ACUTE ONSET RIGHT HEART FAILURE

ΓΕΝΙΚΟ ΝΟΣΟΚΟΜΕΙΟ ΑΘΗΝΩΝ ΙΠΠΟΚΡΑΤΕΙΟ
Α’ ΠΑΝΕΠΙΣΤΗΜΙΑΚΗ ΚΑΡΔΙΟΛΟΓΙΚΗ ΚΛΙΝΙΚΗ
ΣΟΛΩΜΟΥ ΕΙΡΗΝΗ
The right ventricle may be said to be made for the sake of transmitting blood through the lungs, not for nourishing them.”

William Harvey, Exercitatio Anatomica de Motu Cordis et Sanguinis in Animalibus, 1628
‘The Right Heart is a stepchild No More’

E Braunwald 2013
Contemporary management of acute right ventricular failure: a statement from the Heart Failure Association and the Working Group on Pulmonary Circulation and Right Ventricular Function of the European Society of Cardiology

Introduction

Acute right ventricular (RV) failure can be defined as a rapidly progressive syndrome with systemic congestion resulting from impaired RV filling and/or reduced RV flow output. Most often it is associated with increased RV afterload or preload and consequent RV chamber dilatation and tricuspid regurgitation (Figure 1). The prevalence of acute RV failure is difficult to estimate, but its predominant causes [i.e. left-sided heart failure, acute pulmonary embolism (PE), acute myocardial ischaemia] are common. It is observed in 3–9% of acute heart failure admissions, and the in-hospital mortality of patients with acute RV failure ranges from 5 to 17%. Research efforts have disproportionately focused on the failing left ventricle, but recently more attention has been placed on understanding RV anatomy, physiology, dysfunction, and management. Right ventricular failure is a heterogeneous syndrome, and its varied pathologies require individualized treatment.

ventricle, twisting and rotational movements do not contribute significantly to RV contraction. Instead, the most important mechanisms are the bellows-like inward movement of the free wall, the contraction of the longitudinal fibres drawing the tricuspid annulus toward the apex, and the traction on the free wall as a result of left ventricular contraction. The contraction of the right ventricle is sequential, starting with the trabeculated myocardium and ending with the contraction of the infundibulum (25–50 ms delay). Because RV afterload is very low under normal conditions, blood flows from the RV into the pulmonary circulation both during systole and during the early part of diastole, leading to the absence of isovolumetric relaxation.

Aetiology and pathogenesis of right ventricular failure

Right ventricular mechanics and function are altered in the setting of either pressure overload or volume overload (Figure 1, Table 1).
The anatomy and physiology of the RV are both unique and complex and quite different from LV (trapezoidal and crescent shaped rather than the ellipsoidal LV).

Anatomically, RV can be described regarding three components:

- the inlet, which consists of the tricuspid valve, chordal tendineae, and papillary muscles.
- the trabeculated apical myocardium and
- the infundibulum, or conus, which corresponds to the outlet region.

The deep muscle fibers of the right ventricle are longitudinally aligned base to apex (in contrast to the left ventricle where oblique fibers are found superficially, longitudinal fibers on the endocardium, and circumferential fibers in between).
WHAT HAPPENS DURING CONTRACTION?

Under normal afterload, RV contraction has peristaltic/asynchronous bellows-like pattern of contraction from apex to base. In contrast, LV contracts in a squeezing/synchronous pattern by twisting and rotational movements from apex to base (likened to wringing a towel).

The RV contracts by three mechanisms:

- Inward movement of the free wall secondary to the contraction of the right segment of the basal loop (transverse orientation), which produces a bellows effect.
- Contraction of the ascending segment of the apical loop (oblique orientation), which shortens the long axis, drawing the tricuspid annulus toward the apex and
- Traction on the free wall at the points of attachment secondary to LV contraction. The shortening of the RV is mainly longitudinal compared to radial, and the sinus chamber made up 81 ± 6% of the RV end-diastolic volume and 87 ± 4% of the stroke volume.
Normally the right ventricle reaches 15-30 mmHg in peak systole and pushes through a low pressure of 4-12 mmHg in the pulmonary artery.

RV cannot acutely overcome a systolic PAP more than 50 mmHg.

Conversely, acute-on-chronic RVF can tolerate significantly higher PAP.
We define right heart failure as a clinical syndrome due to an alteration of structure and/or function of the right heart circulatory system that leads to sub-optimal delivery of blood flow (high or low) to the pulmonary circulation and/or elevated venous pressures at rest or with exercise.
PATHOPHYSIOLOGY OF ACUTE RVF

- RV inability to respond to acutely increased pulmonary pressure (i.e. afterload)
- RV pressure/volume overload (i.e. preload) causing bowing of the interventricular septum and affecting the left ventricular diastolic function due to RV-LV interdependence
- RV ischemia/infarct

RV wall tension increase leads to
- the cardiomyocyte stress and injury secondary to ischemia, substrate depletion, and mitochondrial energy metabolism impairment
- neutrophil-mediated inflammation secondary to the influx of pro-inflammatory cells and chemokine/cytokine activation producing oxidative damage, cardiomyocyte apoptosis, and direct negative inotropic effects (myosin heavy chain switch and the decrease of myofibrillar sensitivity to calcium)
- coronary vasodilator reserve is exhausted as a consequence of RV ischemia
- The upstream transmission of LV end-diastolic pressure to left atrial pressure, pulmonary arterial wedge pressure, and mean PAP may approach a 1:1 ratio, producing a vicious cycle.
# Diagnosis: Nonspecific Findings

## Table 1—Symptoms of RV Failure

<table>
<thead>
<tr>
<th>Acute</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dyspnea</td>
</tr>
<tr>
<td>Lightheadedness</td>
</tr>
<tr>
<td>Syncope</td>
</tr>
<tr>
<td>Chest discomfort</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chronic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acute symptoms</td>
</tr>
<tr>
<td>Right-upper-quadrant abdominal pain</td>
</tr>
<tr>
<td>Lower-extremity swelling</td>
</tr>
</tbody>
</table>

## Table 2—Signs of RV Failure

<table>
<thead>
<tr>
<th>Acute</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hypotension</td>
</tr>
<tr>
<td>Tachycardia</td>
</tr>
<tr>
<td>Tachypnea</td>
</tr>
<tr>
<td>Cyanosis</td>
</tr>
<tr>
<td>Elevated jugular venous pressure</td>
</tr>
<tr>
<td>Parasternal heave</td>
</tr>
<tr>
<td>RV third-heart sound</td>
</tr>
<tr>
<td>Tricuspid regurgitation</td>
</tr>
<tr>
<td>Accentuated sound of pulmonic valve closure</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chronic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acute signs</td>
</tr>
<tr>
<td>Hepatic enlargement and ascites</td>
</tr>
<tr>
<td>Lower-extremity edema</td>
</tr>
</tbody>
</table>
### CAUSES

- Acute Myocardial Infarction of the right ventricle
- Myocarditis of the right ventricle
- Pulmonary Embolism
- ARDS
- Acute sickle cell crisis
- Cardiac Surgery
- Mechanical ventilation
- Tamponade

#### Increased afterload – acute increase in pulmonary pressure

- Reduced RV contractility

#### Reduced RV ability to expand due to mechanical pressure

- Acute tricuspid valve regurgitation

#### Increased preload

<table>
<thead>
<tr>
<th>Table 1 Causes and differential diagnosis of right ventricular failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acute left ventricular failure</td>
</tr>
<tr>
<td>Right ventricular ischaemia/infarction</td>
</tr>
<tr>
<td>Acute pulmonary embolism</td>
</tr>
<tr>
<td>Exacerbation of chronic lung disease and/or hypoxia</td>
</tr>
<tr>
<td>Acute lung injury or respiratory distress syndrome</td>
</tr>
<tr>
<td>Sepsis</td>
</tr>
<tr>
<td>Chronic pulmonary hypertension (groups 1–5)</td>
</tr>
<tr>
<td>Pericardial disease (tamponade)</td>
</tr>
<tr>
<td>Arrhythmias (supraventricular or ventricular tachycardia)</td>
</tr>
<tr>
<td>Congenital heart disease (e.g. atrial or ventricular septal defects, Ebstein's anomaly)</td>
</tr>
<tr>
<td>Valvulopathies (e.g. tricuspid valve regurgitation, pulmonary valve stenosis)</td>
</tr>
<tr>
<td>Cardiomyopathies (e.g. arrhythmogenic right ventricular dysplasia, familial, idiopathic)</td>
</tr>
<tr>
<td>Myocarditis or other inflammatory diseases</td>
</tr>
<tr>
<td>Cardiac surgery (e.g. cardiac transplant or left ventricular assist device implantation)</td>
</tr>
<tr>
<td>Haematological disorders (e.g. acute chest syndrome in sickle cell disease)</td>
</tr>
</tbody>
</table>
Acute PE is a common cause of acute RVD/RVF due to an excessive increase in afterload secondary to

- obstruction by clots causing V/Q mismatch
- vasoconstriction in non-obstructed areas
- intracardiac hemolysis (resulting from the turbulent flow across the pulmonary arterial tree)

Echocardiographic RVD is present between 30 and 56% of normotensive patients with PE

Cardiogenic shock occurs in ~5% of acute PE cases with a 90-day mortality rate of more than 50%

The presence of elevated BNP and Troponin levels are related to highest risk for adverse outcomes in PE
MCCONNELL'S SIGN
RV myocardial infarction (RVMI) can be complicated by acute RVD in 30–50% of patients with inferior wall ST-elevation MI.

Severe hypotension and low CO are present in 10% on admission in the reperfusion era.

The right coronary artery (RCA) usually is the culprit vessel in RVMI, and more extensive RV myocardial necrosis is associated with proximal RCA occlusions.

The RV tolerates ischemic injury better than the LV because it has a lower oxygen demand, greater coronary flow reserve, dual, right and left, coronary arteries supply, and homogeneous transmural perfusion across the cardiac cycle.

Although RVMI increases the risk of complications in patients with inferior MI, several studies have reported that the acute outcome of patients with RVMI is primarily determined by the amount of accompanying LV necrosis.
ACUTE MYOCARDIAL INFARCTION
Infective Endocarditis

- 7-10% of all infective endocarditis cases
- Severe tricuspid valve regurgitation can lead to acute RVF
- Severe TR and RVF are indications for surgical replacement of TV

Iatrogenic trauma i.e. PPM insertion
ARDS is one of the most common entities to challenge the RV

- The incidence of acute RVD in ARDS varies from 30 to 56%
- Both pulmonary hypertension and RV contractile impairment are the main factors involved in RVD

Mechanisms of ARDS-induced acute RVD include

- hypoxic/hypercarbic vasoconstriction,
- an increased alveolar dead space
- pulmonary microthrombi and
- Pro-inflammatory cytokine activation.
A recent study identified four predictors of acute RVD in ARDS:

- pneumonia-induced ARDS,
- partial pressure of arterial oxygen/fraction of inspired oxygen ratio < 150 mmHg
- partial pressure of carbon dioxide ≥ 48 mmHg and
- driving pressure (plateau pressure − total positive end-expiratory pressure) ≥ 18 cmH$_2$O

Routine echocardiography is recommended in all ARDS patients with a score ≥ 2 (incidence of RVD ≥ 20%) allowing an early implementation of RV-protective strategy that might prevent RVD.

ACUTE SICKLE CELL CRISIS

- Imaging studies of SCD patients at steady state without pulmonary hypertension have shown dilated right heart chambers without significant RV dysfunction in most cases.
- During acute chest syndrome, pulmonary pressures increase, and in a series of 84 consecutive hospital admissions, cor pulmonale was seen in 13% of patients.
- All of these patients had a TRV≥3m/s during the acute event and they were at particularly high risk for multi-organ failure and sudden death.
- Patients with resting pulmonary hypertension and/or evidence of RV dysfunction are the ones most likely to develop acute right heart failure. Acute pressure overload on top of a chronic pulmonary vasculopathy is felt to be the reason for acute RV decompensation.

Cardiovascular Abnormalities in Sickle Cell Disease
Mark T. Gladwin, MD1,2 and Vandana Sachdev, MD3. J Am Coll Cardiol. 2012 Mar 27; 59(13)
Positive pressure ventilation results in increase of intrathoracic pressure

RV afterload is increased and as a result RV pressure is increased

IVS shifts to the left ventricle affecting LV diastolic function

RV ischaemia and systolic dysfunction

Cardiogenic shock
Acute RVF is a serious problem after cardiothoracic surgery.

- It occurs in 0.1% of patients after cardiotomy, in 2-3% of patients undergoing heart transplantation, and in 10–20% of patients needing LV assist device insertion.

- PH and myocardial depression after cardiopulmonary bypass are usually mild, except in vulnerable patients, to whom it may contribute to postoperative RVF.

- In the postoperative cardiac surgery (POCS) patient, acute RVD (RV fractional area change ≤ 25% or severe RV dilation) was present in almost half of the patients hemodynamically unstable (G. J. Vlahakes, “Right ventricular failure after cardiac surgery,” Cardiology Clinics, vol. 30, no. 2, pp. 283–289, 2012).
Several factors may be implicated to RVD/RVF in the POCS patient:

- long cardiopulmonary bypass time
- right coronary embolism or bypass graft occlusion
- inadequate myocardial protection during surgery
- reperfusion lung injury with secondary PH
- protamine-induced pulmonary hypertension (PH)
- atrial arrhythmias or loss of atrioventricular synchrony, and
- preexisting pulmonary vascular disease

The extent of pulmonary parenchymal resection (loss of pulmonary tissue) and the preexisting PVD/RVD predict the risk and severity of postoperative RVD in patients undergoing lung resection. Hypoxia, atelectasis, and hypercarbia may precipitate acute RVD.
TAMPONADE
MYOCARDITIS AFFECTING THE RIGHT VENTRICLE

- Isolated involvement of right ventricle has been described in 4 case reports which may be either because of its rare incidence or because of underreporting due to lack of sufficient diagnostic guidelines and cases reported

DIAGNOSIS

- Echocardiography
- Right Heart Catheterization
### ECHOCARDIOGRAPHY FOR ASSESSMENT OF THE RIGHT VENTRICLE

<table>
<thead>
<tr>
<th>RV structural parameters</th>
<th>RV functional parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basal RV diameter &gt; 42 mm</td>
<td>RV fractional area change</td>
</tr>
<tr>
<td>RV mid-diameter &gt; 33 mm</td>
<td>MPI &gt; 0.43 (pulsed Doppler); &gt; 0.6 (continuous Doppler)</td>
</tr>
<tr>
<td>RV EDD/LV EDD &gt; 0.9</td>
<td>TAPSE &lt; 16 mm</td>
</tr>
<tr>
<td>RV/LV EDA &gt; 0.6</td>
<td>S wave &lt; 10 cm/s</td>
</tr>
<tr>
<td>LV eccentricity index &gt; 1</td>
<td>Peak RV free wall 2D strain</td>
</tr>
<tr>
<td>McConnell’s sign</td>
<td></td>
</tr>
<tr>
<td>RV wall thickness &gt; 5 mm</td>
<td></td>
</tr>
</tbody>
</table>

### RV Outflow Tract Flow Velocity

3 Distinct Patterns

- **No notch**
  - L-heart congestion
  - PH largely 2° PCW
  - Absence of significant pulm vasc disease

- **Mid-systolic notch**
  - Markedly elevated PVR
  - Low PA compliance
  - RV dysfunction

- **Late-systolic notch**
  - Intermediate PVR
  - Mod pulm vasc disease
  - Mod L-heart congestion

Forfia - Hospital of the University of Pennsylvania
ECHO DIASTOLIC D SHAPE OF LEFT VENTRICLE

- D-shaped left ventricle evidenced during systole (particularly end-systole) suggests RV pressure overload
- D-shaped ventricle in diastole suggests RV volume overload
- If severe TR coexists with pulmonary hypertension, combined RV pressure and volume overload results in septal flattening occurring in both systole and diastole

Since diastolic interventricular septal flattening represents relative RV and LV filling, an RV overload pattern may be manifest in the setting of mitral stenosis and less severe forms of TR
Invasive hemodynamic monitoring should be performed:

- Patients being considered for cardiac transplantation or placement of an mechanical circulatory device (MCS)
- Presumed cardiogenic shock requiring escalating pressor therapy and consideration of MCS
- Severe clinical decompensation in which therapy is limited by uncertain contributions of elevated filling pressures, hypoperfusion, and vascular tone;
- Apparent dependence on intravenous inotropic infusions after initial clinical improvement
- Persistent severe symptoms despite adjustment of recommended therapies.

JACC 2013
The usual PAC findings suggestive of acute RVD include:

- an elevated CVP (greater than 20 mmHg),
- an inverse pressure gradient (CVP > PAWP),
- a low cardiac index (<2 L/min/m$^2$) and stroke volume index (<30 mL/m$^2$),
- mixed-venous oxygen saturation (SvO$_2$ < 55%)
TREATMENT

Acute right heart failure

- Volume optimization
  - Volume overload
    - Salt restriction, daily weights (3)
  - Hypovolemia

- Hemodynamic support
  - RV infarct
  - Acute PE
  - Hypotension/Shock

- Treat underlying disease

  - Pulmonary hypertension: diuresis, inhaled NO, intravenous/inhaled prostacyclins (avoid subcutaneous route in severe RHF), PDE5 inhibitors, ET-1 receptor antagonists (1, 3, 5, 7, 10)
  - Pulmonary embolus: anticoagulation, thrombolysis, thrombectomy (surgical or catheter-directed) (5, 7, 11)
  - CTEPH: thrombendarterectomy (5, 11)
  - RV infarct: PCI, thrombolysis (8)
  - LV dysfunction: afterload reduction, diuresis, inotropes, nesiritide, IABP, LVAD (2)
  - CHD/VHD: surgical or percutaneous correction (2, 3, 7, 8)
  - Sepsis/acute lung injury: volume resuscitation, broad spectrum antibiotics, activated protein C, lung protective ventilation strategy (1, 2, 3, 4, 5, 6, 9, 10)
  - Post cardiothoracic surgery: inhaled NO, inhaled/intravenous prostacyclins, milrinone, PDE5 inhibitors (1, 2, 3, 4, 7, 8)

- Rhythm stabilization: cardioversion, antiarrhythmics, pacemaker, resynchronization (1, 2, 8)

- Volume challenge (1, 3) (500 – 1000 ml; no further volume challenge if no effect)

- Vasopressors/inotropes/inodulators: dobutamine, milrinone, levosimendan, norepinephrine, low-dose vasopressin (1, 2, 8)
  - Avoid: dopamine, phentolamine
  - Consider combination therapy with inhaled NO or inhaled/intravenous prostacyclins

- Rescue therapies: atrial septostomy, RVAD, ECMO, transplantation
**TREATMENT**

1. **Assess severity:**
   - Clinical evaluation (arterial pressure, mental status, diuresis)
   - Biochemical evaluation (lactate, liver markers, renal function, BNP, troponins)
   - Imaging (echocardiography, CT scan)
   - Invasive evaluation (central venous or pulmonary artery catheter)

2. **Identify and treat triggering factor(s):**
   - Sepsis, arrhythmias, drug withdrawal
   - Ensure cause-specific management:
     - PCI for RV infarction, repertusion for acute high-risk PE

3. **Optimize fluid status:**
   - IV diuretics if volume overload
   - RRT if situation insufficiently managed with diuretics
   - Cautious fluid filling if low CVP; avoid overfilling

4. **Maintain arterial pressure:**
   - Norepinephrine

5. **Consider inotropes reducing cardiac filling pressures:**
   - Levosimendan
   - Dobutamine
   - Phosphodiesterase III inhibitors

6. **Further measures for afterload reduction:**
   - Inhaled NO
   - Inhaled prostacyclins

---

**Haemodynamic monitoring and support** (ICU or Intermediate Care Unit)

**Consider transfer to hospital with possibility for ECMO/mechanical circulatory support**
PULMONARY VASODILATORS

- **iNO** use (or combined with dobutamine or milrinone) for PH and/or RVF in patients undergoing orthotopic heart or lung transplantation was associated with lower mortality compared with its use in cardiac surgery or medical patients with hypoxemia. Decrease also cytokine production.

- **Prostacyclins** activate cyclic adenosine monophosphate, resulting in pulmonary and systemic vasodilation and inhibition of platelet aggregation (sparse data on acute RHF).

- The short half-life (3 to 6 min) and its potent effects make epoprostenol the preferred prostacyclin in the ICU. Initiated at 1 to 2 ng/kg/min, the drug is increased by 0.5 to 1 ng/kg/min every 15 to 30 min, it decreases PAP and PVR and increases CO, although FIRST terminated due to mortality.

- Inhaled Iloprost improves PH and RV function in patients undergoing mitral valve surgery, cardiopulmonary bypass, or heart transplantation.

- **PDE-5** inhibitors block degradation of cyclic guanosine monophosphate, decrease PAP and increase CO.

- **Sildenafil** decreases RV mass.

Am J Cardiol 2002;90:677–80
In acute PH, low-dose dobutamine (2 to 5 g/kg/min) increases CO and decreases PVR, whereas higher doses (5 to 10 g/kg/min) only induce tachycardia and increase myocardial oxygen consumption; while may cause hypotension through peripheral β2 stimulation.

The combination of dobutamine and inhaled nitric oxide (iNO) improved CO, decreased PVR, and increased the PaO2/FiO2 ratio.

Levosimendan increases CO, decreases PVR, and improves regional perfusion, together with a protective effect against endothelial dysfunction by inhibiting expression of soluble adhesion molecules.
Noradrenaline is primarily indicated:

- to restore blood pressure and improve cerebral, coronary, and other organ perfusion
- improve systemic haemodynamics by improvement of ventricular systolic interaction and coronary perfusion without change in pulmonary vascular resistance

Dopamine should be used with caution in low doses (higher doses can increase pulmonary artery resistance)
Extracorporeal membrane oxygenation (ECMO)

Right ventricular assisting device (RVAD)

BAS – balloon atrial septostomy (right to left shunt to decrease RV preload)
(Should not be offered to patients with significant hypoxemia (90% on room air), and/or PVR index 4,400 dynes s cm5/m2Is contraindicated with concomitant LV failure)

Heart, lung, or combined heart-lung transplantation is the last resort for end-stage RVF. In patients with PAH, RVF (RAP >15 mm Hg and/or cardiac index <2.0 l/min/m2)
Among the clinical situations to be RVAD considered, we highlight RV myocardial infarction, PE, myocarditis, and postoperative low cardiac output syndrome, following LV assist device implantation or primary graft failure after heart transplantation.

ECMO support with either peripheral or central cannulation is indicated whenever respiratory failure is present while awaiting pulmonary recovery, with or without RVF or biventricular failure.
WHAT TO REMEMBER?

- Treat the underlying cause!!
- Regulate preload and afterload
- Reduce pulmonary pressure
- Increase RV contractility
- Mechanical support

Flowchart:
- Acute RV Failure
  - Treatable Cause? (PE, RV infarct)
    - YES: Treatment Successful
    - NO: Excessive Preload?
  - Excessive Afterload
    - NO: Decreased RV Perfusion?
    - YES: Decreased RV Contractility
      - YES: RV Failure Resolved
      - NO: Consider ECLS Lung Transplantation
    - NO: Correct Factors That Increase PVR
      - NO: Volume Reduction (Diuresis, Ultrafiltration)
      - YES: Pulmonary Vasodilators
        - NO: Pressors
        -YES: Maximize myocyte function (correct metabolic abnormalities, treat sepsis)
THANK YOU FOR YOUR ATTENTION