Pulmonary Hypertension and RV Dysfunction

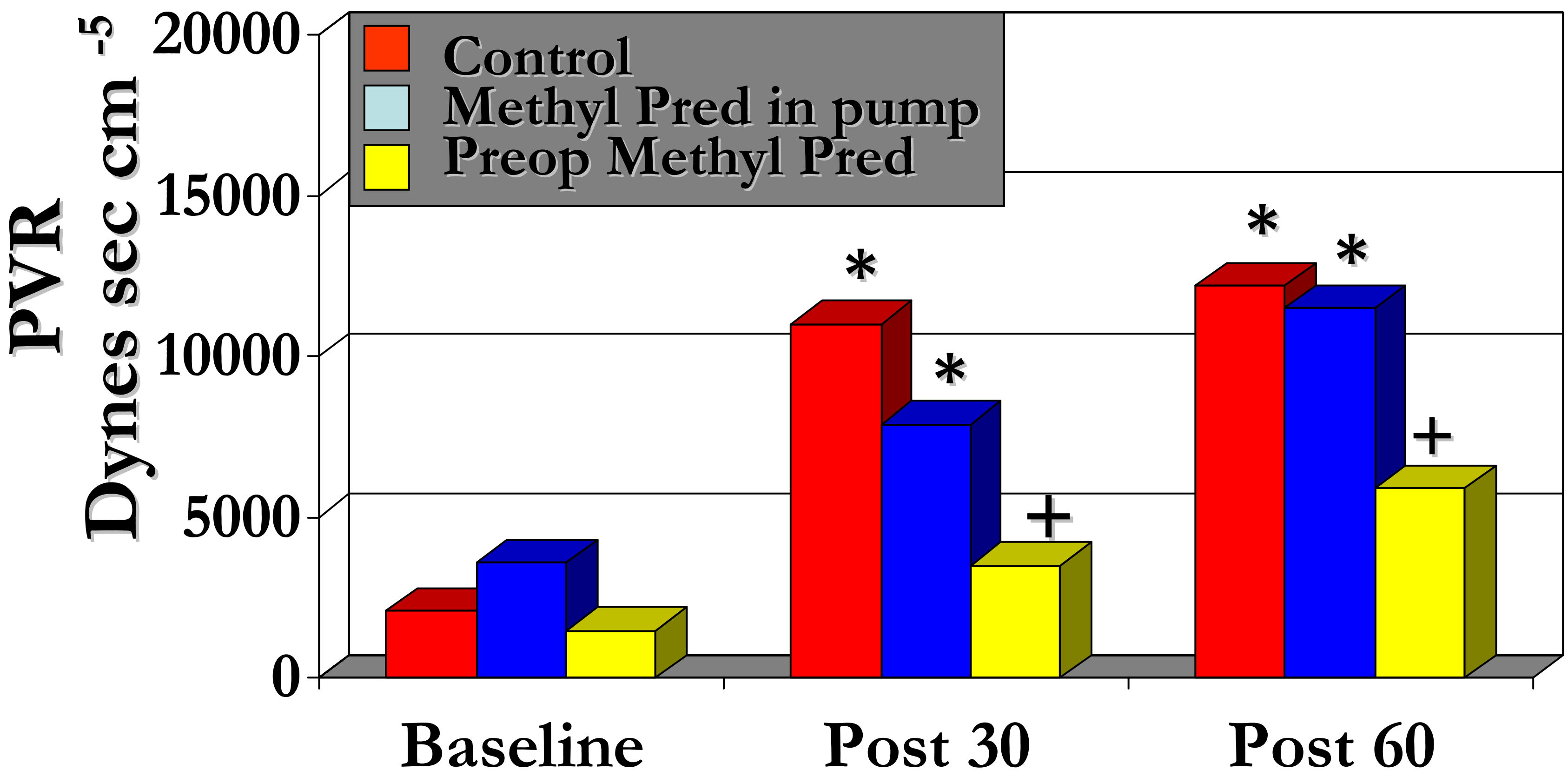
Pathophysiology of PAH

- **Development of a pathologic elevation in pulm vascular resistance**
- **Criteria**
  - **Mean PAP > 20 mmHg**
  - **Systolic PAP > 30 mmHg**
  - **Pulm vascular resistance >3 woods units**
- **Newborns with hypoxia, acidosis or sepsis**
- **CHD with R to L shunts, obstructed veins, mitral valve stenosis and**

RV Dysfunction

- **RV dysfunction – Dreaded complication of PAH**
  - **Sudden increase in PAP**
  - **PAH climbs to systemic / supersystemic PAP**
  - **Specific cardiac lesions: TAPVR, R – L shunt**
  - **Exposure to CPB (↓NO and ↑Endothelin - 1)**
  - **Surgery: Changing loading conditions**
    - **Transannular patch in TOF**

Effects of CPB on PVR: The Role of Steroids

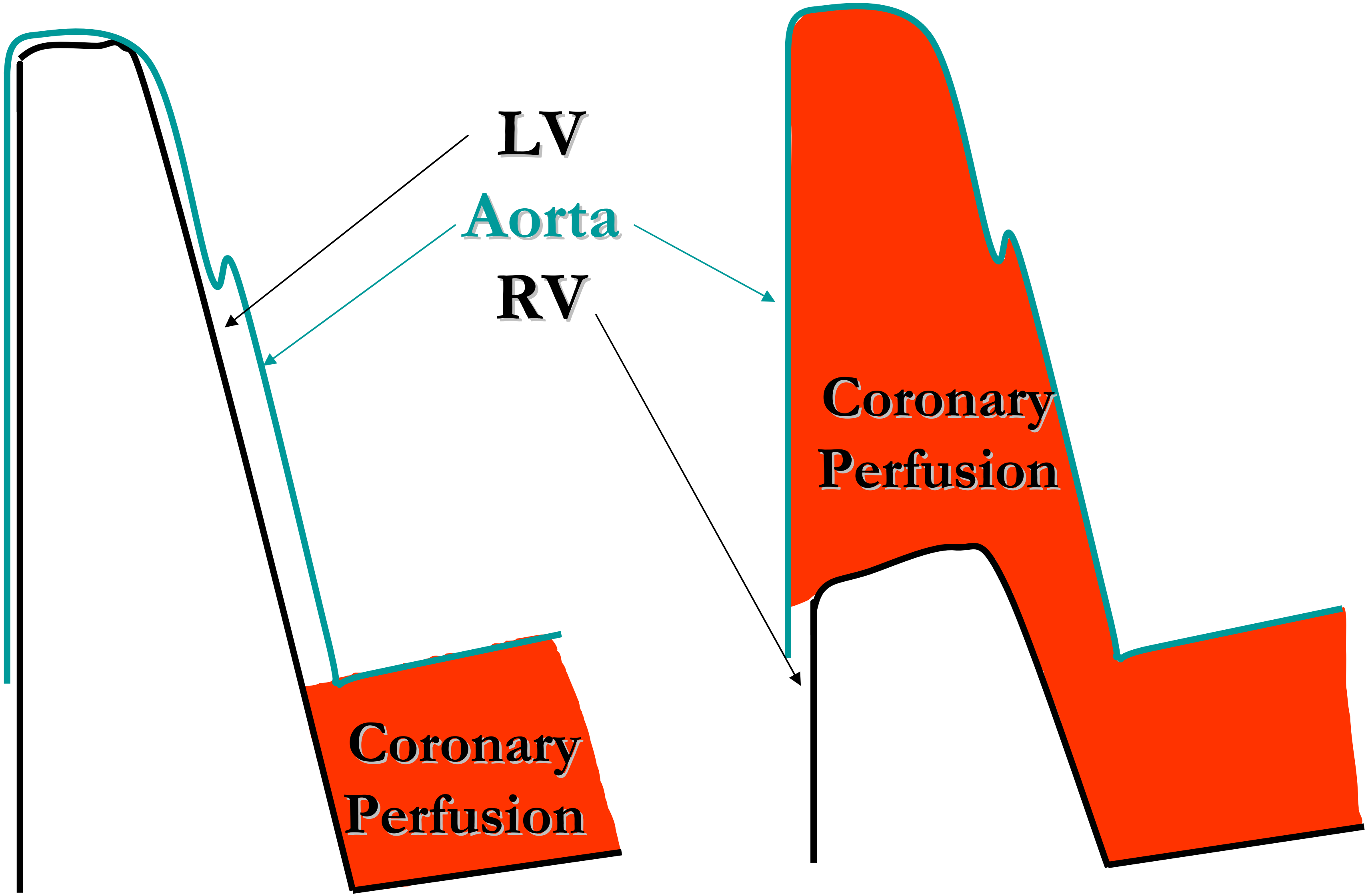


Lodge AJ 1999

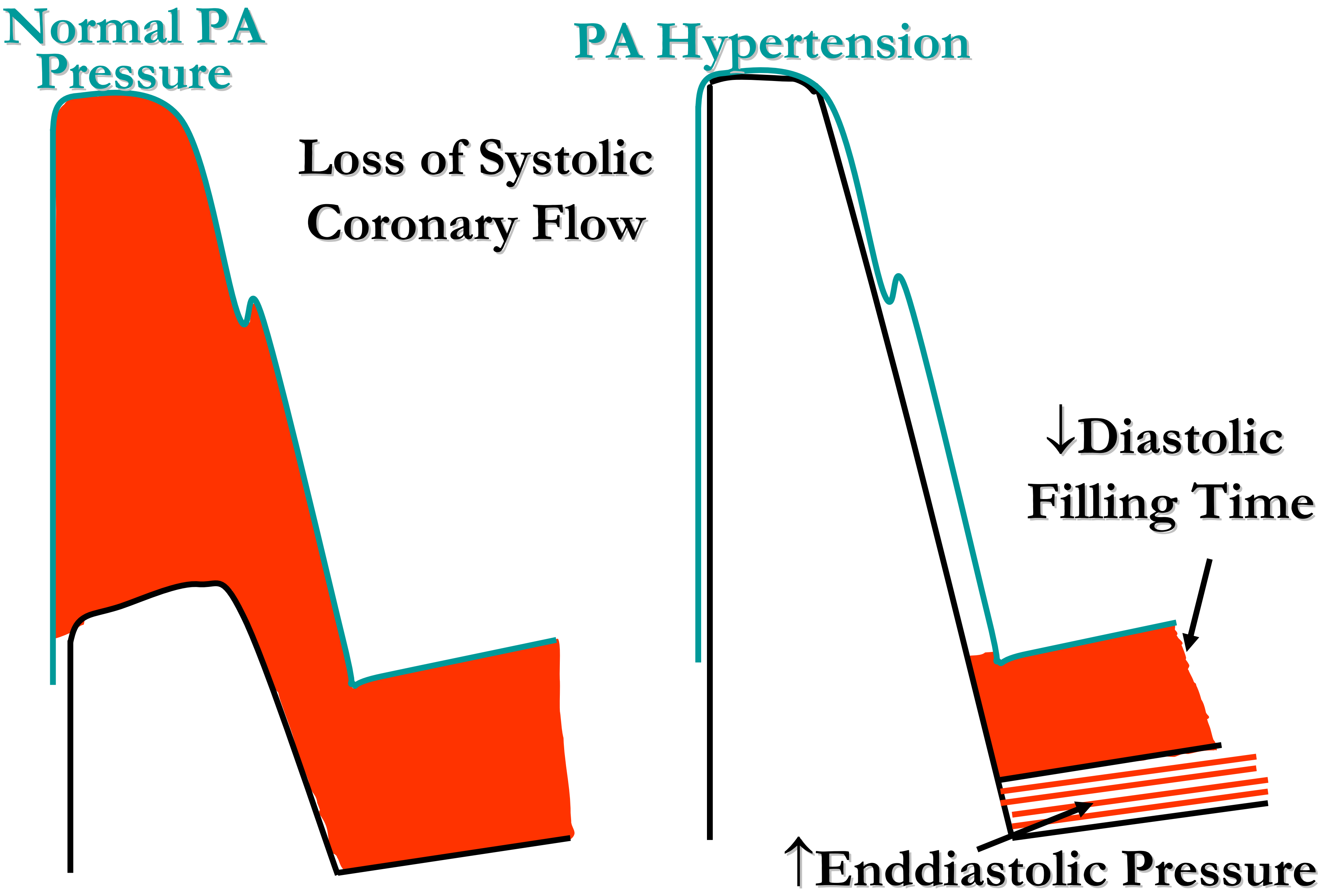
Pulmonary Artery Hypertension

- **Well tolerated until develop RV dysfunction**
- **RV dysfunction results in ↓CO & DO2**
  - **Ischemia**
  - **Leftward shift of the intraventricular septum**
  - **↓ in LV preload**
- **PAH – RV coronary hypoperfusion**
  - **↓diastolic filling time (tachycardia)**
  - **Systemic hypotension**

Coronary Perfusion LV vs RV



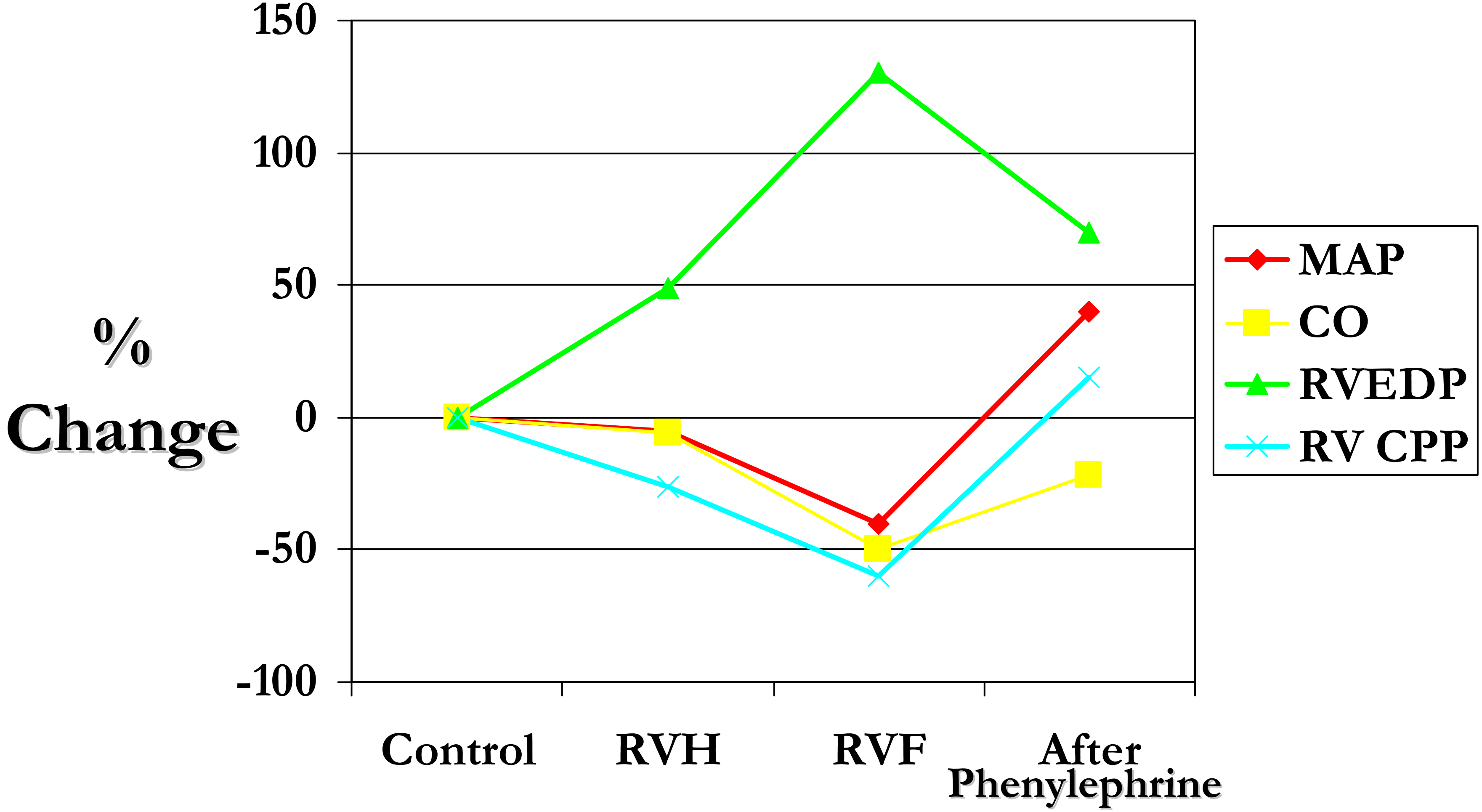
Coronary Perfusion with PAH



Maintain RV coronary perfusion

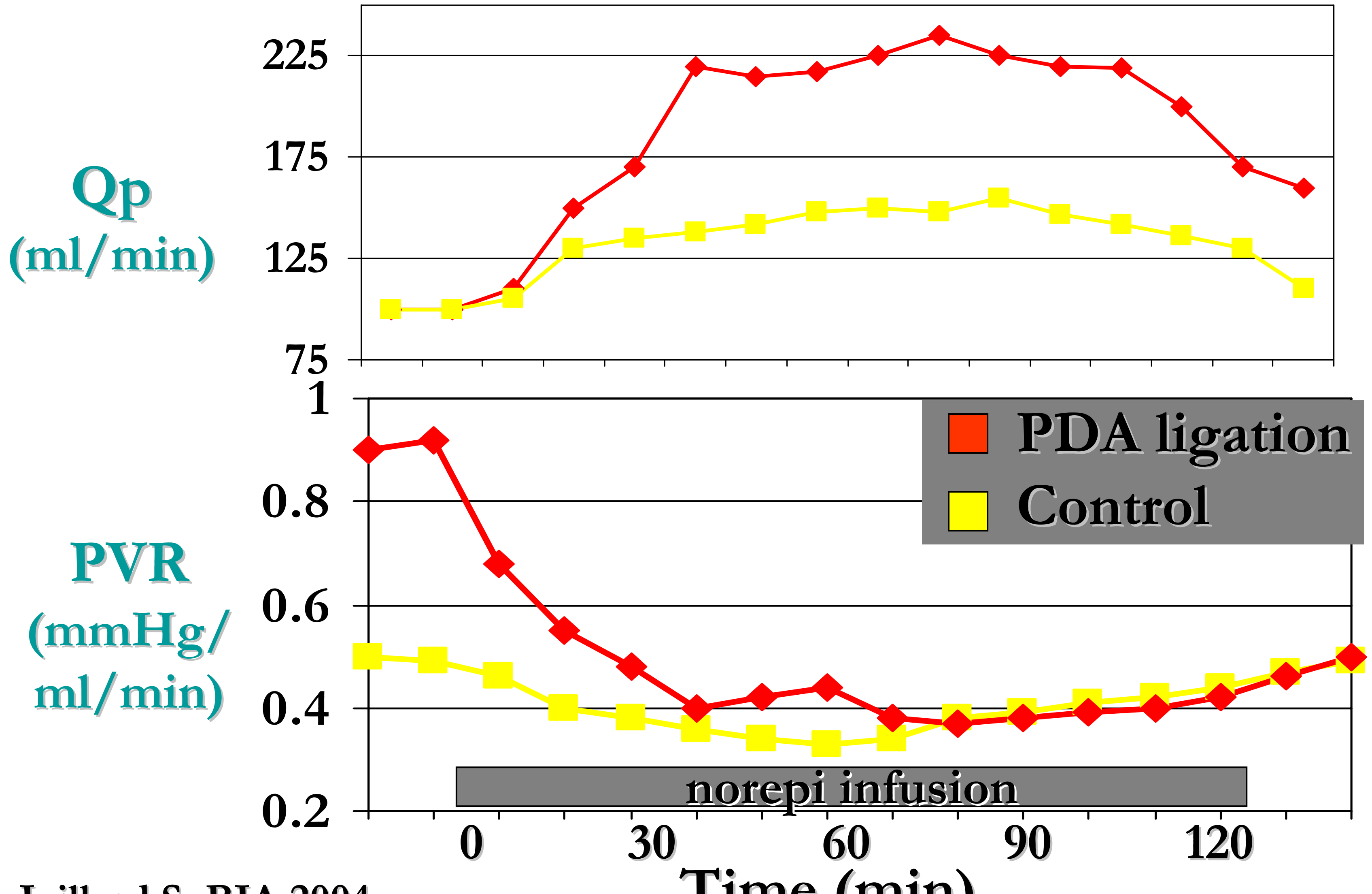
- **Intervention needed to preserve RV function and provide time to treat PAH**
- **Increase Systemic Afterload (Diastolic)**
  - **Phenylephrine: Acutely failing RV**
  - **Inotropic Agents (epi, norepi)**
  - **? Vasopressin**

Sequential Analysis of ↑ PAP



Vlahakes 1980

Antenatal Partial Ductal Ligation and Effect of Norepinepherine



Jaillard S, BJA 2004

Reduce RV Afterload

- **Direct Pulmonary Vasodilators**
  - **Alkalinization**
  - **Inhaled Medical Gases**
    - **Oxygen**
    - **Nitric Oxide**
  - **Do Not ↓ SVR**

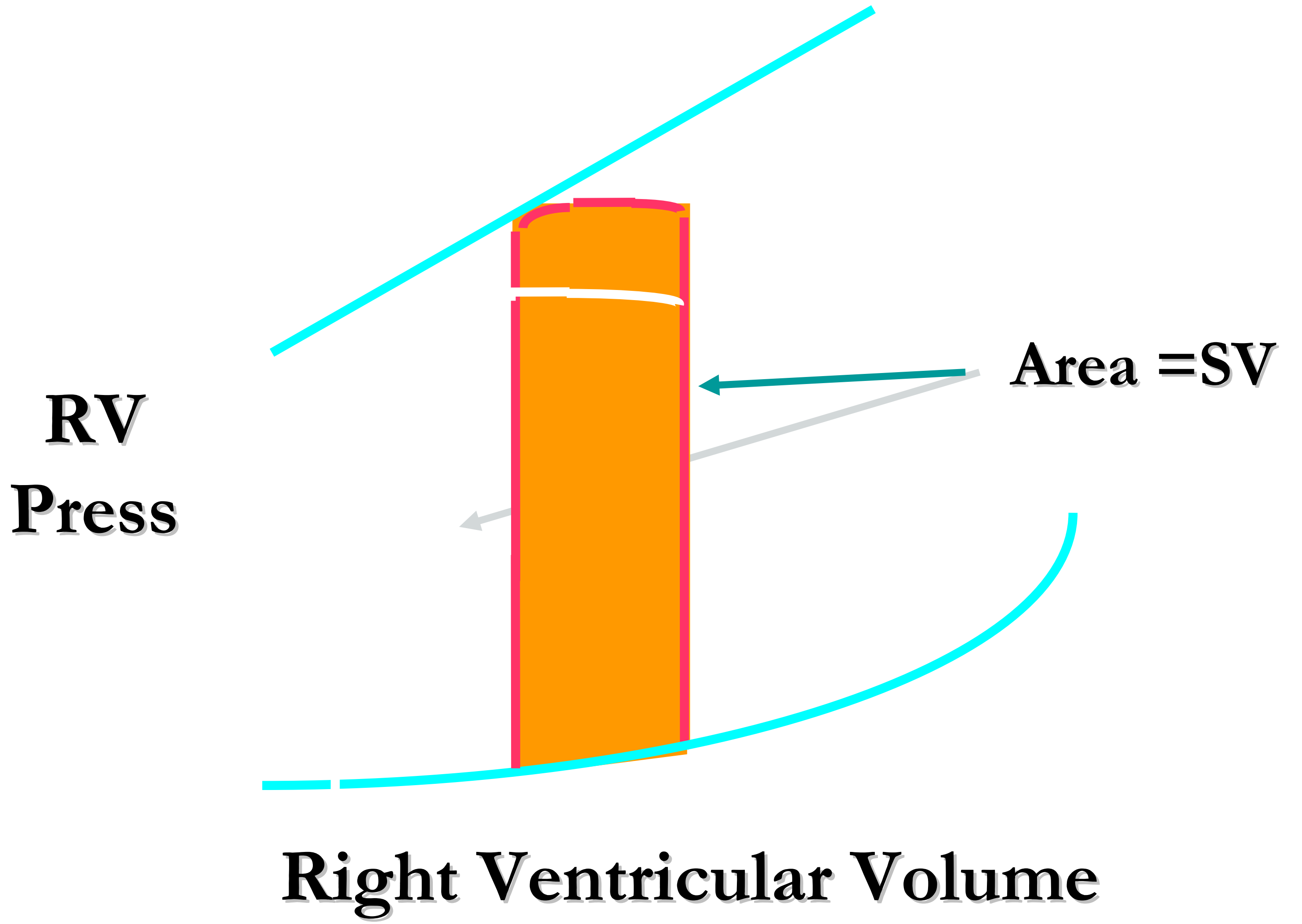
Adjunctive Rx for RV Dysfunction and PAH

- **Optimize Mechanical Ventilation**
  - **Minimize Intrathoracic Pressure (MAP)**
  - **Shorten Inspiratory Time**
  - **Utilizing Ventilator as an “RV Assist Device”**
- **Creation or Retaining an Atrial Level Shunt**
  - **Optimize Systemic DO2**
- **ECMO**

Mixed Pulmonary / Systemic Vasodilators

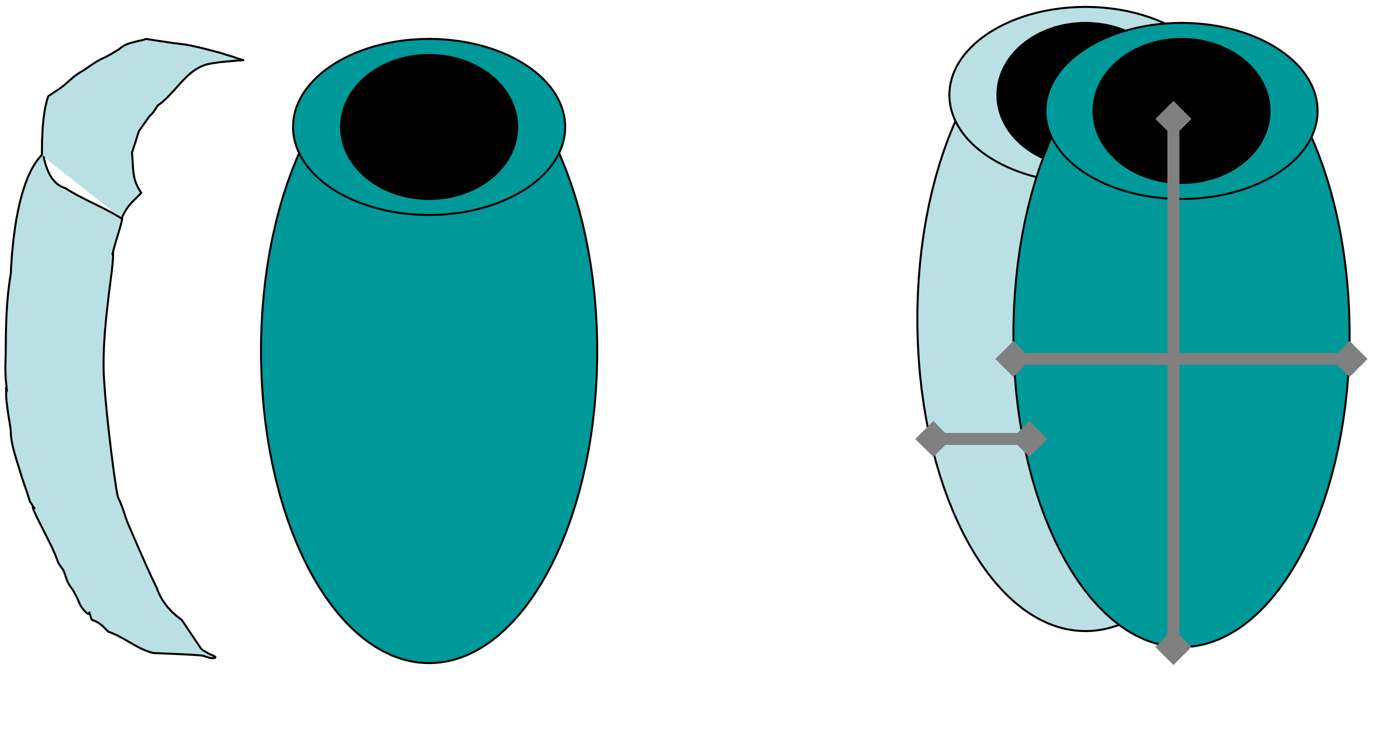
- **Phosphodiesterase Inhibitors**
  - **Type III inhibitors (Milrinone)**
    - **Problem with low systemic BP**
  - **Type V inhibitors (Sildenafil)**
    - **Adjunct to NO**
- **Prostacyclin (IV and Inhaled)**
- **Endothelin -1 Antagonists**

Effects of Afterload on RV Stroke Volume



Oxygen Therapy

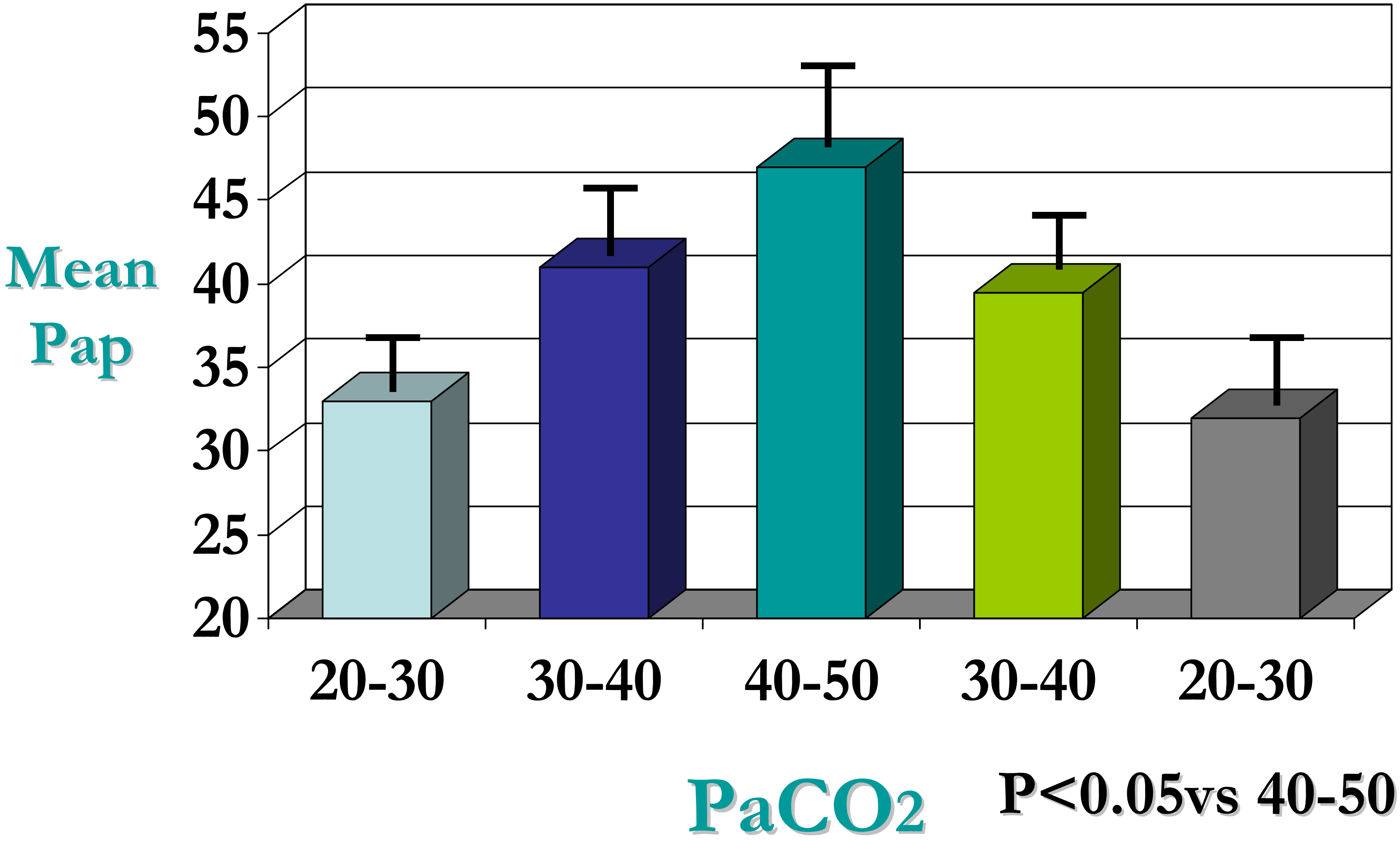
RV Shell Subtraction



Metabolic Alkalinization

Effects of PaCO2 on PAP

Morray JP 1988

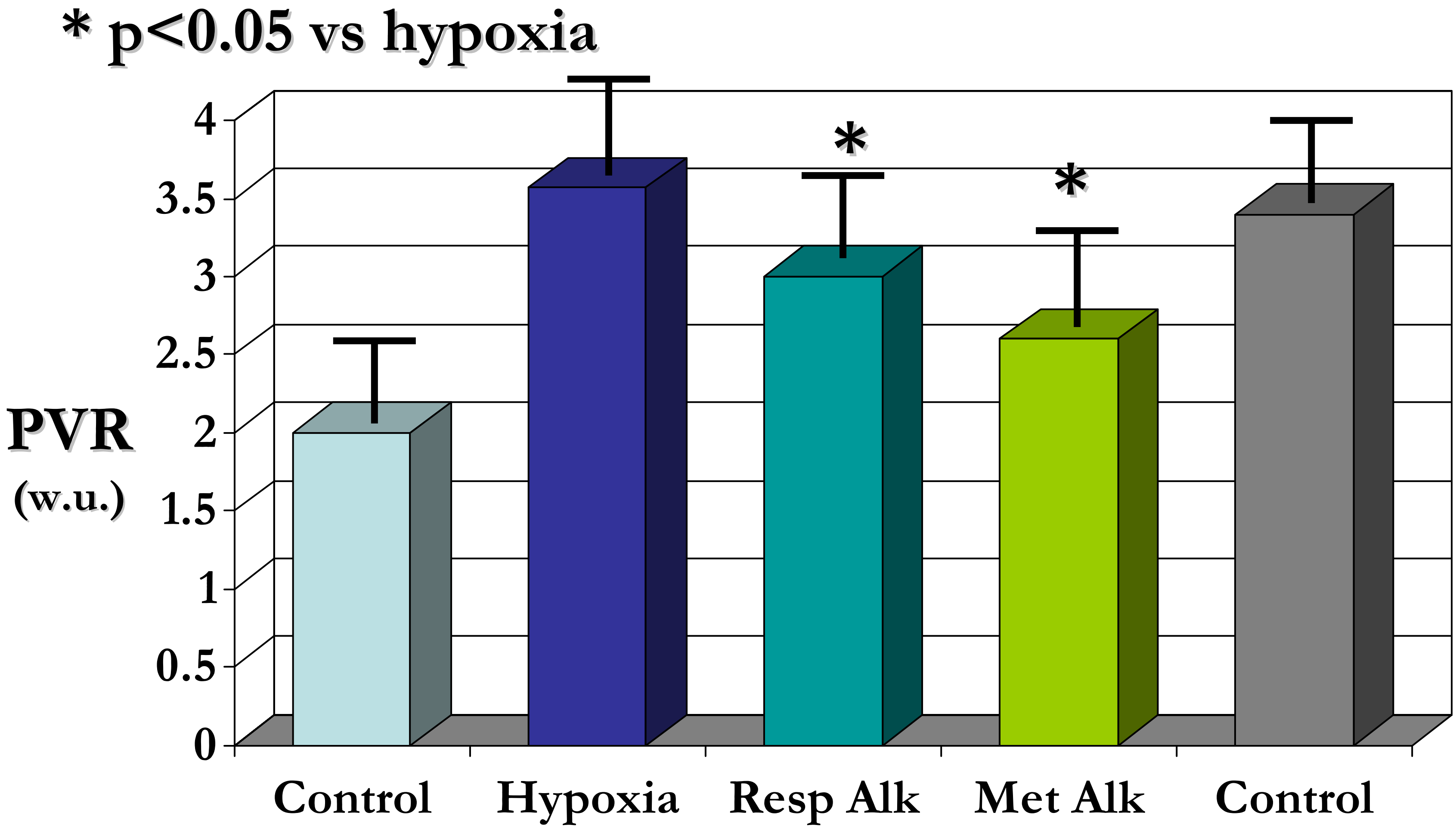


P<0.05vs 40-50

Respiratory Alkalinization

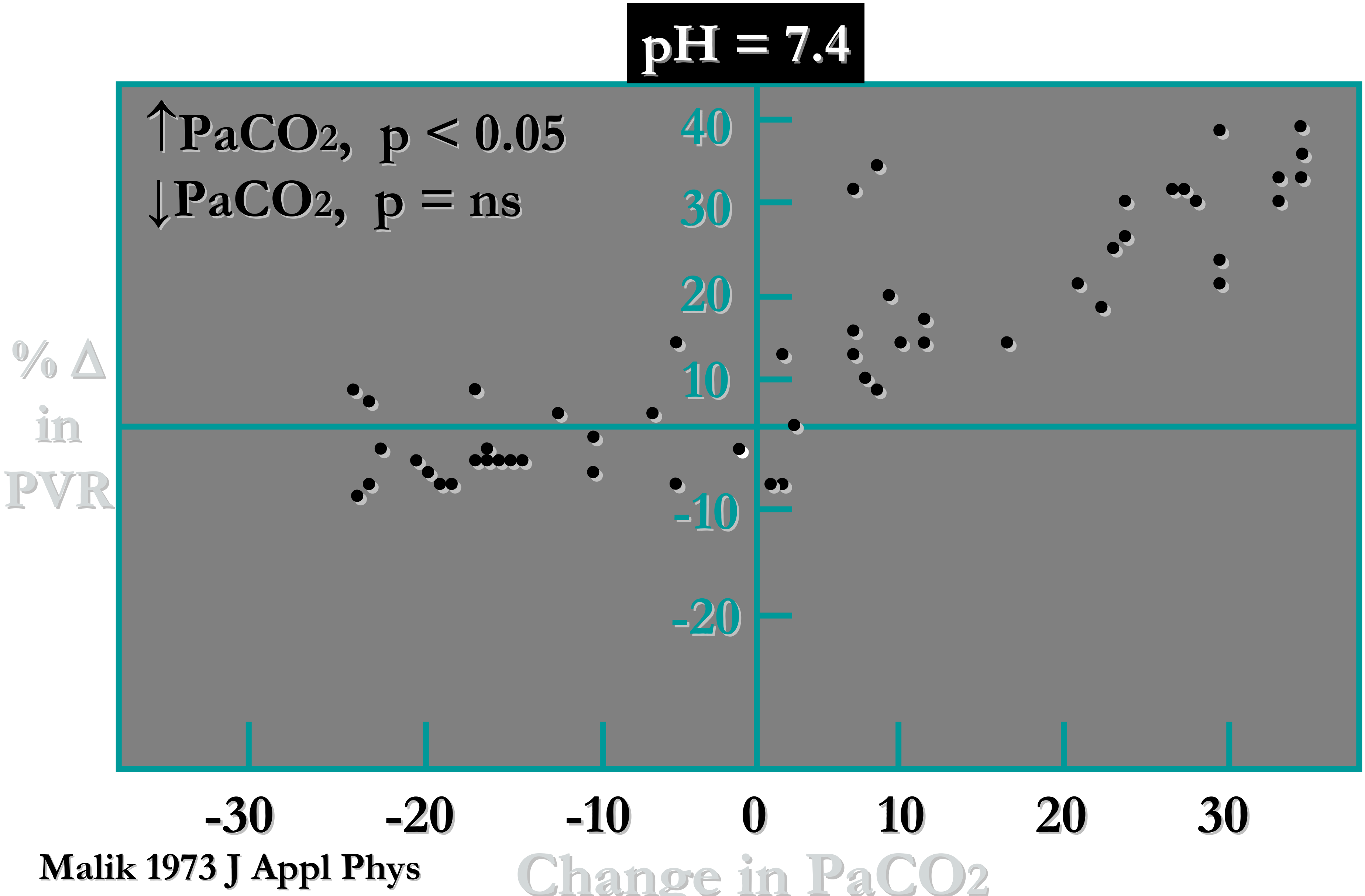
- **Requires hyperventilation**
- **↑ intrathoracic pressure**
- **Impairs RV filling**
- **↓ Systemic CO and DO_2**

Effects of pH on PVR



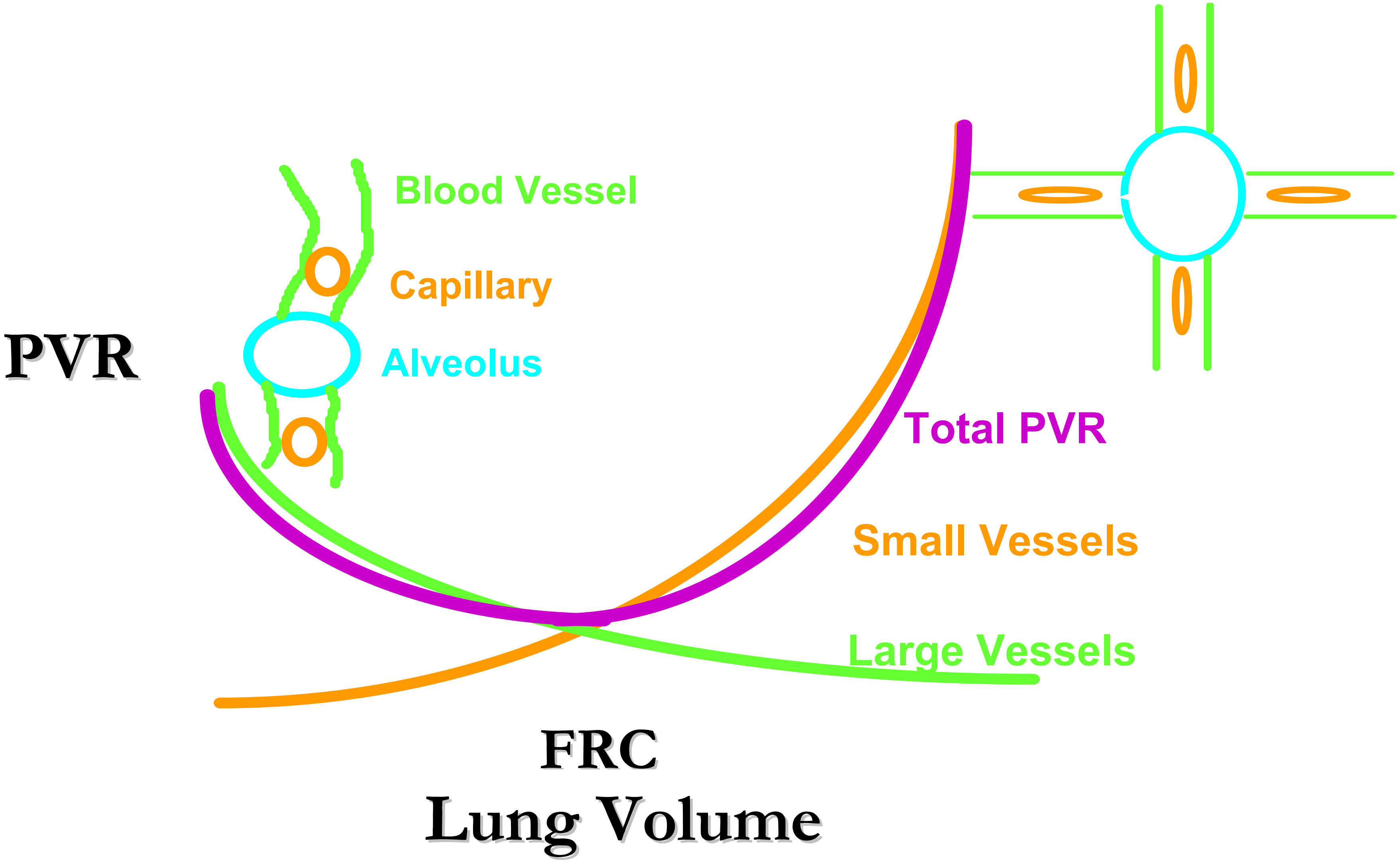
Lyrene RK, 1985

Effects of $PaCO_2$ on PVR



Malik 1973 J Appl Phys

Effect of Lung Volume



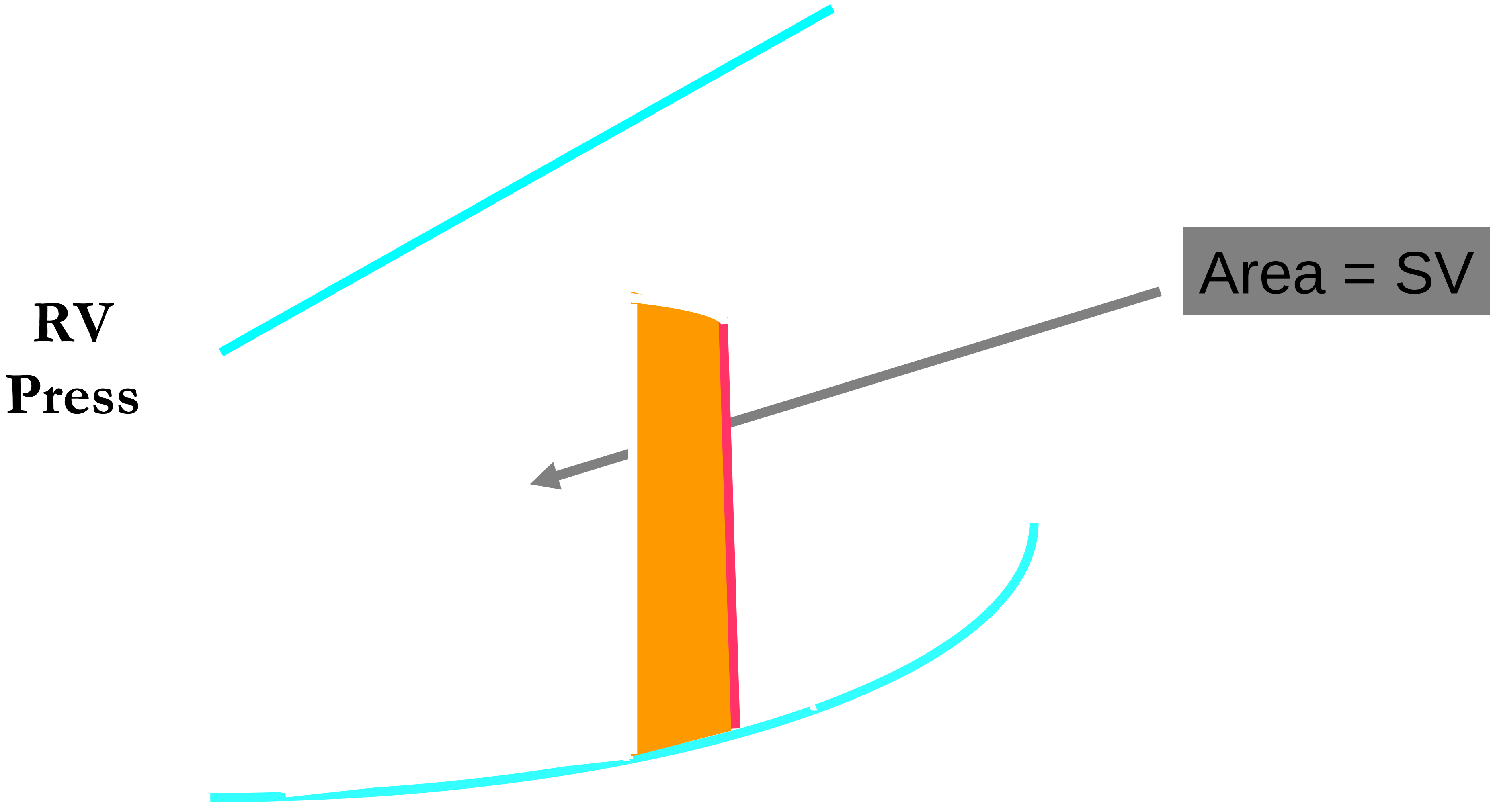
Optimize Preload In Patients with Pulmonary Hypertension and RV dysfunction

Cardiac Output (CO)

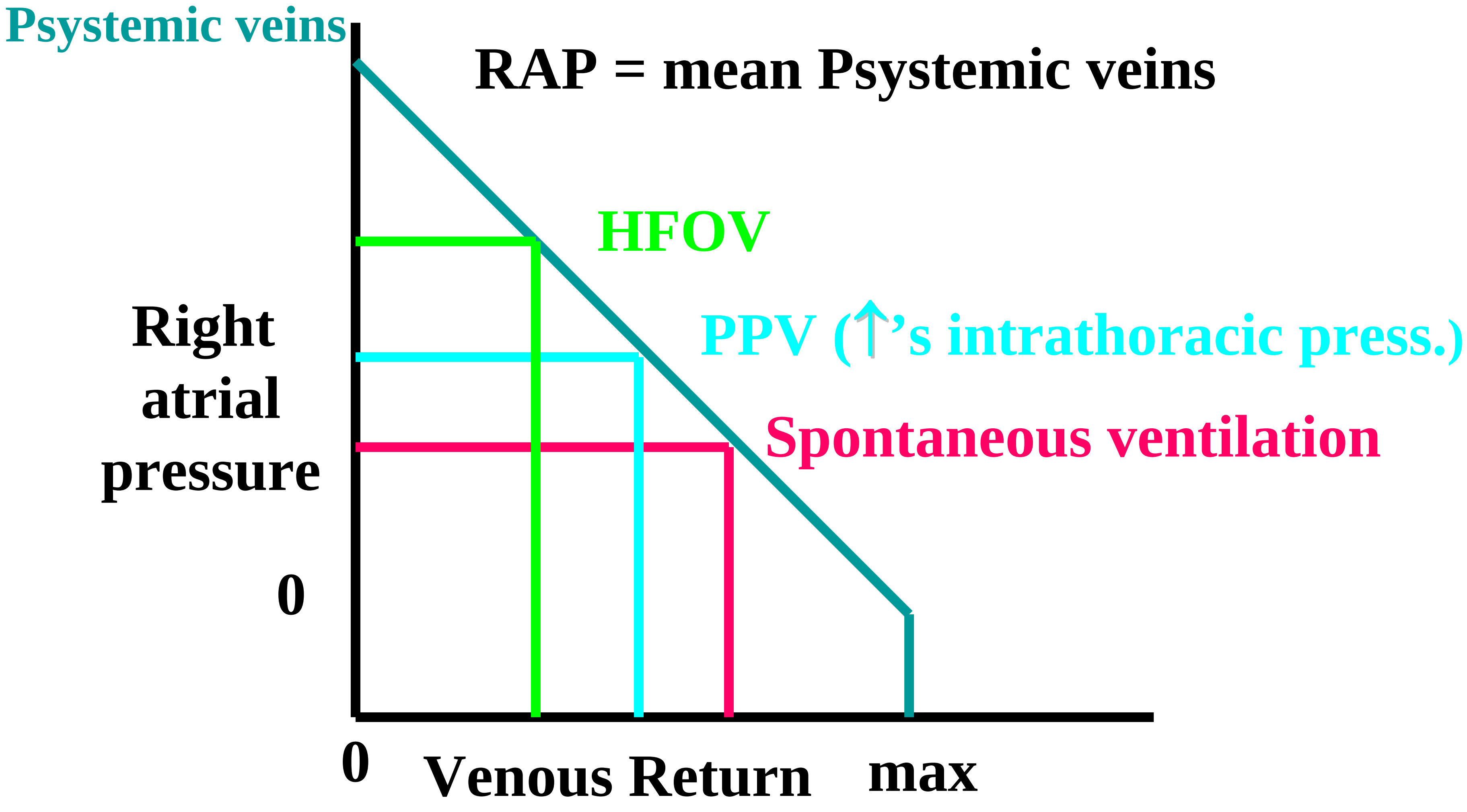
- **CO = Stroke Volume x HR**
- **Determinants of Stroke Volume**
  - **Preload**
  - **Contractility**
  - **Afterload**

$DO_2 = CaCO_2 \times CO$

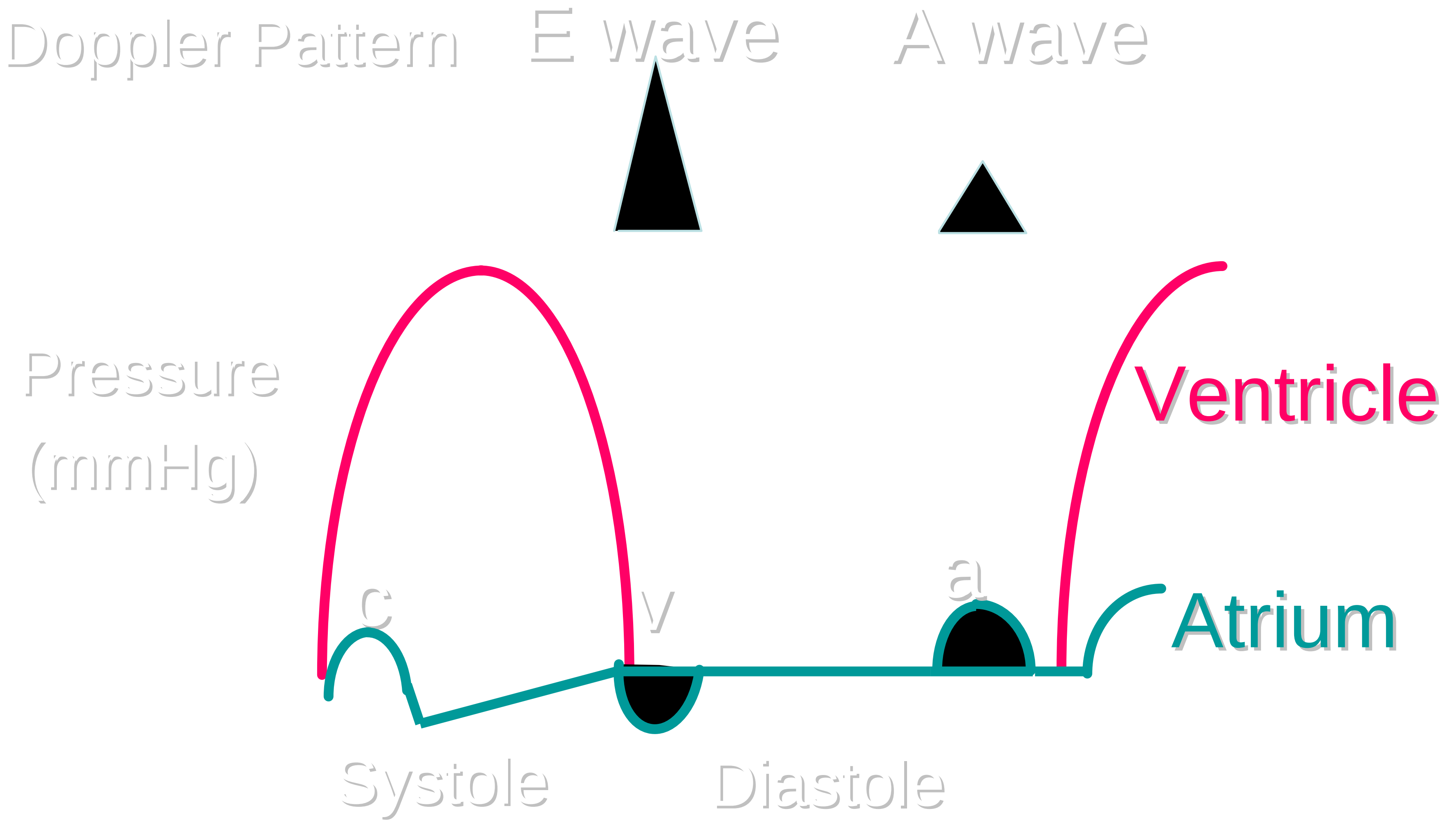
Effects of Preload on Stroke Volume



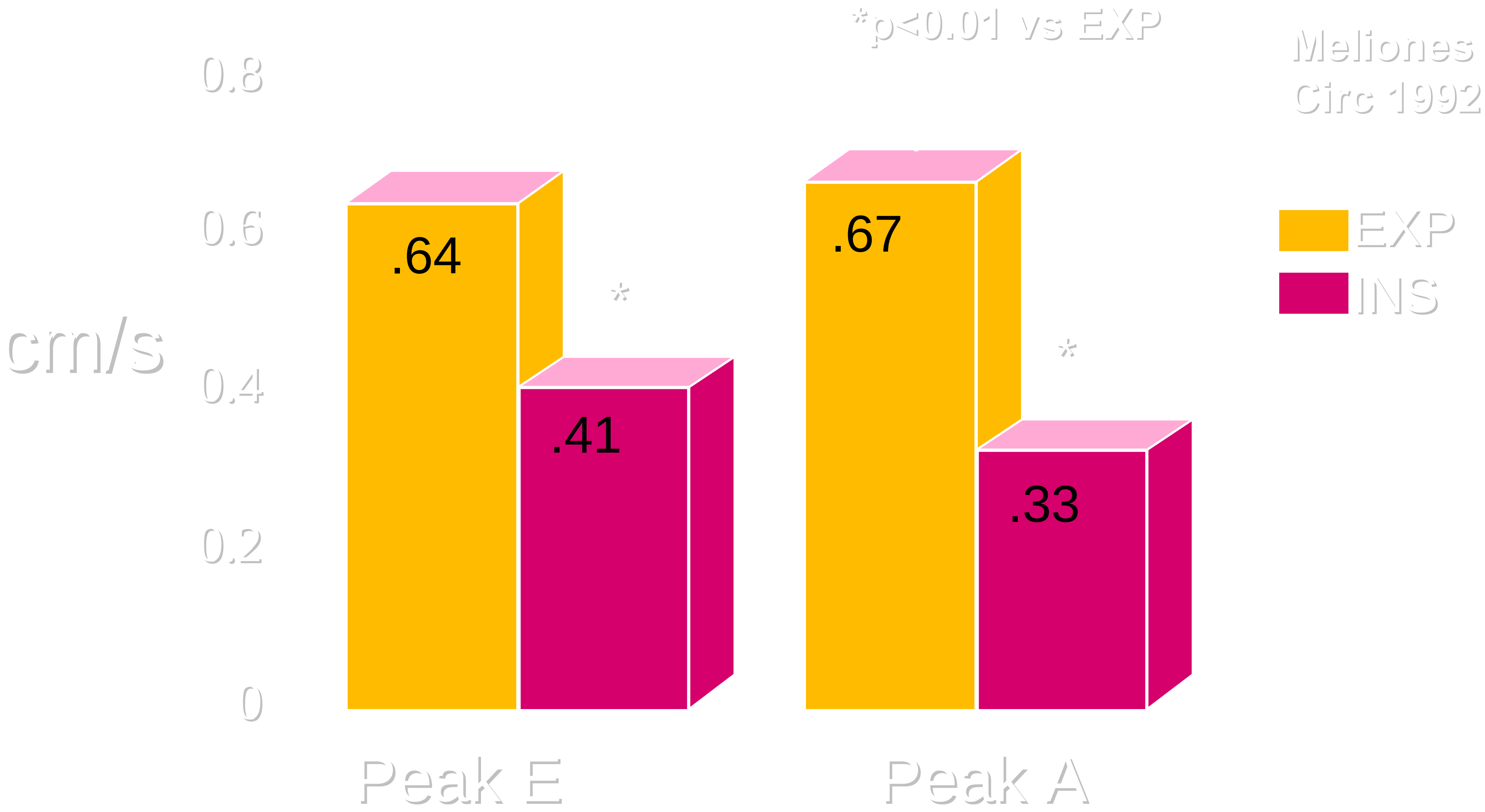
Systemic Venous Return and Ventilation



Diastolic Filling



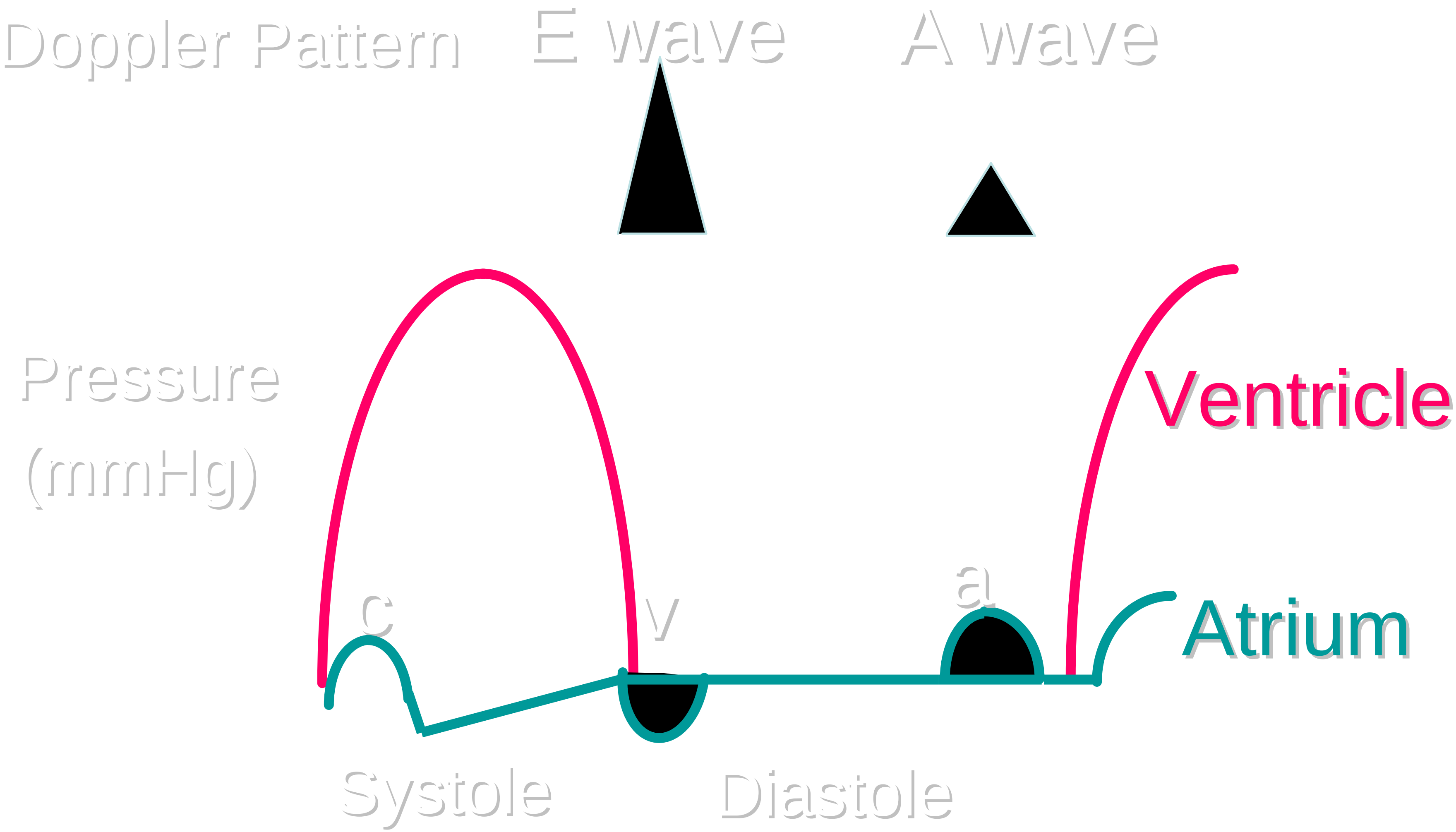
TV Filling Patterns During PPV



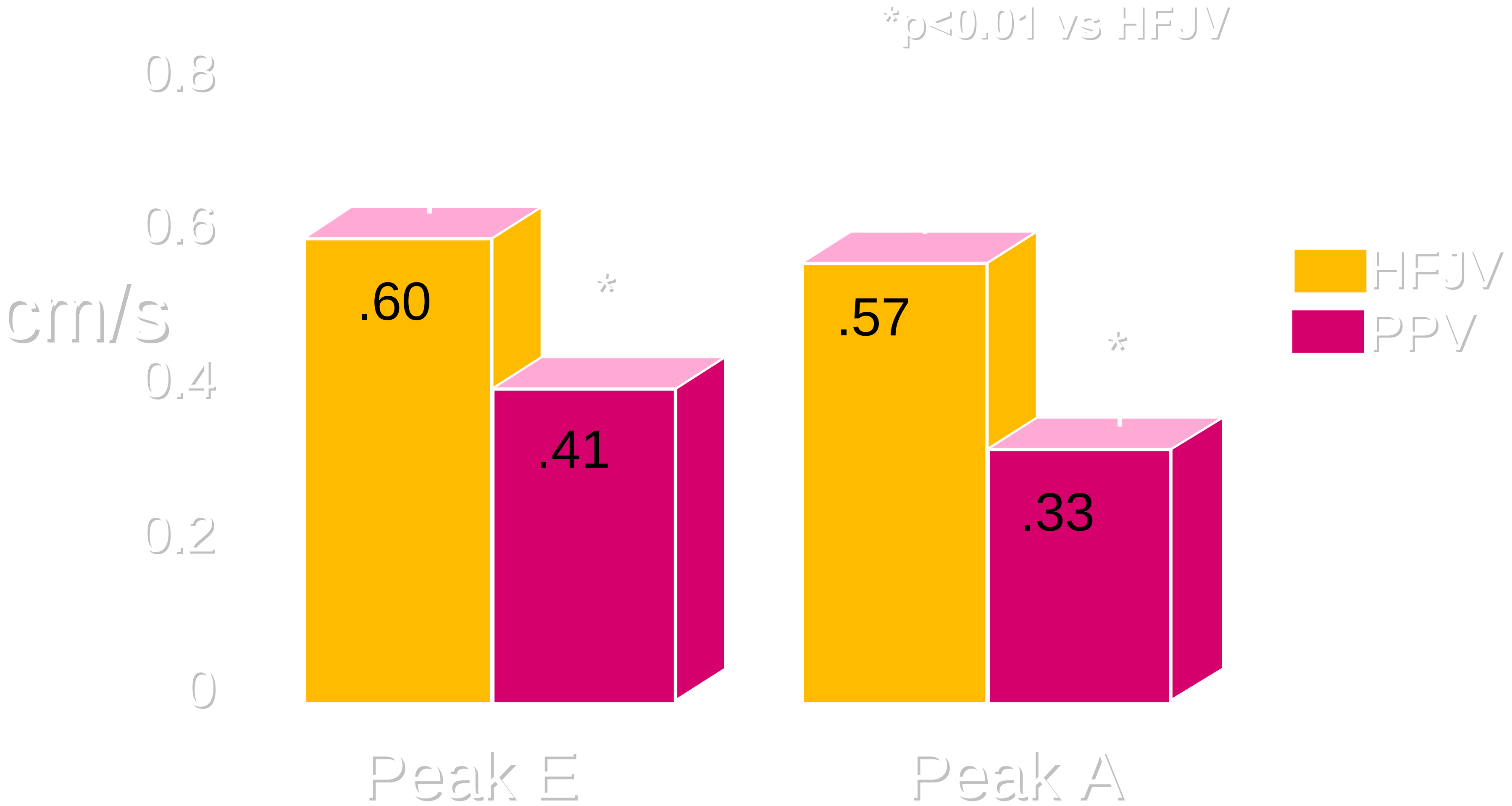
Systemic Venous Return (Preload)

- **Impaired by ↑ intrathoracic pressure**
  - **Positive pressure ventilation**
  - **Mean airway pressure**
- **Most critical in patients with**
  - **RV dysfunction / PA hypertension**
  - **High MAP – High Frequency Oscillator**

Diastolic Filling

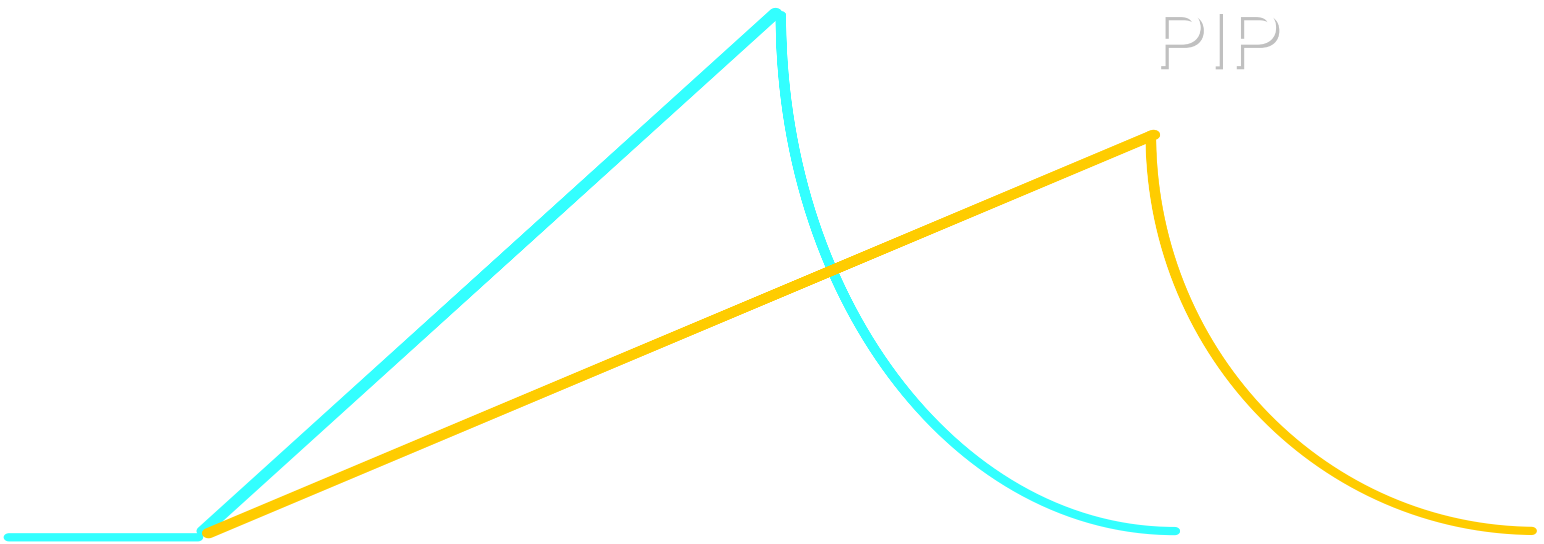


TV Filling HFJV vs PPV

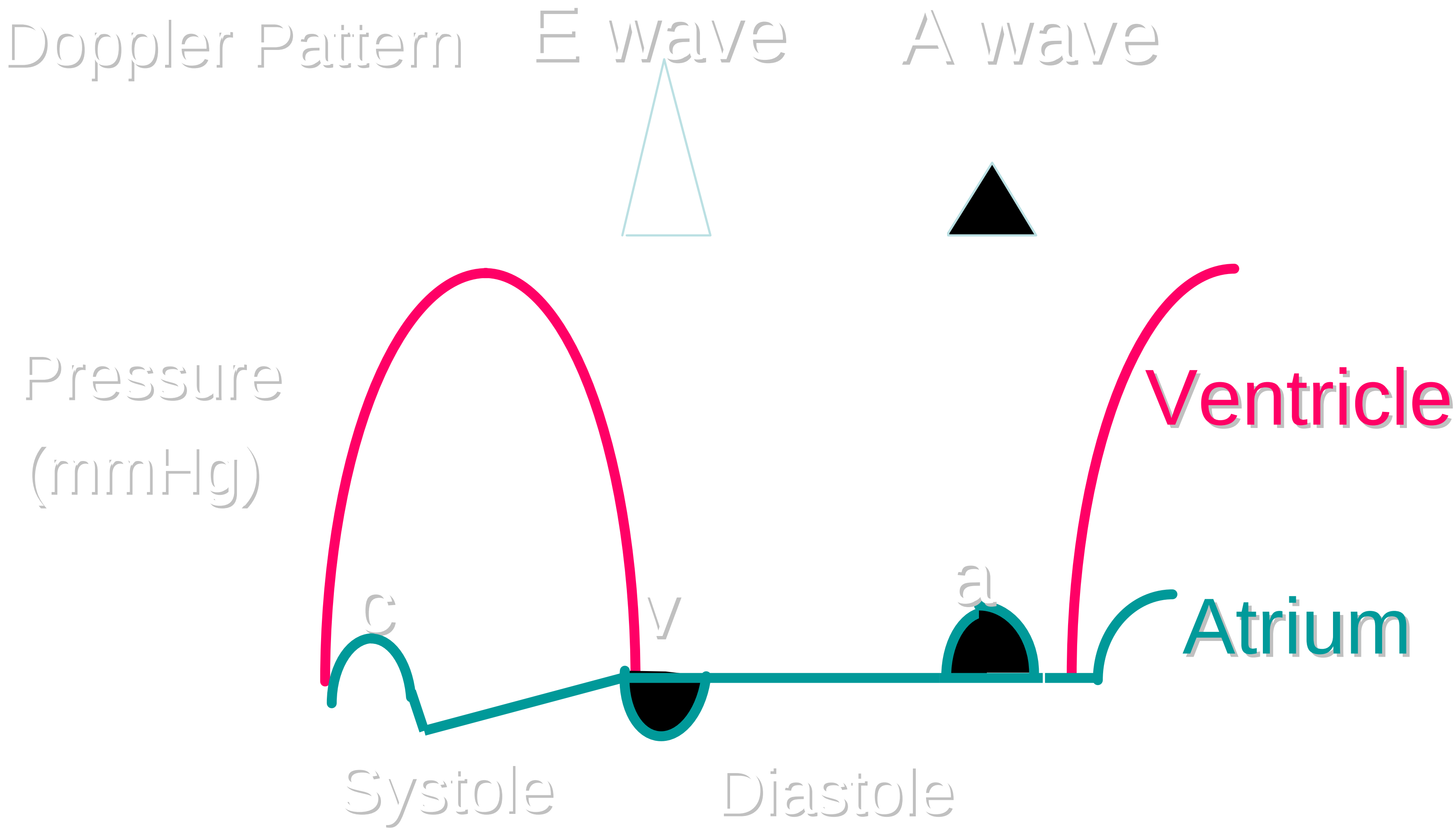


Cardiac Output Can be Enhanced in PAH and RV Dysfunction By Using Lower Mean Airway Pressure During Mechanical Ventilation

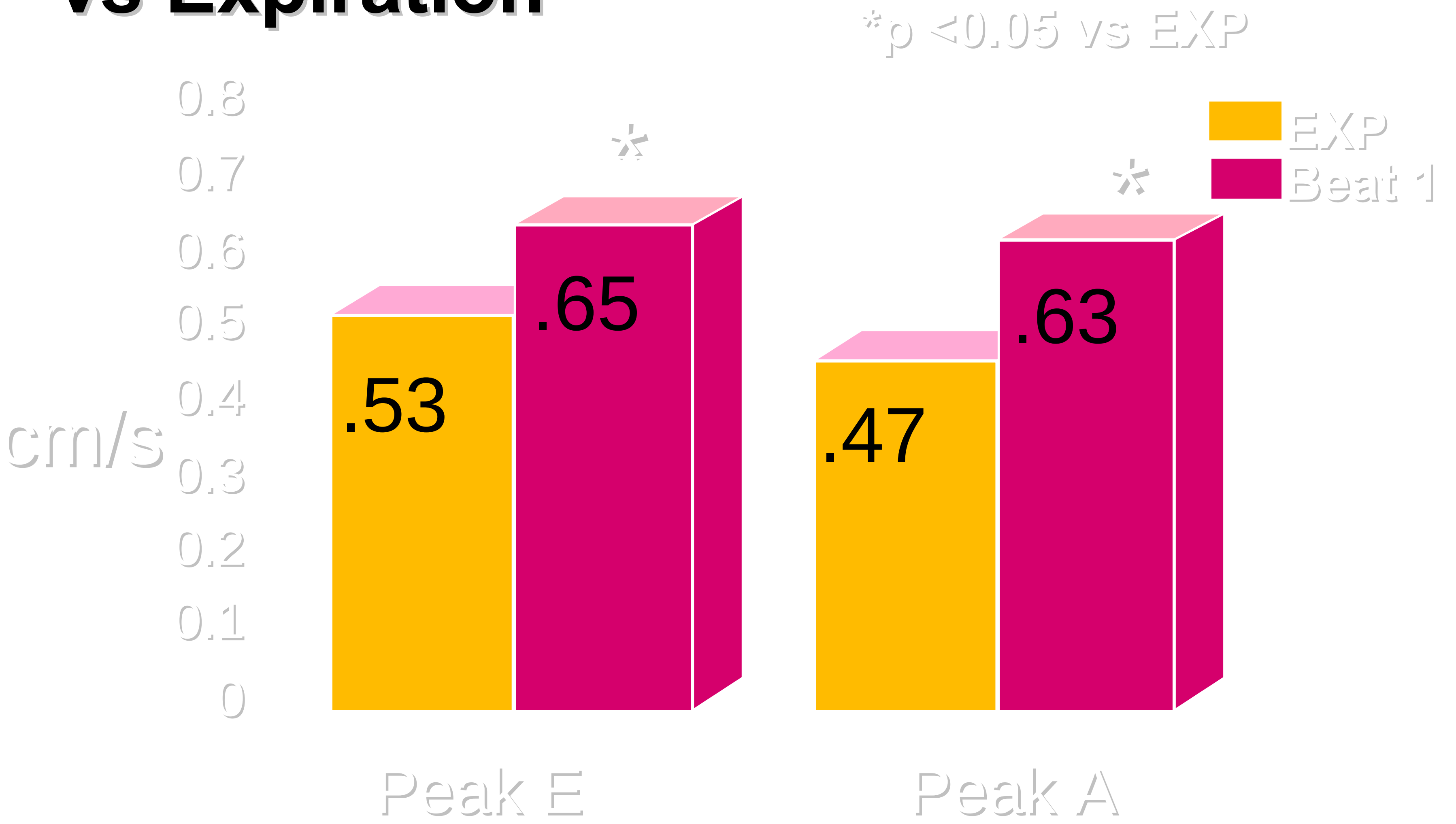
Inspiratory Time: Inspiration Occurs Over Multiple Cardiac Cycles



Diastolic Filling



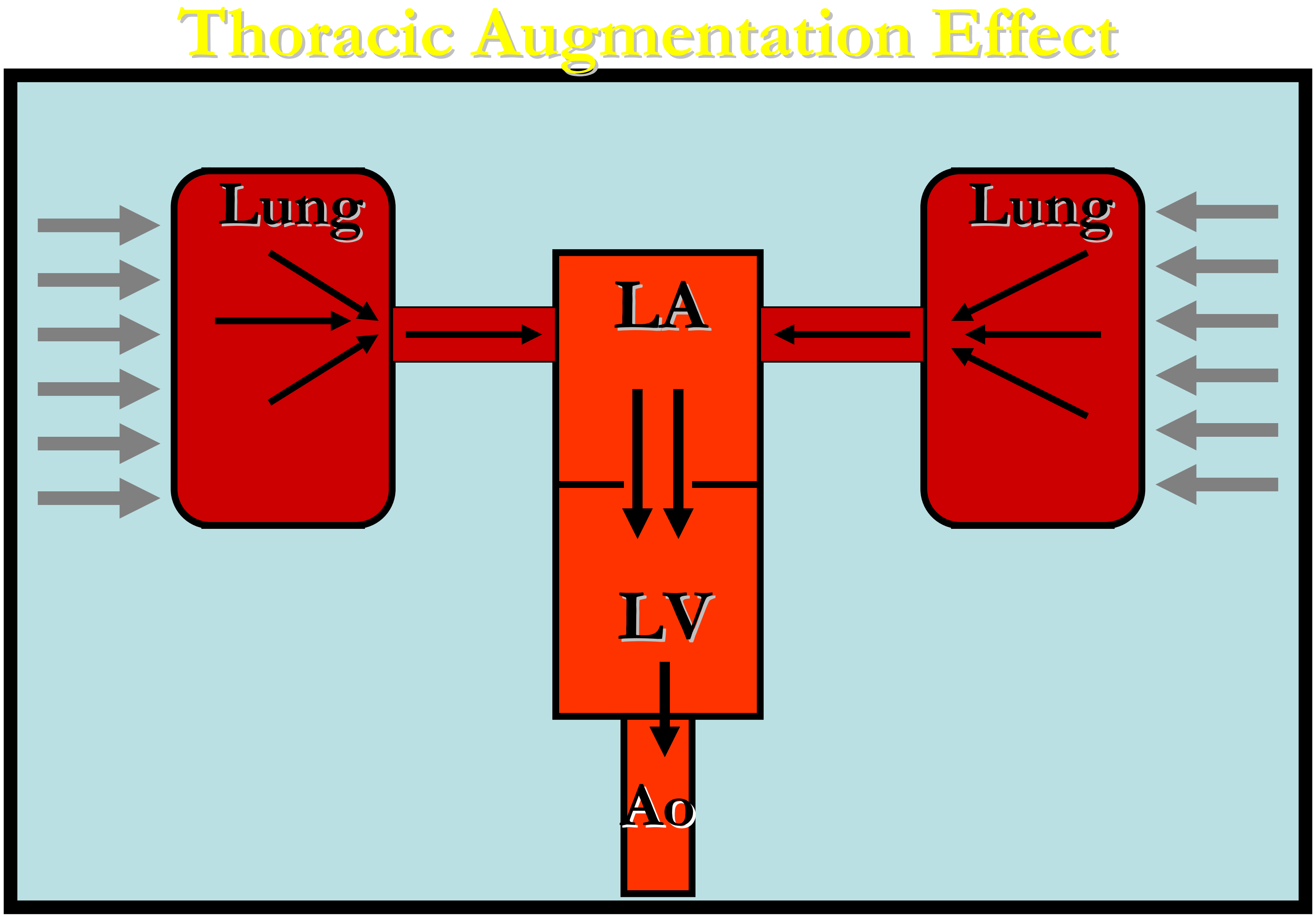
LV Filling Patterns: Inspiration (beat 1) vs Expiration



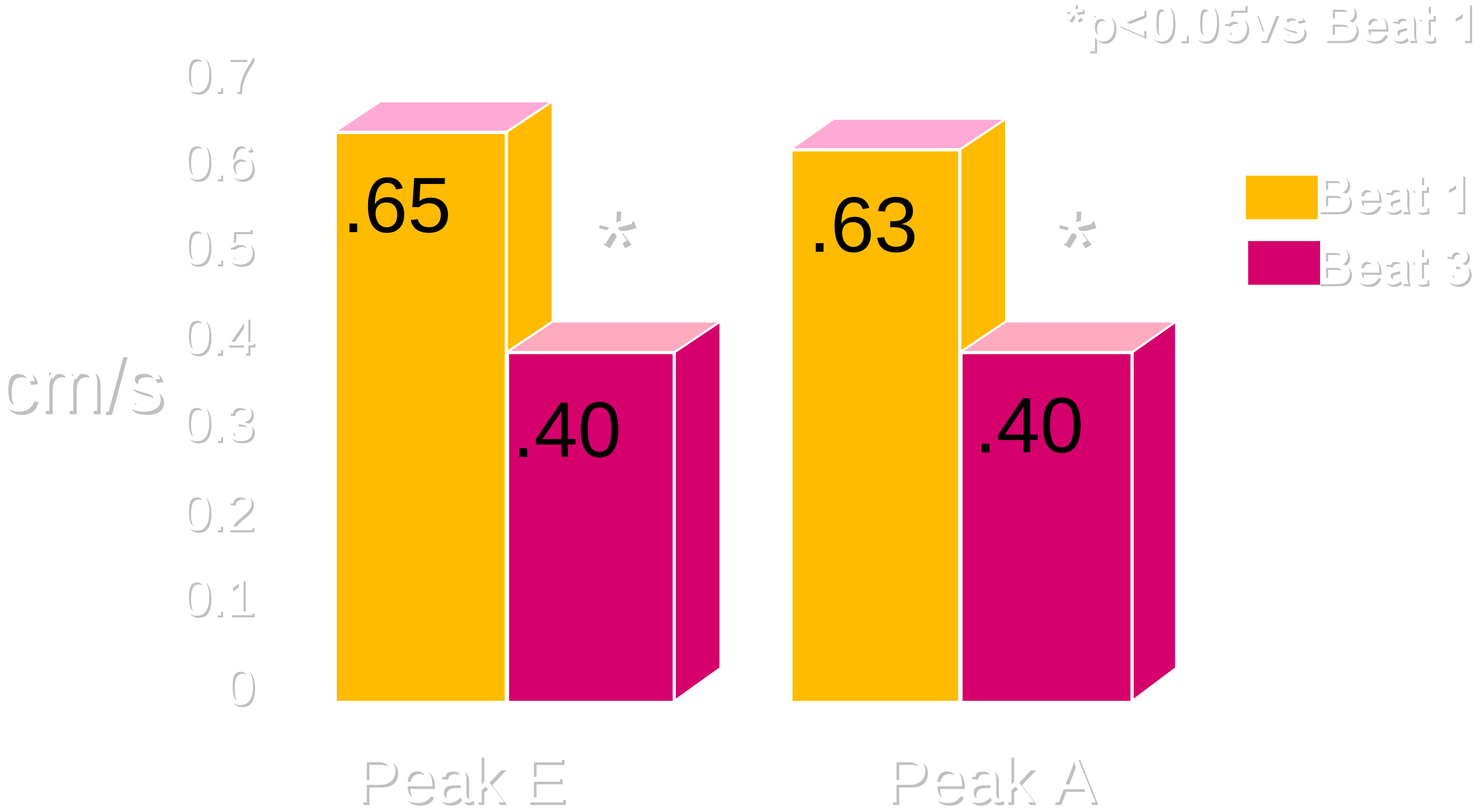
Thoracic Pump Mechanism

- **Transient increase in intrathoracic pressure**
  - **Pushes blood through lungs to LV**
- **Valveless system**
  - **LV fills by pressure gradient**
  - **Pulmonary veins – venous capacitance**
  - **Augment LV filling**

PPV Effects on LV Filling



LV Filling Patterns: Inspiration
Beat 1 vs Beat 3



LV Filling

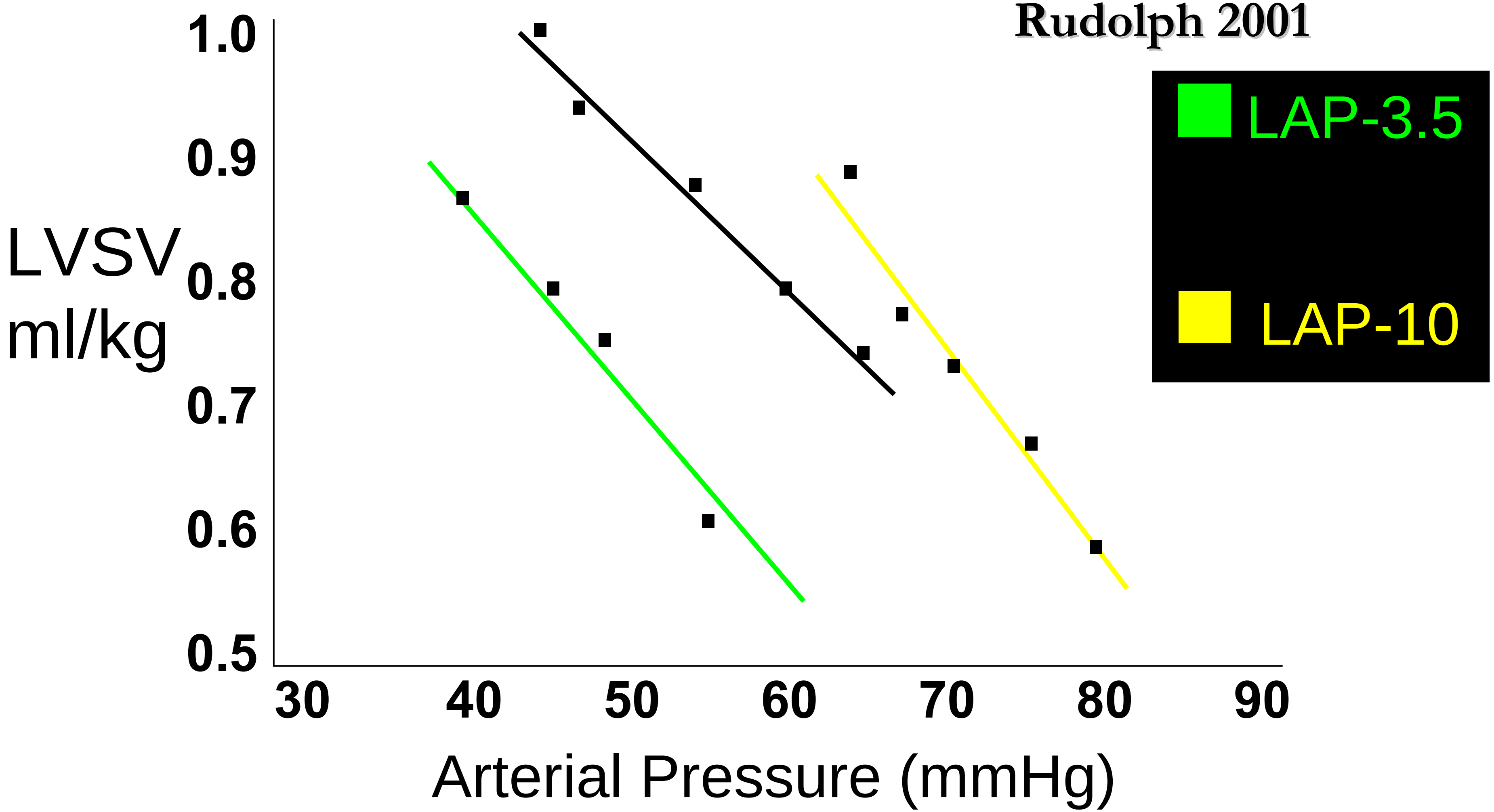
	Beat 1	Beat 2	Beat 3	Release
Pulm. Pump	+++	++	+	0
RV Effects	0	-	---	---
Total Effects	+++	+	--	---

CO can be optimized by maintaining an inspiratory time of 1-2 cardiac cycles

Effect of Preload and Afterload on Left Ventricular Stroke Volume

Hawkins J. 1989

Rudolph 2001

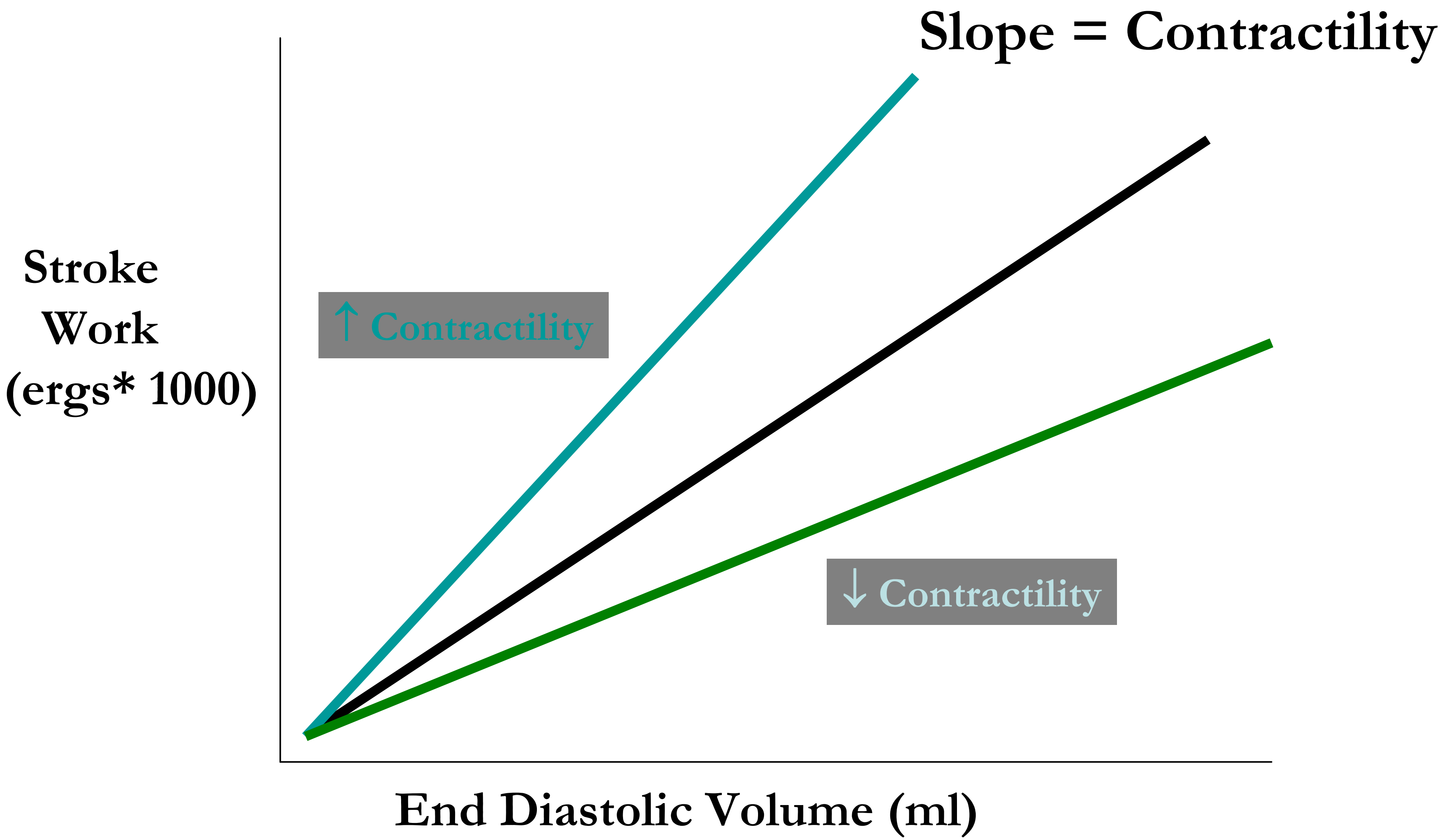


Optimizing Right Ventricular Contractility

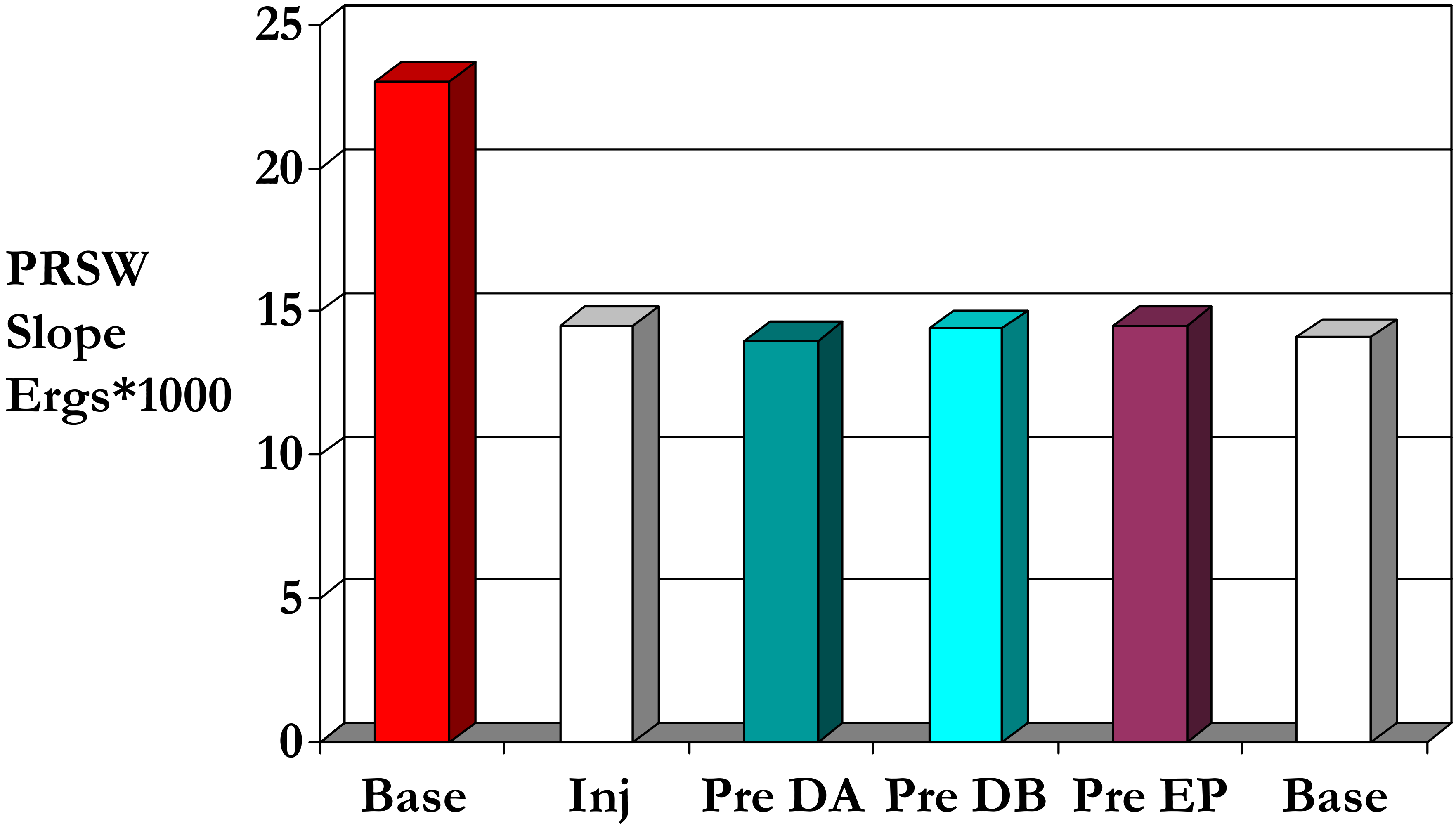
Effects of Inotropes on RV Function

- **Minimal data on RV injury and Inotropes**
- **Piglet model – Cryablation Injury to the RV**
- **Exposure to three inotropes**
  - **Dopamine (DA)**
  - **Dobutamine (DB)**
  - **Epinephrine (EP)**

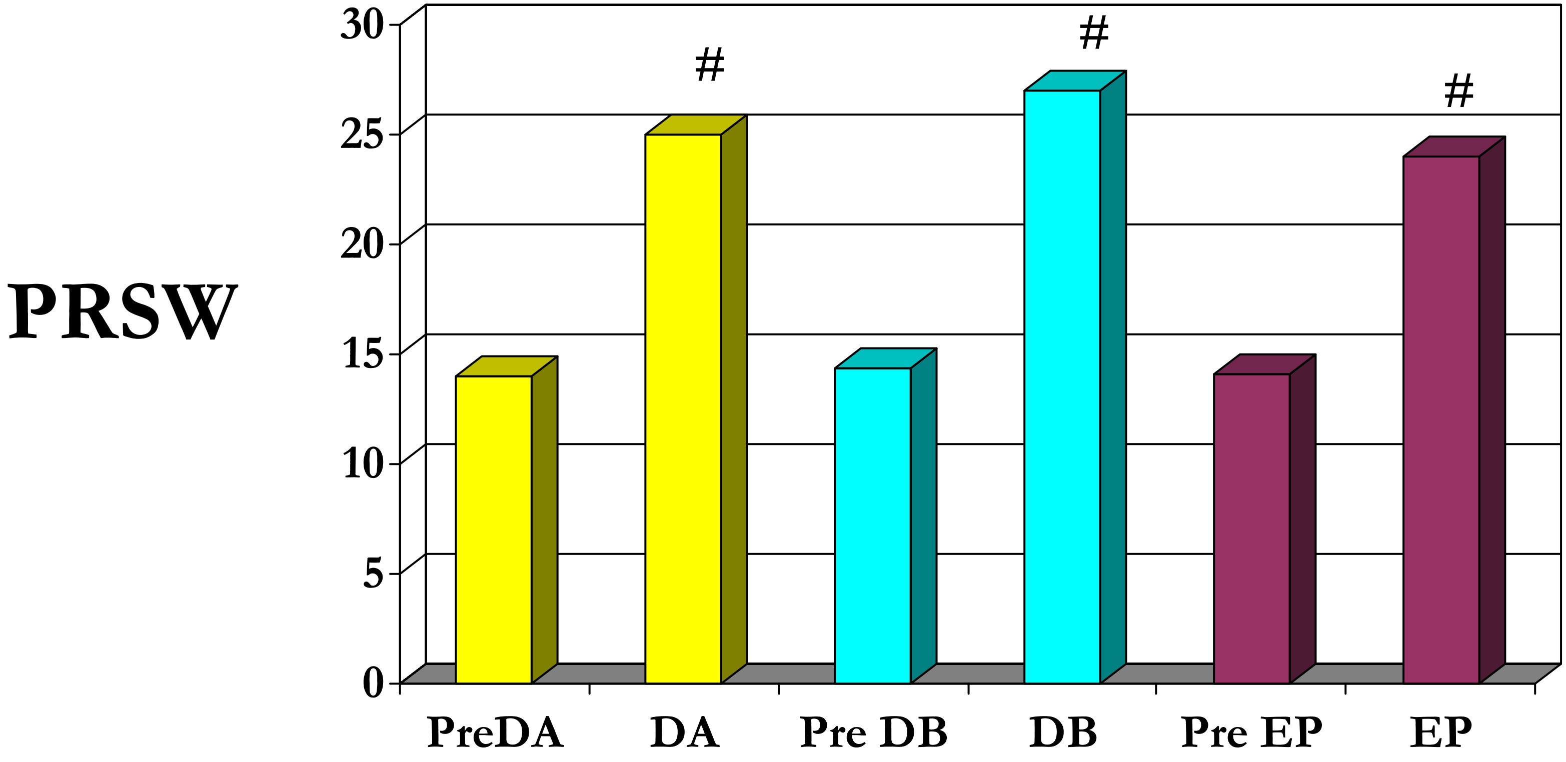
RV Systolic Function-PRSW



RV PRSW: Model Stability

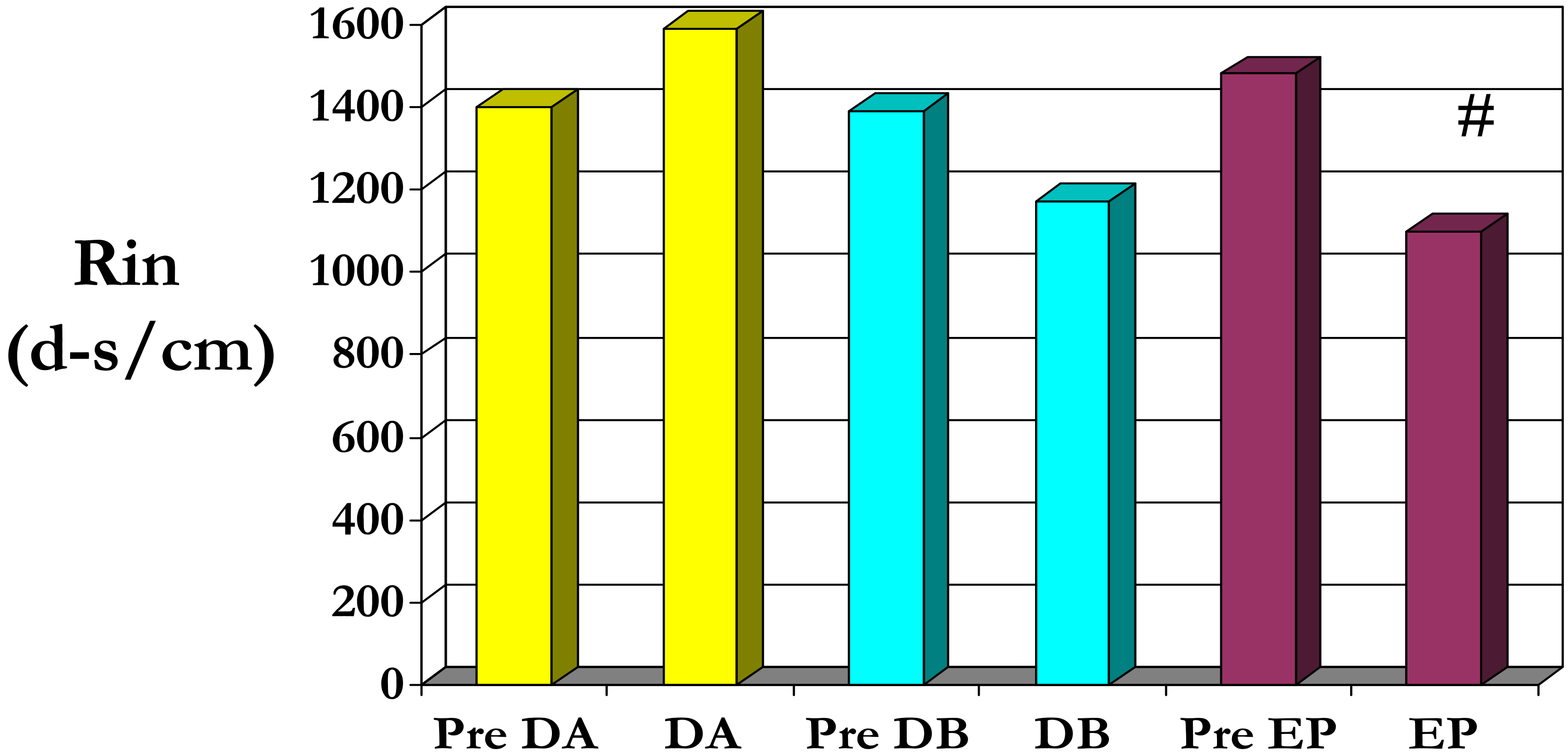


RV PRSW: Catecholamine Effect



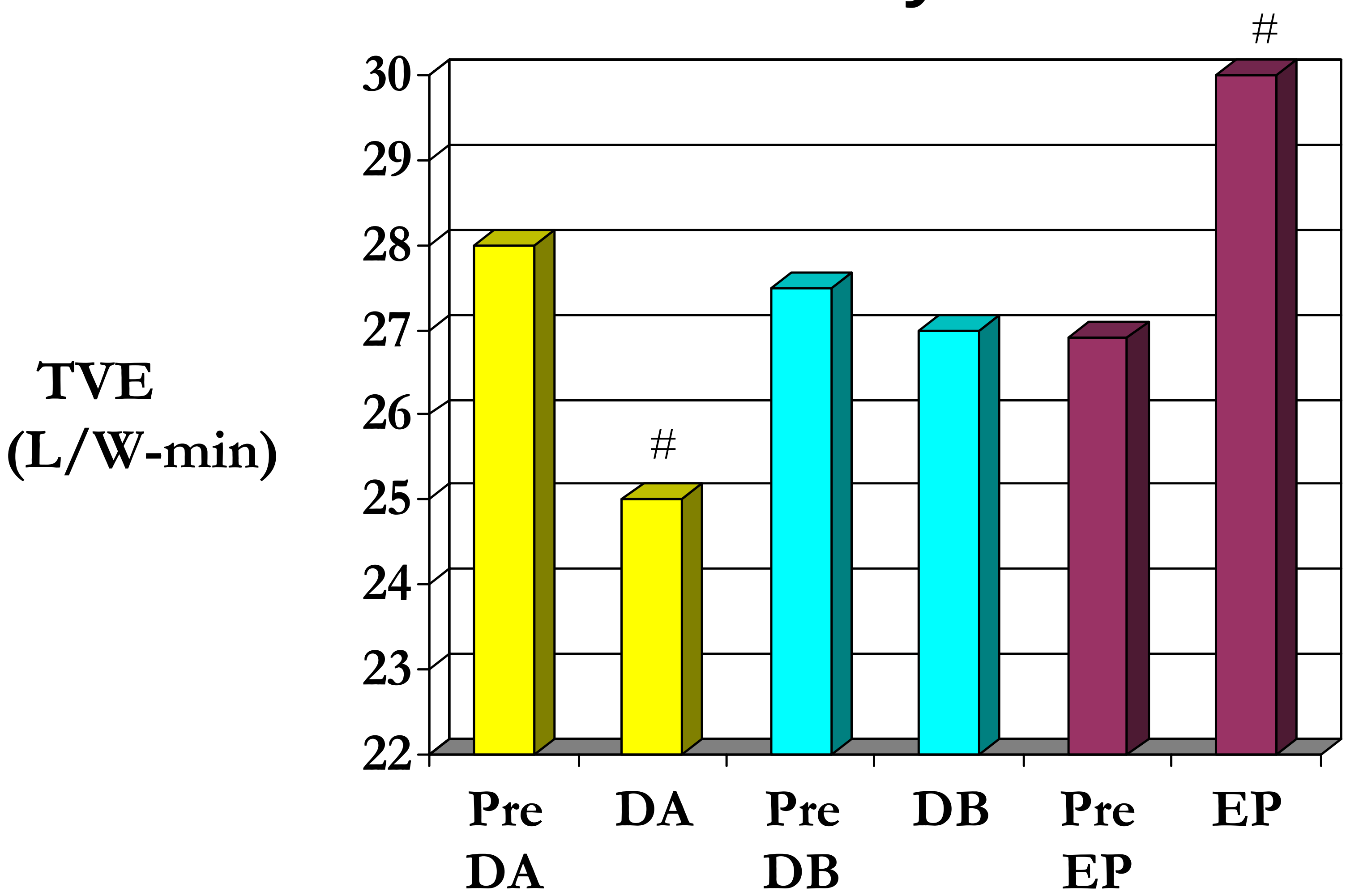
# $p < 0.05$ vs. Pre Drug

Input Resistance



# p<0.05 vs. Pre EP

Transpulmonary Vascular Efficiency



 # p < 0.05 vs Pre drug

Nitric Oxide

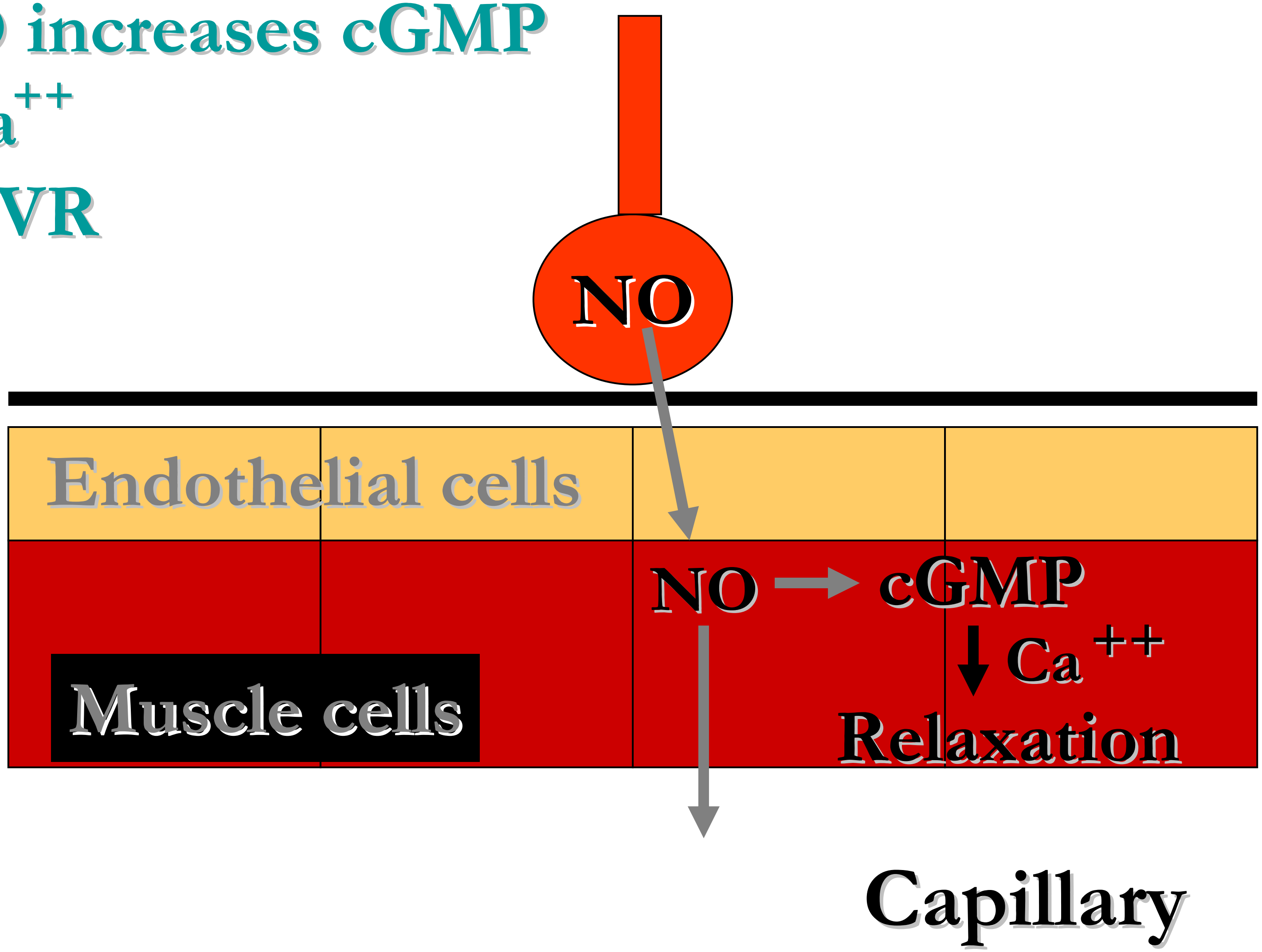
- **Remains a mainstay therapy for PAH**
  - **Direct pulmonary vasodilator**
  - **No effect on SVR**
  - **Maintain RV coronary perfusion**

Inhaled NO

NO increases cGMP

↓Ca^{++}

↓ PVR

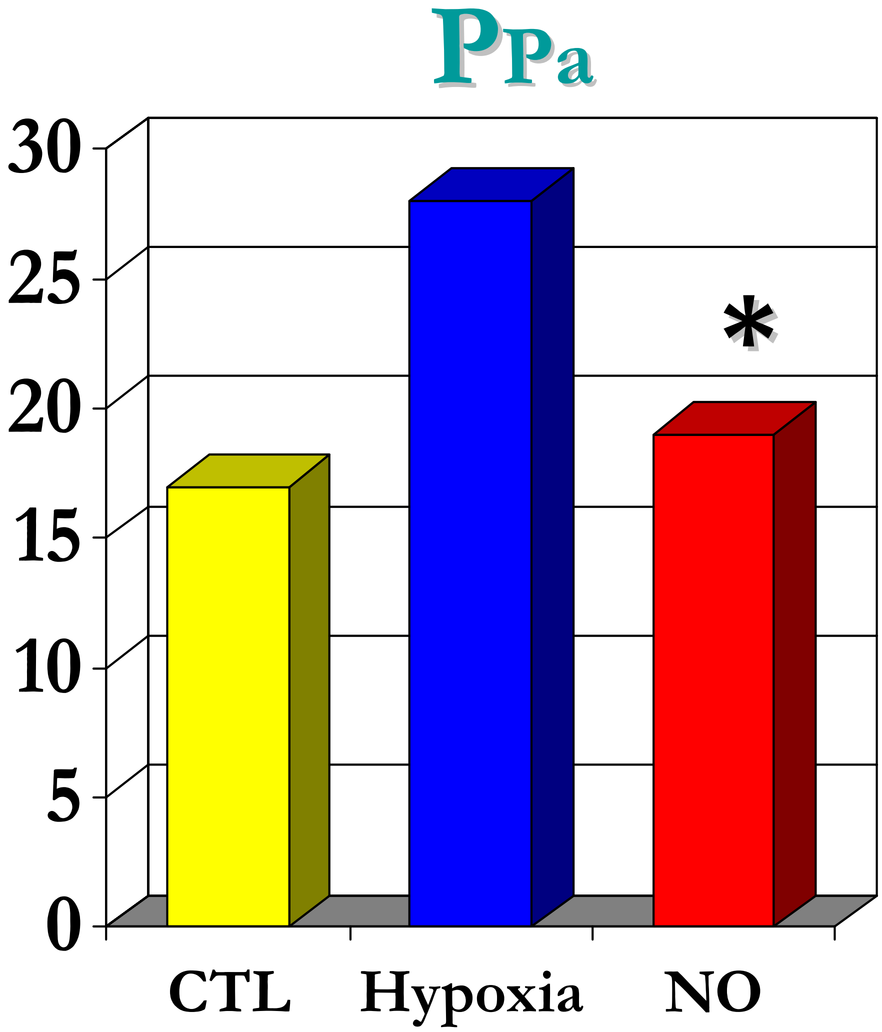


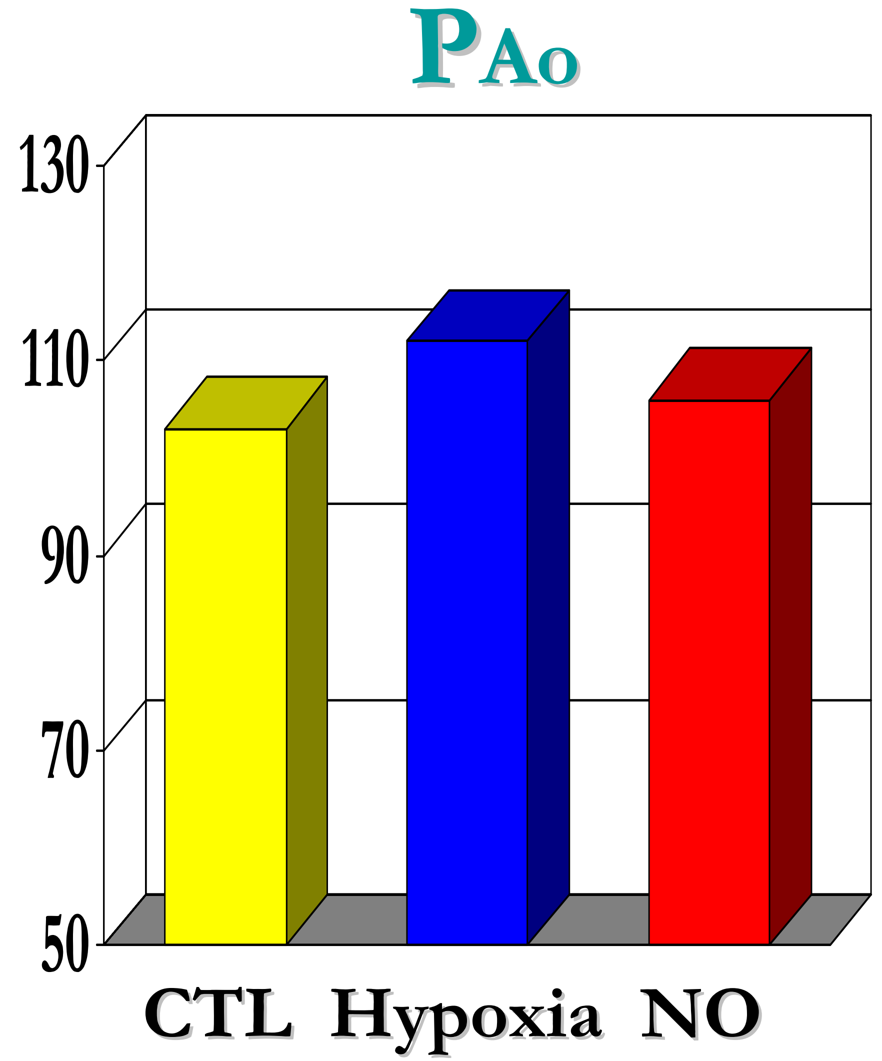
NO: A Selective Pulm Vasodilator

- **↓PA pressure**
- **↓ Right to left shunt**
- **↓ RV Work**
- **↑ Oxygenation**
- **↑ DO2**

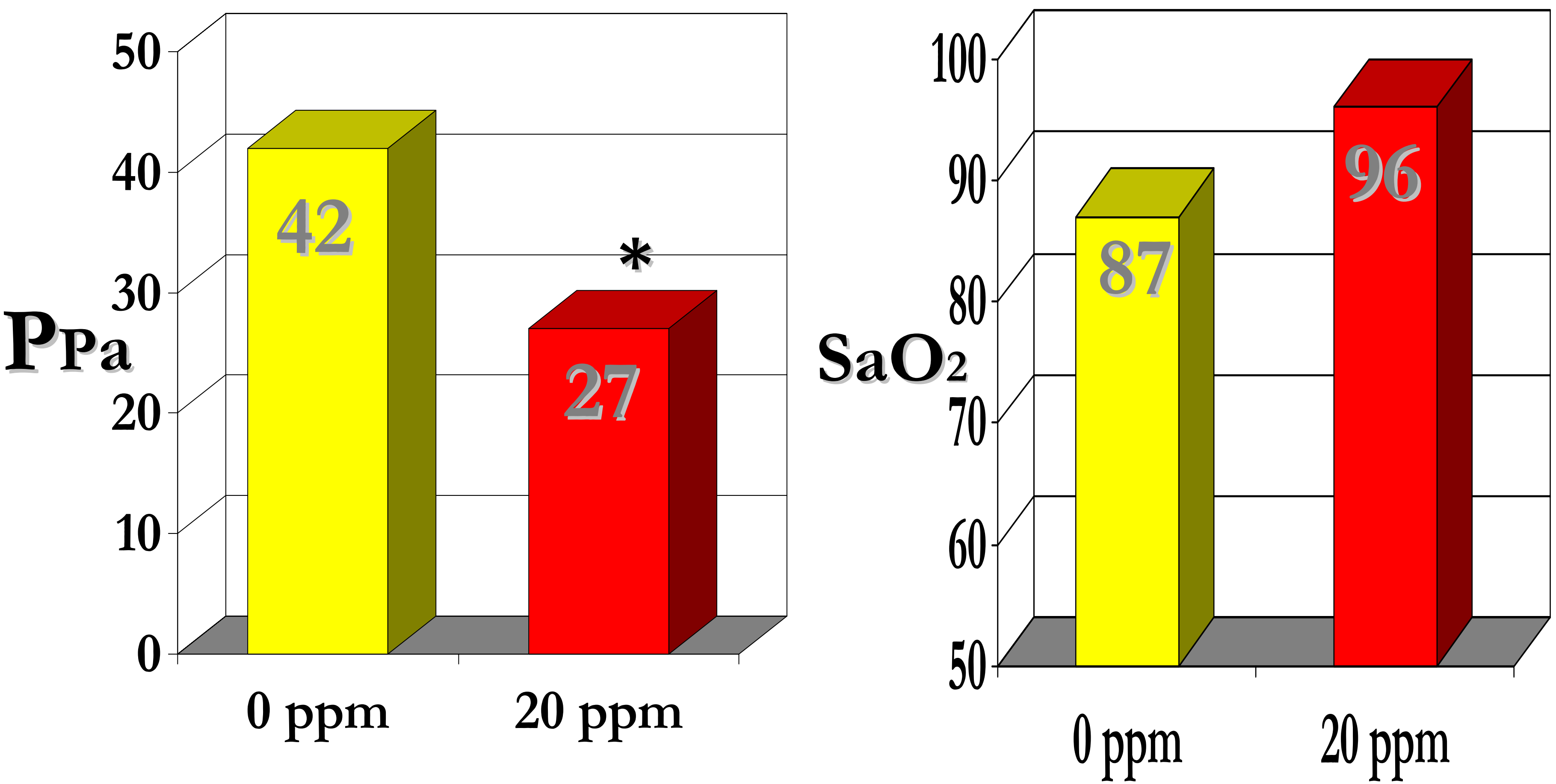
Nitric Oxide Effect on Pulmonary and Aortic Pressure

Frostel C, Circ 1991



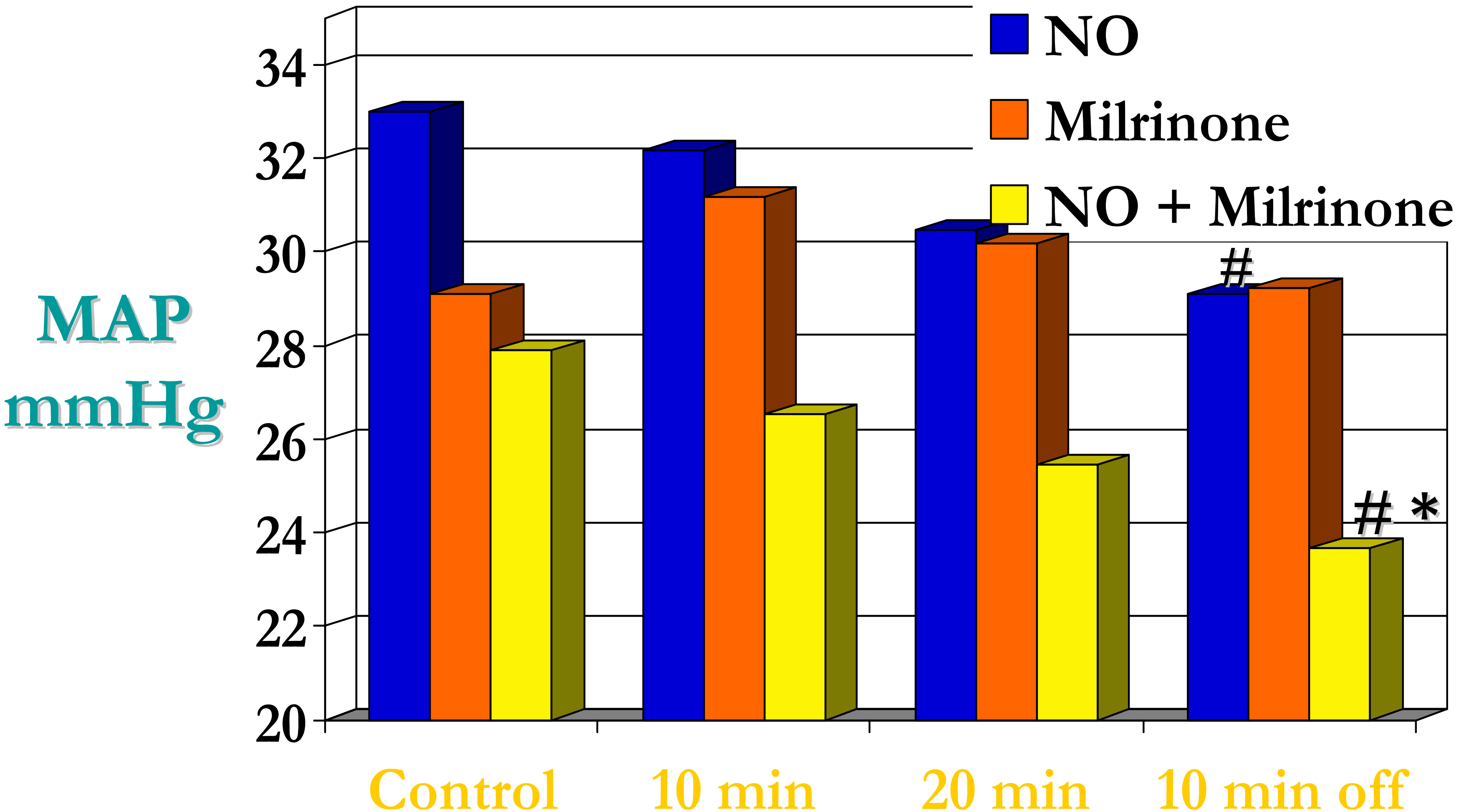


NO for PAH after Surgery for CHD



Milrinone and Nitric Oxide

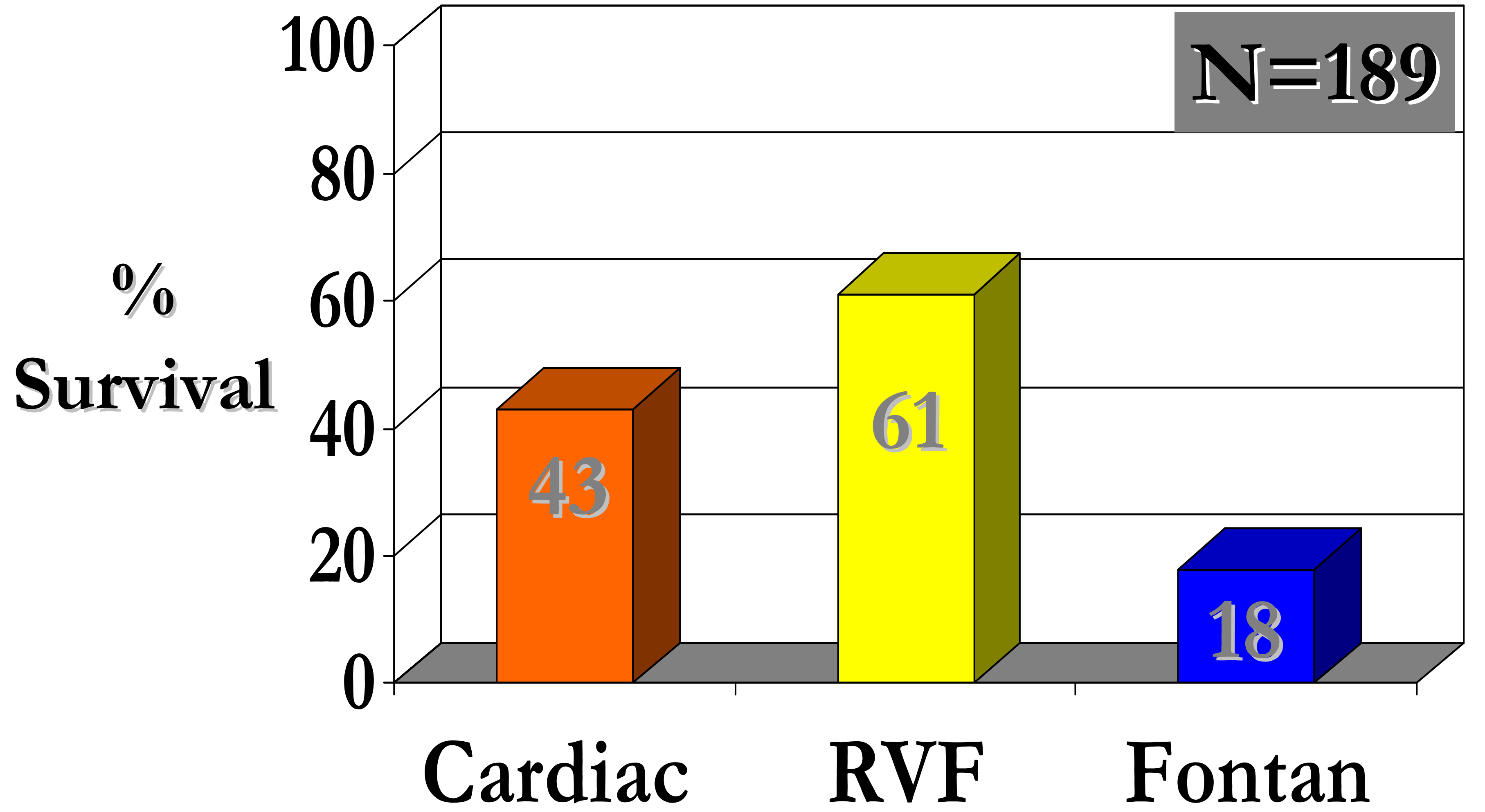
Khazin et al J Cardiothor Vasc Anesth 2004



# p<0.05 vs control, * vs NO group

ECMO for Pediatric Cardiac Support

1981-1990



Meliones, Circ 1991

ECMO for Pediatric Cardiac Support ESLSO Registry Between 1996-2000

- **740 CHD Patients placed on ECMO**
- **Diagnosis of TGA and PPHN had a significantly higher survival**
- **Survival Rate**
  - **Non HLHS = 57.9%**
  - **HLHS = 55.9%**

ECMO

- **Become a standard therapy in CHD**
  - **200/yr in 2000 vs 189 from 1981 - 1990**
  - **HLHS**
- **32% Improvement in survival with ECMO (1991-2000)**
  - **43% vs 55.9-57.6%**

ECMO and Shunt Management

- **Jaggers 2000 Ann Thorac Surg**
  - **Maintaining patent shunt**
    - **0/4 survival with shunt clipping**
    - **4/5 with shunt open**
  - **Flow rates**
    - **200ml/kg/min**

Create or Leave an ASD/PFO

Allows a Right to Left Shunt at the Atrial Level

- **Marked increase in Systemic C.O.**
- **Moderate reduction in O2 Content**
- **Overall increase in Systemic DO2**
- **Increase in Systemic BP – Improved RV perfusion**

Leaving Chest Open

- **Improve lung and RV compliance**
- **Improved lung compliance**
  - **↓ MAP during ventilation**
  - **↑ in RV preload**
- **Improved RV compliance**
  - **↓ RVEDP**
  - **↑ RVEDV**
  - **↑ CO and DO2**

Summary

1. **Defined pathophysiology of PAH and RV dysfunction**
2. **Treatment - RV coronary perfusion, alkalinization, medical gases, ventilatory strategies, inotropes, phosphodiesterase inhibitors, ECMO, surgical options**