Anesthesia for the cardiac compromised patient
Right ventricular failure

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Significance of the right ventricle

Starr I, Jeffers WA, Meade RH

*The absence of conspicuous increments of venous pressure after severe damage to the right ventricle* of the dog, with a discussion of the relation between clinical congestive failure and heart disease.

Am Heart J 1943; 26:291–301
Significance of the right ventricle
Significance of the right ventricle

RV-function independent predictor of morbidity and mortality in patients with:

- **COPD**

- **PPH**

- **Left-sided valvular heart disease**

- **Inferior myocardial infarction**

- **Chronic Heart Failure**
  - de Groote P: Right ventricular ejection fraction is an independent predictor of survival in patients with moderate heart failure. *J Am Coll Cardiol* 1998; 32: 948-54

- **Congenital Heart Disease**

- **Pulmonary Artery Embolism**

- **ARDS**

- **Cardiothoracic Surgery**

- **Liver Transplantation**
Epidemiology of RV failure in the perioperative period

**Cardiac Surgery**

- Few prospective data
- 48% of LCOS, mortality 44% Davila-Roman, Ann Thor Surg 1995
- Heart transplant: 50% of early complications; 42% of perioperative mortality Haddad, CanJCardiol 2008
- LVAD-implantation: 30-50%; mortality: 46% Matthews, JACC 2008

**ARDS**

- Few prospective data
- 25-30% using modern ventilation strategies (mortality: 30-40%) Vieillard-Baron, CCM 2001; Jardin, ICM 2007; Osman, ICM 2009
Right ventricular paradoxon

Passive Conduit

Low

RV Afterload

Increased

Active part of circulatory homeostasis
Anatomy of the right ventricle
The right ventricle is not just a small left ventricle!

- Shape: triangular/crescent (LV: ellipsoid)
- Thin-walled (2-5mm vs. LV: 7-11mm):
  → poor contractile reserves
Pathophysiology of the right ventricle
Consequences of an increase in afterload

- Specific anatomy
- Poor contractile reserves

Increased susceptibility to elevations of afterload

1) RV Output ↓

Haddad F et al.
The Right Ventricle in Cardiac Surgery, a Perioperative Perspective: I. Anatomy, Physiology, and Assessment

Right ventricle
Left ventricle

Stroke volume (% of control value)
Arterial pressure (mmHg)
Pathophysiology of the right ventricle
Consequences of an increase in afterload

2) LV Output ↓

Ventricular Interdependence

Diastolic ventricular interaction:
Leftward septal shift → LV preload ↓

Systolic ventricular interaction:
Leftward septal shift → LV contractility ↓
3) Septal dysfunction → RV Output ↓

Ventricular Interdependence

Systolic ventricular interaction:
- Leftward septal shift → LV contractility ↓ → RV output ↓
4) RV Coronary Perfusion ↓

Van Wolferen et al.  
Right coronary artery flow impairment in patients with pulmonary hypertension.  
5) Activation of apoptotic pathways

- ↓ RV and septal expressions of Bcl-2 *(antiapoptotic)*
- No changes in expressions of Bax *(proapoptotic)*
  \[ \rightarrow \] ↑ Bax/Bcl-2 ratio *(proapoptotic)*
- ↑ RV caspase-8, caspase-9 and caspase-3 *(proapoptotic)*

Dewachter C et al. Activation of apoptotic pathways in experimental acute afterload-induced right ventricular failure
*Crit Care Med* 2010; 38:1405–1413
Pathophysiology of the right ventricle
The vicious cycle of RV failure

A.

↑ RV Preload

↑ RV Afterload

Acute RV Failure and Dilation

↓ RV Output

Leftward septal shift

↓ LV contractility

↓ LV compliance

↓ LV preload

↓ Cardiac output

Tricuspid Regurgitation

↓ RV Output

↓ RV contractility

↑ RV wall tension

Right-Left-Shunting

↓ RV O₂ Supply/Demand

↓ RV coronary perfusion

Systemic hypotension

B.

↓ RV Output

↓ Cardiac output

↓ RV contractility

↑ RV Afterload

↑ RV Preload

↓ LV contractility

↓ LV compliance

↓ LV preload

↓ Cardiac output

↓ RV O₂ Supply/Demand

↓ RV coronary perfusion

Systemic hypotension
Pathophysiology of the right ventricle
The vicious cycle of RV failure

- ↑ RV afterload
  - RV dilatation
  - RV dysfunction
  - Tricuspid Regurgitation

- ↓ RV contractility
  - RV ischemia

- ↑ RV wall tension
  - ↑ RV diastolic dysfunction

Venous Congestion

Liver Failure
Renal Failure

Gaynor et al.
Right Atrial and Ventricular Adaptation to Chronic Right Ventricular Pressure Overload.
Circulation. 2005;112[suppl I]:I-212–I-218
Etiology of RV failure in the perioperative period

- Ischemia
- Postoperative contractile dysfunction (Stunning, Air embolism)
- Sepsis
- Cardiac Surgery
- "Adult congenital heart disease"
- Tricuspid regurgitation
- Pulmonary regurgitation

RV Contractility

RV Afterload
- PHT
- CPB
- Pulmonary Embolism
- Mechanical Ventilation
- ALI/ARDS
- Pulmonary Valve Stenosis

Intracardiac shunt

RV Preload
- Intracardiac shunt
- Pulmonary regurgitation
Etiology of RV failure
Post-Cardiotomy

- Air Embolism (RCA!)
- Suboptimal myocardial protection (Stunning)
- RV Ischaemia
- Protamine
- CPB-associated PHT
  - Release of pulmonary vasoconstrictors
  - Depression of pulmonary vasodilators

![Diagram of heart with arrows indicating blood flow and air emboli]

**Courtesy P. Wouters**
Monitoring the right ventricle in the perioperative period

Pulmonary Artery Catheter

- CVP
- RVP
- PAP

Right ventricular failure
Monitoring the right ventricle in the perioperative period

**Echocardiography**

- RV Shape
- Relative Size
- IVS
- IAS
- RVSP

- RVEDA < 0.7 LVEDA
- RVFAC > 40%
Monitoring the right ventricle in the perioperative period

Echocardiography: Longitudinal Function!

**TAPSE =**

Tricuspid Anular Plane Systolic Excursion

Vogel et al.
**Validation of Myocardial Acceleration During Isovolumic Contraction as a Novel Noninvasive Index of Right Ventricular Contractility.**
Circulation. 2002;105:1693-1699

Misannt, Rex et al.
**Load-sensitivity of Regional Tissue Deformation in the Right Ventricle: Isovolumic versus Ejection-phase Indices of Contractility.**
Eur Heart J 2008
Therapy/Prevention of RV failure in the perioperative period

Maintain RV intrinsic protective mechanism:

Homeometric Autoregulation:
Adaptation of RV contractility to match an increase in afterload

Avoid/Stop Sympathicolysis

Rex et al.
Thoracic epidural anesthesia impairs the hemodynamic response to acute pulmonary hypertension by deteriorating right ventricular–pulmonary arterial coupling.
Crit Care Med 2007; 35:222–229
Therapy/Prevention of RV failure in the perioperative period

Maintain Homeometric Autoregulation:

Avoid/stop cardiac sympathicolysis

Missant C., Rex S. et al.

Differential effects of lumbar and thoracic epidural anaesthesia on the haemodynamic response to acute right ventricular pressure overload.

*British Journal of Anaesthesia 104 (2): 143–9 (2010)*
Therapy/Prevention of RV failure in the perioperative period

Avoid Hypoxia

Hypoxic Pulmonary Vasoconstriction
Therapy/Prevention of RV failure in the perioperative period

Adjust the ventilator

- **PEEP**
  - HPV
  - Alveolar vessels
    - Compression by overinflation
    - Avoid high airway pressures/high tidal volumes
  - Extra-alveolar vessels
    - Avoid hypoxia

- **Total PVR**

**Axes:**
- Pulmonary Vascular Resistance (Y-axis)
- Lung Volume (X-axis)
  - RV (Right Ventricular End-diastolic Pressure)
  - FRC (Functional Residual Capacity)
  - TLC (Total Lung Capacity)
Pharmacological Therapy of RV failure in the perioperative period

1. **Vasodilation**
   - ↑ RV Afterload
     - RV Dilatation
     - RV Dysfunction
     - ↓ RV Output
     - Leftward septal shift

2. **Inodilators**
   - ↓ RV contractility
     - RV Ischemia
     - RV diastolic dysfunction

3. **Inotropy**
   - ↑ RV wall tension
     - ↑ RV VO$_2$
     - ↓ RV DO$_2$
     - ↓ Coronary perfusion pressure

4. **Venous Congestion**
   - Shunt (R-L)

5. **Vasopressors**
   - ↓ LV Preload
   - ↓ CO
   - Optimization Preload
   - Hypotension

- Vasopressors
- Optimization Preload

Right ventricular failure
Therapy of RV failure in the perioperative period

- No RCT‘s!
- Therapeutic concepts derived from LV failure
- Volume: Caution!
  - Tricuspid regurgitation
  - Wall tension
- Inotropy
  - Poor contractile reserves of RV
  - Inodilator (levosimendan, milrinone) vs. Inopressor (epinephrine)
- Vasoconstriction
  - Coronary artery perfusion pressure
  - Optimization of ventricular interdependence
  - Caution: PVR
- Vasodilation
  - Caution: Systemic hypotension / oxygenation
  - Selective pulmonary vasodilation (iNO, iloprost)
Inhaled NO

**Potential Benefits of Inhaled NO**

- Mild Bronchodilation
- Improved V/Q
- Pulmonary Shunt
- Selective pulmonary vasodilation

**Problems:**

- Non-Responders
- Toxic metabolites (NO$_2^-$, NO$_x$)
- Sophisticated monitoring (NO, NO$_2^-$)
- Met-Hemoglobinemia

- Inhibition of platelet-aggregation
- Rebound-effects (PHT, Hypoxia)
- Extremely short duration of action
- Not approved
- Costs
- No proven impact on outcome (ARDS)

**Dosing:**

- 20 (bis zu 40) ppm, weaning!
Right ventricular failure
Selective pulmonary vasodilation

Inhaled nitric oxide therapy in adults: European expert recommendations

- Clinical experience suggests that in ... acute RV dysfunction and elevated PVR, use of iNO may result in haemodynamic improvement when used during or after cardiac surgery
- Prior to iNO administration RV function should be optimised with conventional treatment

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Roman Ullrich
## Therapy of RV failure

### Selective pulmonary vasodilation: Iloprost

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stable carbacyclin derivative of PG1 (_2)</td>
<td>Special nebulizer required</td>
</tr>
<tr>
<td>Half-life: 6-9 mins</td>
<td>Ill-defined dose-response-relationship</td>
</tr>
<tr>
<td>Duration of action: 20-60 mins</td>
<td></td>
</tr>
<tr>
<td>→ Intermittent nebulization</td>
<td></td>
</tr>
<tr>
<td>Solution stable at room temperature</td>
<td>Non-responders</td>
</tr>
<tr>
<td>Solution stable at physiologic pH</td>
<td>Costs</td>
</tr>
<tr>
<td>Light-stable</td>
<td>No impact on outcome</td>
</tr>
</tbody>
</table>

### Dosing:

- 20 (up to 40) \(\mu\)g, every 1-4-6 h
Therapy of RV failure
Selective pulmonary vasodilation: Iloprost

Inhaled iloprost to control pulmonary artery hypertension in patients undergoing mitral valve surgery: a prospective, randomized-controlled trial.
Therapy of RV failure
Selective pulmonary vasodilation

Sildenafil

Advantages:
• "selective" inhibition of PDE-V → cGMP
• Low costs
• Inotropic effects in RV hypertrophy

Disadvantages:
• Few experience
• Systemic vasodilation

Indications:
• Mitigation of rebound-PHT during weaning from iNO
• Chronic therapy of PHT
• Combination therapy with inhaled iloprost

Dosing:
Start: 3x12.5mg p.o., then increase to up to 3x50mg, Caution: SVR!!!
Levosimendan improves right ventriculovascular coupling in a porcine model of right ventricular dysfunction.

Crit Care Med 2007; 35:707–715
RV failure

Summary

- Neglected problem in anaesthesia and intensive care medicine
- Poor prognosis
- Unique (patho)physiological characteristics
  - Necessitate tailored prophylaxis and therapy
- Therapy: Selective pulmonary vasodilation, vasopressors, inodilators
- Need for RCT‘s
Thank you very much for your attention