Pathophysiology of Right Heart Failure

Professor T A McDonagh, Consultant Cardiologist, King’s College Hospital, London, UK.
Congestion....
Right Heart Failure

The syndrome of right heart failure

Acute Heart Failure Syndromes

Pathophysiology

Clinical Features

Specific Cardiac Causes
AHF Syndromes

"HF due to R sided pathophysiology – ↑JVP and liver size, usually accompanied by peripheral oedema as unique or concomitant To L-HF"
EHFS II-3085 admitted with HF, 133 ESC Centres

<table>
<thead>
<tr>
<th>Classification of AHF %</th>
<th>All</th>
<th>De novo AHF</th>
<th>ADCHF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decompensated HF</td>
<td>65.4</td>
<td>52.4</td>
<td>73.0***</td>
</tr>
<tr>
<td>Pulmonary oedema</td>
<td>16.2</td>
<td>26.0</td>
<td>10.4***</td>
</tr>
<tr>
<td>Cardiogenic shock</td>
<td>3.9</td>
<td>6.8</td>
<td>2.2***</td>
</tr>
<tr>
<td>Hypertensive HF</td>
<td>11.4</td>
<td>11.4</td>
<td>11.3</td>
</tr>
<tr>
<td>Right HF</td>
<td>3.2</td>
<td>3.4</td>
<td>3.0</td>
</tr>
</tbody>
</table>

Nieminem, M. S. et al. Eur Heart J 2006
<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Total</th>
<th>Decomp. HF</th>
<th>Pulmonary oedema</th>
<th>Cardiogenic shock</th>
<th>Hypert. HF</th>
<th>Right HF</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of patients (% of total)</td>
<td>3580</td>
<td>2340 (65.4)</td>
<td>581 (16.2)</td>
<td>139 (3.9)</td>
<td>407 (11.4)</td>
<td>113 (3.2)</td>
</tr>
<tr>
<td>Age (years), mean (SD)</td>
<td>69.9 (12.5)</td>
<td>69.7 (12.8)</td>
<td>71.2 (11.5)</td>
<td>67.3 (12.7)</td>
<td>69.8 (11.2)</td>
<td>69.6 (13.4)</td>
</tr>
<tr>
<td>Age, IQR</td>
<td>62.6–78.7</td>
<td>62.3–78.7</td>
<td>64.6–79.7</td>
<td>59.5–77.2</td>
<td>61.9–78.4</td>
<td>63.0–79.5</td>
</tr>
<tr>
<td>Male (%)</td>
<td>61.3</td>
<td>62.1</td>
<td>59.4</td>
<td>67.6</td>
<td>60.4</td>
<td>50.4</td>
</tr>
<tr>
<td>Body mass index (kg/m²)</td>
<td>26.8</td>
<td>26.5</td>
<td>26.9</td>
<td>26.4</td>
<td>28.0</td>
<td>26.6</td>
</tr>
<tr>
<td>New-onset AHF (%)</td>
<td>37.1</td>
<td>29.7</td>
<td>59.6</td>
<td>64.7</td>
<td>37.3</td>
<td>39.8</td>
</tr>
<tr>
<td>Hospitalization for HF within last 12 months (%)</td>
<td>44.5</td>
<td>48.0</td>
<td>33.7</td>
<td>29.3</td>
<td>45.1</td>
<td>46.4</td>
</tr>
<tr>
<td>Underlying diseases (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CHD (%)</td>
<td>53.6</td>
<td>54.0</td>
<td>54.9</td>
<td>52.5</td>
<td>53.8</td>
<td>38.1</td>
</tr>
<tr>
<td>Hypertension</td>
<td>62.5</td>
<td>56.0</td>
<td>70.1</td>
<td>54.0</td>
<td>94.6</td>
<td>52.2</td>
</tr>
<tr>
<td>Diabetes mellitus</td>
<td>32.8</td>
<td>30.9</td>
<td>39.4</td>
<td>34.3</td>
<td>34.5</td>
<td>29.2</td>
</tr>
<tr>
<td>Atrial fibrillation/flutter</td>
<td>38.7</td>
<td>41.3</td>
<td>28.1</td>
<td>24.6</td>
<td>37.7</td>
<td>58.4</td>
</tr>
<tr>
<td>Previous stroke or TIA</td>
<td>13.3</td>
<td>12.4</td>
<td>15.7</td>
<td>11.8</td>
<td>16.0</td>
<td>13.3</td>
</tr>
<tr>
<td>Valvular disease</td>
<td>34.4</td>
<td>37.5</td>
<td>26.2</td>
<td>18.0</td>
<td>31.7</td>
<td>43.8</td>
</tr>
<tr>
<td>Renal failure</td>
<td>16.8</td>
<td>16.6</td>
<td>15.8</td>
<td>18.1</td>
<td>18.7</td>
<td>17.7</td>
</tr>
<tr>
<td>Anaemia</td>
<td>14.7</td>
<td>15.0</td>
<td>15.7</td>
<td>14.4</td>
<td>11.3</td>
<td>16.8</td>
</tr>
<tr>
<td>Chronic obstructive pulmonary disease</td>
<td>19.3</td>
<td>19.2</td>
<td>19.3</td>
<td>18.1</td>
<td>18.0</td>
<td>27.4</td>
</tr>
<tr>
<td>Pacemaker Implantal</td>
<td>9.1</td>
<td>10.6</td>
<td>5.9</td>
<td>10.8</td>
<td>4.9</td>
<td>8.8</td>
</tr>
<tr>
<td>Dilated cardiomyopathy</td>
<td>19.3</td>
<td>21.8</td>
<td>11.4</td>
<td>10.2</td>
<td>20.2</td>
<td>15.9</td>
</tr>
<tr>
<td>Precipitating factors (on admission)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ACS (%)</td>
<td>30.2</td>
<td>24.7</td>
<td>49.4</td>
<td>71.9</td>
<td>24.4</td>
<td>14.2</td>
</tr>
<tr>
<td>STEMI</td>
<td>11.1</td>
<td>8.4</td>
<td>17.0</td>
<td>55.4</td>
<td>4.7</td>
<td>6.2</td>
</tr>
<tr>
<td>Non-STEMI</td>
<td>10.0</td>
<td>7.7</td>
<td>22.4</td>
<td>12.9</td>
<td>5.4</td>
<td>5.3</td>
</tr>
<tr>
<td>Unstable angina</td>
<td>9.1</td>
<td>8.6</td>
<td>10.0</td>
<td>3.6</td>
<td>14.3</td>
<td>2.7</td>
</tr>
<tr>
<td>Arrhythmia (%)</td>
<td>32.4</td>
<td>32.9</td>
<td>29.3</td>
<td>29.7</td>
<td>34.5</td>
<td>33.9</td>
</tr>
<tr>
<td>Atrial</td>
<td>29.4</td>
<td>30.1</td>
<td>25.7</td>
<td>18.8</td>
<td>34.0</td>
<td>33.0</td>
</tr>
<tr>
<td>Ventricular</td>
<td>4.1</td>
<td>3.7</td>
<td>5.2</td>
<td>13.0</td>
<td>2.0</td>
<td>2.7</td>
</tr>
<tr>
<td>Valvular cause (%)</td>
<td>26.8</td>
<td>30.2</td>
<td>24.1</td>
<td>17.4</td>
<td>12.6</td>
<td>32.7</td>
</tr>
<tr>
<td>Infection</td>
<td>17.6</td>
<td>18.5</td>
<td>17.1</td>
<td>11.8</td>
<td>15.6</td>
<td>17.1</td>
</tr>
<tr>
<td>Non-compliance with therapy (%)</td>
<td>22.2</td>
<td>24.6</td>
<td>16.9</td>
<td>7.9</td>
<td>21.9</td>
<td>18.1</td>
</tr>
</tbody>
</table>
In-hospital mortality in EHFS II by history of HF and clinical class

Nieminien, M. S. et al. EHJ 2006 27:2725
EURObservational Research Programme: The Heart Failure Pilot Survey (ESC-HF Pilot)

Prospective, multicentre, observational survey in 136 cardiology centres from 12 European countries

All outpatients with HF and patients admitted for acute HF were included during the enrolment period (1 day per week for 8 consecutive months). From October 2009 to May 2010, 5118 patients were included in this pilot survey, of which 1892 (37%) were admitted for acute HF and 3226 (63%) for chronic HF

Maggioni A et al EJHF 2010
RV Function and Outcome in Heart Failure

Patients with heart failure, RVEF is an independent predictor of mortality

Juilliere Y et al EHJ (1997) 18, 276-280

817 patients with new onset or worsening heart failure

FU-median 4.7 years

↓RV function (TAPSE) is associated with ↑mortality independent of LV function.

The co-existence of COPD is also associated with an adverse prognosis independent of the ↓RV function

Kjaergaard J et al EJHF2007;8: 610–616
RV-Anatomical and Physiological Considerations

Low pressure segment of the circulation, working against a very much lower impedance,

RV is more coarsely trabeculated, (has a prominent moderator band)

No middle layer of circumferential fibres –RV is more reliant on longitudinally aligned fibres.

RV -very sensitive to changes in afterload, more compliant than the LV.

LV contributes very importantly to right ventricular function

dog model, RV free wall removal RV still generated near normal pressure.

Ventricular Interdependence

RA and RV distension reduce LV filling (reduced LV compliance)

↓SV and contribute to pulmonary oedema development

effect is present in both systole and diastole
STARLINGS LAW

RV is subject to the same haemodynamic mechanisms as the left: as the right heart fails, so a higher filling pressure is required to maintain right heart output. In health, the CVP is around zero.

RV -very sensitive to changes in afterload, more compliant than the LV.

  - accommodates volume overload well, with only small increases in systemic venous pressure
  - tolerates pressure overload poorly (hence R heart failure in Lheart or pulmonary vascular pathology)
Right Ventricular Failure

Diastolic
- abnormal elevation in RH filling pressure

Systolic
- low RV forward output
- accompanies low LV output

Mechanism
- RV hypertrophy, ↓RV function, RV dilatation, ↑TR,
- Starling mechanism is overcome
- Mixture of RV pressure and volume overload
The Syndrome of “Right Heart Failure”

Characterised by Peripheral Oedema
- Ankle, sacral oedema
- Ascites

Anasarca-ανασάρα

Genuine Fluid overload
- At least 5 litres for ankle oedema
- Often, 20 litres or more

Gradual
- Key stage, neurohormonal response to poor renal perfusion
- Increase venous hydrostatic pressure
- Starling forces
- Fluid loss from vessels into tissues
The Cardio-Renal Syndrome in HF

- Decreased cardiac performance
- Decreased cardiac output
- Impaired renal function
- Decreased renal perfusion
- Increased venous pressure
- Diminished blood flow
- Neurohormonal Activation
- Increased water & Na$^+$ retention (Congestion)

Modified from Abraham WT
Renin-Angiotensin-Aldosterone-System

Francis; Cardiovascular Medicine 1998
AII in Heart Failure

+ Increased susceptibility to arrhythmias
Pathophysiology of PAH, RV failure in LV disease

**Pathophysiology (1)**
- Passive pulmonary venous stretch
- Usually reversible with acute vasodilator testing

**Pathophysiology (2)**
- Active, PH out of proportion to LV disease
  - ↑TPG
  - ↑PVR
- Pulmonary vasoconstriction and remodelling
- Endothelial dysfunction
- Raised endothelin 1 concentrations
The filling pressure required = haemostatic pressure
tending to drive fluid out of the vasculature.

Decreasing right heart function, the haemostatic pressure will ultimately exceed the forces tending to retain fluid in the vasculature:

colloid osmotic pressure
resistance provided by the basement membrane
the lymphatic drainage
oedema in the tissues
## Differential Diagnosis

<table>
<thead>
<tr>
<th>Cause</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dependent oedema</td>
<td>Sedentary life style</td>
</tr>
<tr>
<td>Venous insufficiency</td>
<td>Past history of DVTs; iron staining; varicose veins</td>
</tr>
<tr>
<td>Drugs</td>
<td>Dihydropyridine calcium antagonists</td>
</tr>
<tr>
<td>Hypoalbuminaemia</td>
<td>Nephrotic syndrome</td>
</tr>
<tr>
<td>Lymphoedema</td>
<td>High protein fluid; woody swelling</td>
</tr>
<tr>
<td>Fat</td>
<td>Generalised obesity</td>
</tr>
<tr>
<td>Venous obstruction</td>
<td>IVC obstruction; retroperitoneal fibrosis</td>
</tr>
<tr>
<td>Fluid overload</td>
<td>Pregnancy; iatrogenic</td>
</tr>
<tr>
<td>Arthritis</td>
<td>Pain and stiffness common</td>
</tr>
<tr>
<td>Cardiac</td>
<td></td>
</tr>
</tbody>
</table>
# Aetiology of RH Failure

<table>
<thead>
<tr>
<th>Left Heart Disease</th>
<th>Specific RV Failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHF due to LV Dysfunction</td>
<td>RV Infarction</td>
</tr>
<tr>
<td>Left Valve disease</td>
<td>Primary PAH</td>
</tr>
<tr>
<td></td>
<td>Thromboembolic disease</td>
</tr>
<tr>
<td></td>
<td>Cor Pulmonale</td>
</tr>
<tr>
<td></td>
<td>R valve disease</td>
</tr>
<tr>
<td></td>
<td>Carcinoid</td>
</tr>
<tr>
<td></td>
<td>ASD</td>
</tr>
<tr>
<td></td>
<td>Complex Congenital Heart Disease</td>
</tr>
<tr>
<td></td>
<td>Constrictive Pericarditis</td>
</tr>
<tr>
<td></td>
<td>ARVD</td>
</tr>
<tr>
<td></td>
<td>RA tumours</td>
</tr>
<tr>
<td></td>
<td>Pacemaker thrombosis and infection</td>
</tr>
</tbody>
</table>
Clinical signs

Ankle oedema
  Legs
  Abdominal wall

Pleural effusions

Ascites

Pericardial effusions

Sinus tachycardia or AF,
low SBP, ↑JVP, TR, cardiomegaly, S3,

Clear lungs or some pulmonary oedema
**RV Infarct**

**Cardiogenic shock post MI**

clear CXR

normal LV function

↓RV function

ST elevation on V4R
Cor Pulmonale

End Stage of COPD

Pathophysiology
Chronic hypoxia, pulmonary vasoconstriction and remodelling, ↑ PVR, PAH, RVH and RV Failure

Potentially helpful clinical features

cough and sputum
cyanosis

Lancet 1981;1:845
Ann Int Med 1980;93:391
Valve Disease

Rheumatic ® sided alone- very rare, often with L valve disease
Severe TR at the time of MVR-TV ring
Chronic Right Heart Failure and TR
Associated with an adverse prognosis
10 years after surgery for LV valve disease
Aggressive approach to TR at time of surgery ↓ long term risk of TR

Endocarditis
IV drug use

Carcinoid

Song H et al Heart 2009;95:931
Finnegan et al Heart 1973;35:1207
Connolly H et al JACC 1995;25;410
Pericardial Constriction

TB

Trauma

post cardiac surgery

Pericarditis

uraemia and CT disease

Clinical picture dominated by RH failure liver congestion, ascites, cardiac cirrhosis and cachexia

↑JVP, abrupt y descent , loud S3

As the constriction usually affects all cardiac chambers, there is equalization of the diastolic pressure in all cardiac chambers
Arrhythmogenic Right Ventricular Dysplasia

Cardiomyopathy often specifically affecting the RV, loss of RV myocytes, replacement by fibrous and fatty tissue

Genetic predisposition, AD with variable penetrance, abnormality often in the ryanodine receptor

Feature is ventricular arrhythmia

McKenna W et al Br Heart J 1994;71:8215
Basso C et al Lancet 2009;373:1289
ASD and COMPLEX CONGENITAL HEART DISEASE

## ASD

Unoperated ASDs often present late in life

**Clinical Clues**
- RV ventricular heave
- Pulmonary flow murmur
- Fixed splitting of S2 (unclear)
- ECG
  - RVH, RAD and RBBB-secundum ASD
  - RVH, RAD and LBBB-primum ASD

## Complex ACHD

Failure systemic right ventricle

Older patients with TGA palliated with a Mustard or Senning procedure have a right ventricle supporting the systemic circulation.

Patients with congenitally corrected transposition have similar physiology. The systemic right ventricle is likely to fail in early middle age.
Pathophysiology of Right Heart Failure

Syndrome of congestion

High Morbidity and Mortality

Heterogenous aetiology

Much less studied than the Left !

"Your left ventricle doesn't know what your right ventricle is doing."
London 2012?