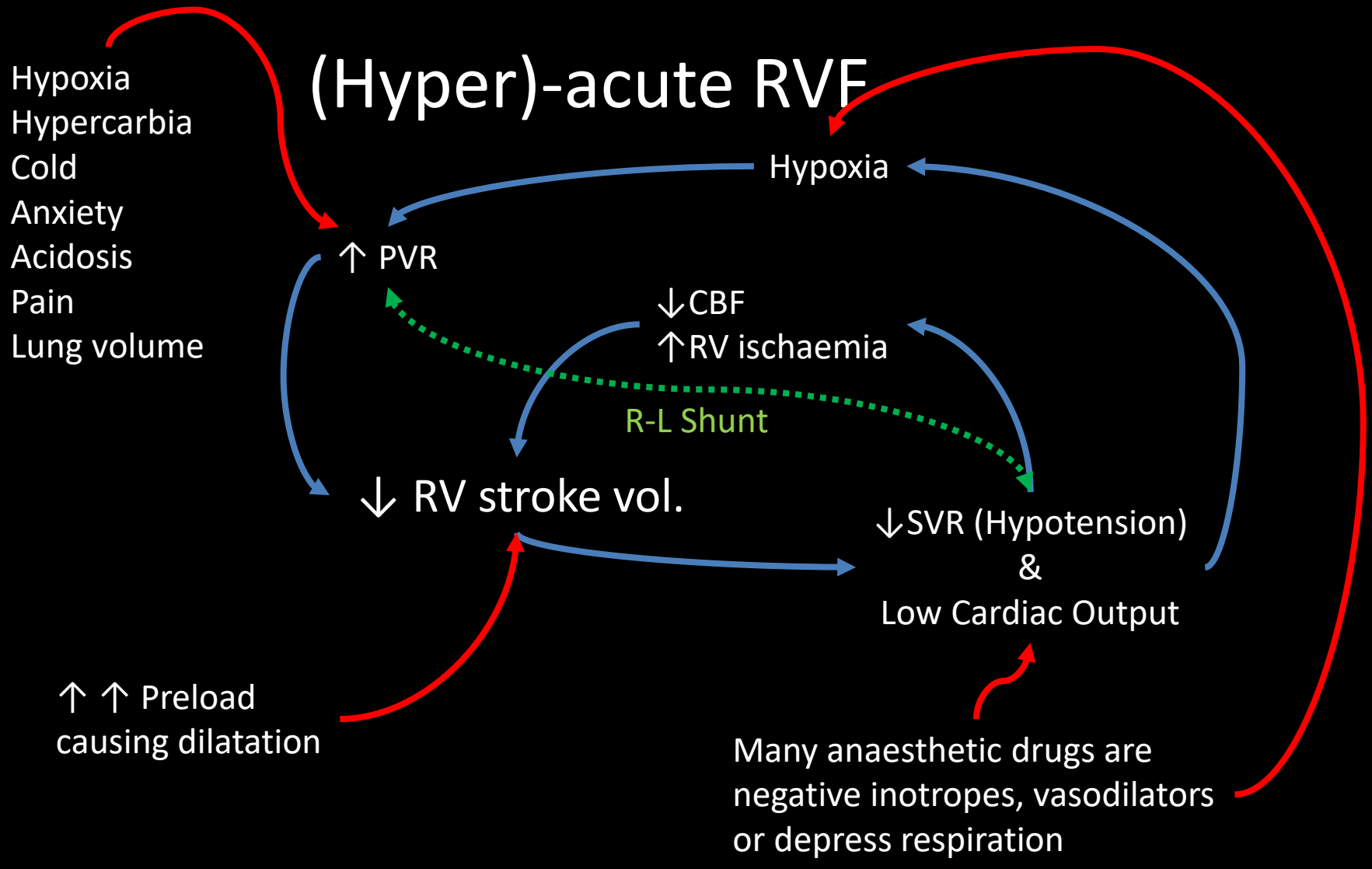
mPAP = PVR x CO + LAP

Gp 1 – Arterioles (IPAH, scleroderma)
Gp 3 – lung hypoxia (COPD, OSA)
Gp 4 – CTEPH
Gp 5 – misc. (sarcoidosis)

Gp 2 – LH disease (MV, AV, DHF, CM)

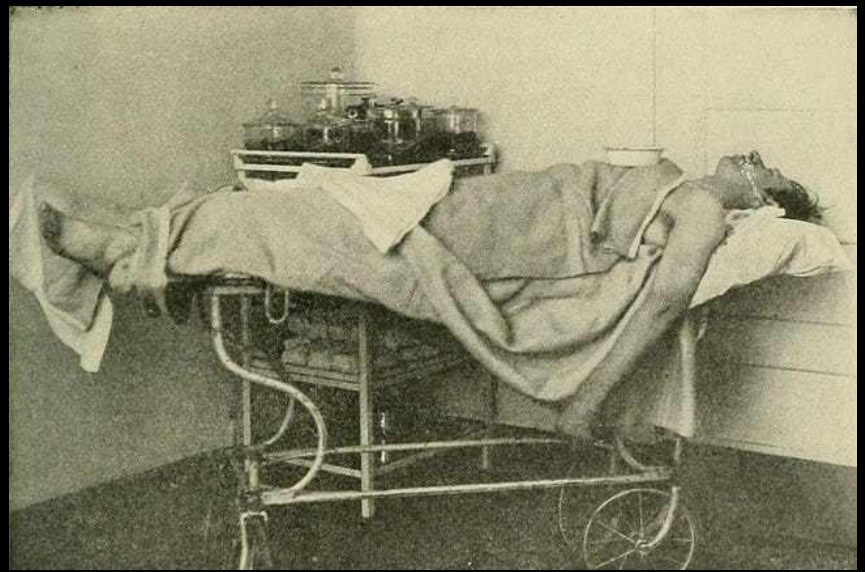
acute RVF (spiral)




Hypoxia
Hypercarbia
Cold
Anxiety
Acidosis
Pain
Lung volume
(Hyper)-acute RVF
Hypoxia
↑ PVR
↓CBF
↑RV ischaemia
R-L Shunt
↓ RV stroke vol.
↓SVR (Hypotension)
&
Low Cardiac Output
↑ ↑ Preload
causing dilatation
Many anaesthetic drugs are
negative inotropes, vasodilators
or depress respiration

Hyper-acute RV failure

- Most common sequence of events leading to death:
  - Minor stimulation
  - Tachycardia (and/or)
  - Increased PVR
  - Refractory cardiovascular collapse



MANAGEMENT

TABLE 1

Summary of anaesthetic recommendations for patients at risk of right ventricular decompensation. The level of monitoring recommended is patient-specific and not procedure-specific.

Intervention	No PHT: RVF	Severe PHT: no RVF	Severe PHT: RVF
Premedication			
sildenafil 25-50 mg po	–	–	+
Pre-induction			
iloprost (10 μg) neb	–	+/–	+
Monitoring			
CVP: spontaneous ventilation	–	–	–
IPPV	+	+	+
invasive BP: spontaneous ventilation	–	–	+
IPPV	+	–	+
PAC (or other cardiac output monitor)			
spontaneous ventilation	–	–	+
IPPV	–	–	
TOE	+/–	–	+/–

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Intervention	No PHT: RVF	Severe PHT: no RVF	Severe PHT: RVF
Neuraxial anaesthesia	+	+	+
Ventilation			
high FiO_2	+	+	+
mild hyperventilation	+	+	+
low ventilating pressures	+	+	+
Anaesthetic agents	+	+	+
ketamine: children	+	+	+
ketamine: adults	+/–	–	–
thiopentone/etomidate	+	+	+
propofol	+	+	–
N_2O	–	–	–
isoflurane/halothane/enflurane	+	+	+
desflurane	–	–	–
fentanyl/sufentanil/remifentanil	+	+	+

RVF=right ventricular failure, PHT=pulmonary hypertension, NO=nitric oxide, N_2O=nitrous oxide, PEEP=positive end-expir pressure, CVP=central venous pressure, TOE=transoesophageal echocardiography, PAC=pulmonary artery catheter, BP=bloo pressure, IPPV=intermittent positive pressure ventilation, BP=blood pressure, +=recommended, – =not recommended.

TABLE 2

Summary of recommended pharmacologic therapies for perioperative right ventricular failure

	PVR normal	PVR high
Pulmonary vasodilators		
NO (10 ppm)	–	+
iloprost (10 μg neb)	–	+
milrinone (2-5 mg neb)	–	+
sildenafil (50 mg po)	–	+
Vasopressors		
phenylephrine	+	+/–
noradrenaline	+	+
vasopressin	+	+
Inotropes		
dobutamine	+	+
adrenaline	+	+
milrinone	+	+
levosimendan	+	+

PVR=pulmonary vascular resistance, NO=nitric oxide, +=recommended, – =not recommended.

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INHALED AGENTS

Iloprost (stable analogue of prostacyclin)

- Clinical duration 60min
- Easy to deliver via nebuliser
- No specialized equipment needed (unlike iNO)
- Do not need to be intubated (unlike iNO)
- May be more effective than iNO in some situations (IPAH)

- Both milrinone and Iloprost can be given together (milrinone neb/IV)

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vasopressin	+	+
Inotropes		
dobutamine	+	+
adrenaline	+	+
milrinone	+	+
levosimendan	+	+

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INOTROPIC AGENTS

Adrenaline

- ↓PVR, PAP and PVR:SVR ratio sig. more than dopamine

Dobutamine

- Drug of choice for RV infarction
- Increases RV contractility without effecting PVR

Acute RV Failure

Table 11: Specific interventions for therapy of intra- and/or postoperative increase of pulmonary arterial pressure (mod. [30, 31, 38, 39, 48, 59, 60]).

Reduction of right-ventricular afterload:	
Intravenous vasodilation	
(1) Milrinone	50 μg/kgBW bolus, followed by 0,5–0,75 μg/kgBW/min continuously
(2) Dobutamine	2–5 μg/kgBW/min continuously
(3) Prostacyclin	4–10 ng/kgBW/min continuously
(4) Na-nitruprusside	0,2–0,3 μg/kgBW/min continuously
(5) Nitroglycerine	2–10 μg/kgBW/min continuously
Pulmonary-selective inhalative vasodilatation	
(1) Iloprost	5–10 μg for 10–15 min (by untrasonic nebulizer)
(2) Nitrogen monoxide	0,5–20 ppm continuously
(3) Prostacyclin	30–40 ng/kgBW/min continuously
(4) Milrinone	2 mg (−5 mg) for 10–15 min (diluted in 10–15 mL NaCl0,9%)

Acute RV Failure

- Which vasopressor?
  - Noradrenaline:
    - Improves SVR (coronary perfusion, increases LVEDP and shifts septum towards RV and thus may improve RV function)
    - Increases PVR - though no reduction in RVEF
  - Vasopressin
    - Vasopressin binds to V1 receptors on vascular smooth muscle cells
    - At lower doses (e.g., 0.01–0.03 U/min), it causes pulmonary vasodilatation via stimulation of endothelial nitric oxide
    - At high doses, it increases responsiveness to catecholamines and causes pulmonary and coronary artery vasoconstriction

Vasoconstrictor Responses to Vasopressor Agents in Human Pulmonary and Radial Arteries

An In Vitro Study

Dale A. Currigan, M.B.B.S., Richard J. A. Hughes, B.Sc.Hons., M.Phil., Christine E. Wright, B.Sc.Hons., Ph.D., James A. Angus, B.Sc.Hons., Ph.D., Paul F. Soeding, B.Sc.Hons., Ph.D., M.B.B.S.

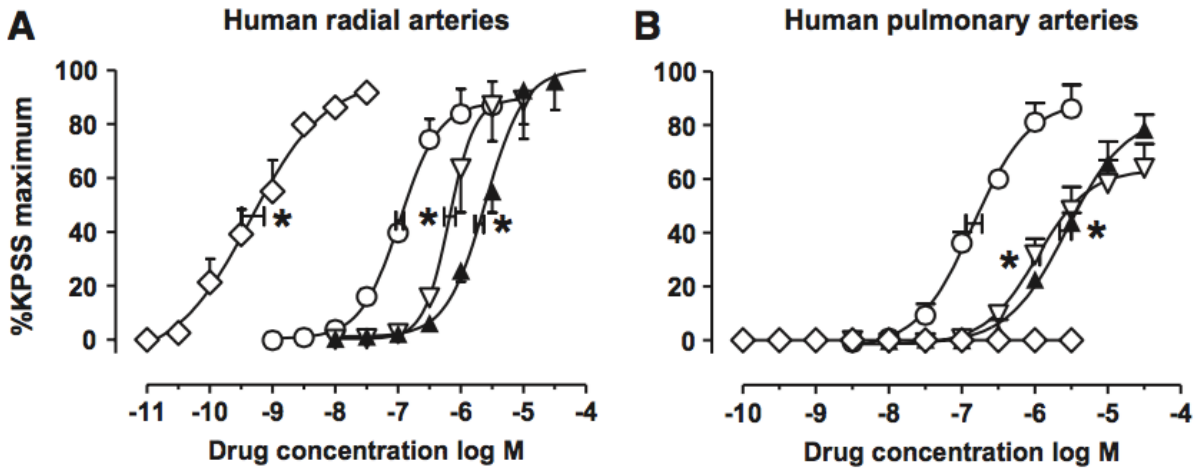
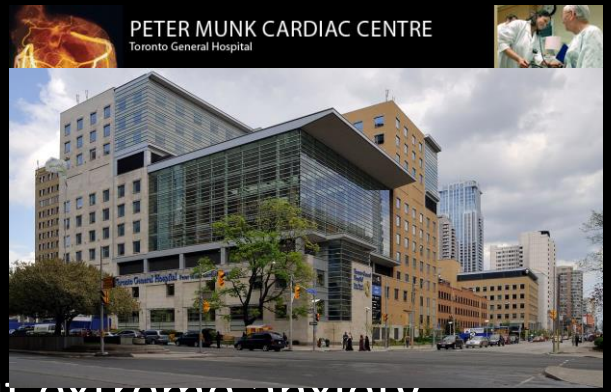


Fig. 1. Contractile responses to vasopressor agents in human isolated (*A*) radial and (*B*) pulmonary arteries. Cumulative concentration–response curves to arginine vasopressin (◇, $n = 4$), norepinephrine (○, $n = 4$), phenylephrine (▽, $n = 4$), or metaraminol (▲, $n = 3$–5) were constructed in each tissue. Data are shown as a percentage of KPSS (potassium depolarizing solution) maximum contraction. *Vertical error bars* are ±1 SEM; where no error bar is visible the SEM is within the symbol. *Horizontal error bars* represent EC_{50} ± 1 SEM. n = number of arteries each from different patients. *$P < 0.01$ (one-way analysis of variance, Dunnett's post hoc comparison to norepinephrine).



Case study

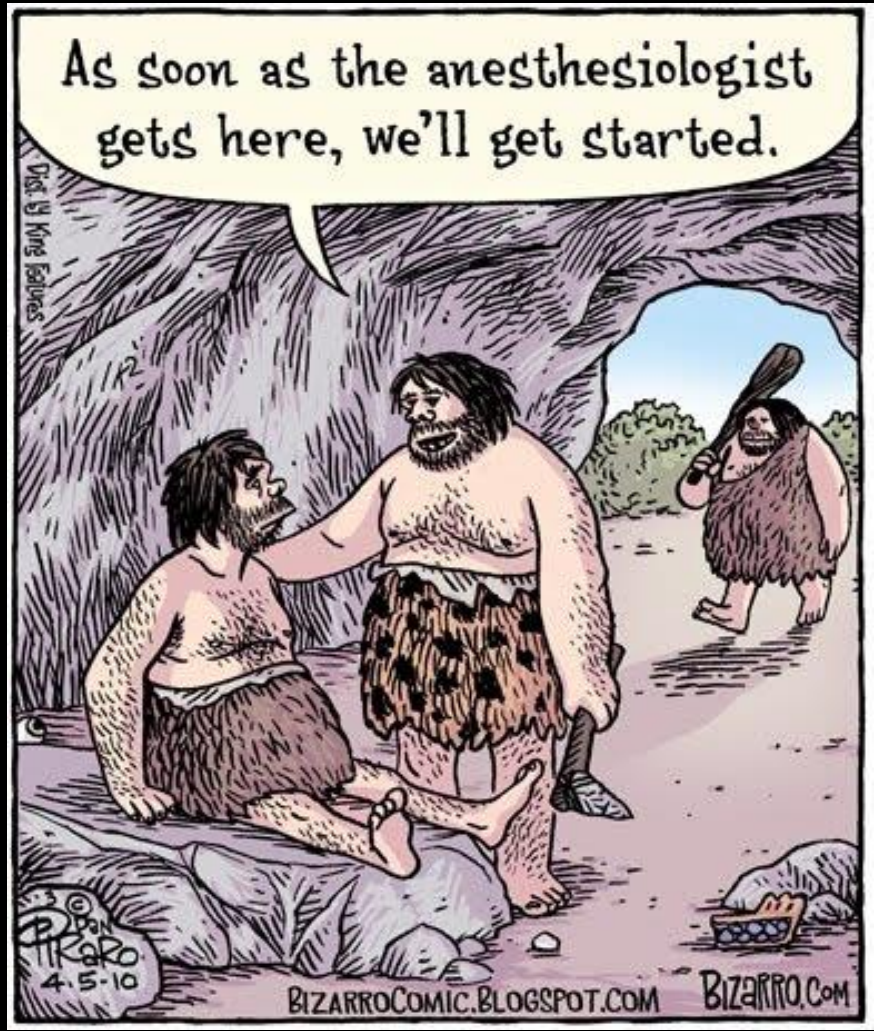
- What went wrong?
  - Difficult balance of opiod/drug tolerance but extreme anxiety
  - Ketamine possibly not the best choice (adults vs kids)
  - Pain resulting in sudden tachycardia + apnoea causing rapid increase in PVR
- Treatment
  - Adrenaline (this was pre-arrest)
  - Reverse trendelenberg (off loads the RV)
  - Diuresis and brief period of mechanical ventilation and low dose-inotropes in recovery
  - Extubated 2 hours later feeling very good without any harm

Summary

- Anaesthesia (GA or Sedation) can quickly transform a stable patient to acute RV failure
  - Anaesthetic drugs are negative inotropes / vasodilators
  - Airway issues / sedation can lead to hypoxia / hypercarbia
  - Invasive monitoring critical in many (but not necessarily all)
  - Attention to detail paramount
- Golden Rule = Good exercise tolerance is a good thing! Probably be okay

"Correct. And in the case of arrest, every second counts. Who can tell me why? Anyone? Clock's ticking."

RV failure /



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