Fluid Status in Heart Failure and Critically Ill Patients

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San Bortolo Hospital, Vicenza, Italy
Heart Failure (HF) is common and is a leading cause of morbidity and mortality.

**Chart 7A.** Prevalence of heart failure by sex and age (NHANES: 1999–2002). Source: CDC/NCHS and NHLBI.

**Chart 7B.** Hospital discharges for heart failure by sex (United States: 1970–2003). Note: Hospital discharges include people discharged alive and dead. Source: National Hospital Discharge Survey, CDC/NCHS and NHLBI.

8. Other Cardiovascular Diseases

Heart Disease and Stroke Statistics—2006 Update
A Report From the American Heart Association Statistics Committee and Stroke Statistics Subcommittee
Decreased cardiac output, venous congestion and the association with renal impairment in patients with cardiac dysfunction

Kevin Damman, Gerjan Navis, Tom D.J. Smilde, Adriaan A. Voors, Wim van der Bij, Dirk J. van Veldhuisen, Hans L. Hillege

High Central Venous Pressure

1. High Central Venous Pressure
   - Renal Venous Pressure
   - Intrarenal Angiotensin II
   - RAAS
   - ANP

2. Renal Interstitial Pressure
   - Hypoxic Trigger
   - Hydrostatic pressure in Bowman's capsule

3. RAAS
   - Angiotensin II
   - Filtration Coefficient

4. SNS Activation
   - [22]

5. Hyporesponsiveness to ANP in CHF
   - [21, 31]

6. Reduced GFR

7. ANP

8. Reduced GFR
Patterns of Weight Change Preceding Hospitalization for Heart Failure

Sarwat I. Chaudhry, MD; Yongfei Wang, MS; John Concato, MD, MPH; Thomas M. Gill, MD; Harlan M. Krumholz, MD, SM

Nested case control study
134 case pts with HF hosp, vs 134 control pts
Increase in BW alone is not sensitive in assessing clinical deterioration in established HF

## Assessment of Fluid Overload

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<td>Heart rate and rhythm</td>
<td>Both bradycardia and tachycardia can contribute to congestion.</td>
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<td>BP</td>
<td>Either no change in BP or an increase in BP from supine to the upright position or during Valsalva maneuver usually reflects a relatively high LV filling pressure (113).</td>
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<td>Jugular venous pressure</td>
<td>Equals RA pressure. In a chronic state, the RA pressure correlates with PCWP/LVDP.</td>
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<td>Patients often do not tolerate lying flat when there is a rapid increase in filling pressure. However, in a chronic state, this position may be tolerated in spite of a relatively high filling pressure.</td>
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<td>Marker of increased LV filling pressures.</td>
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Acute Heart Failure Syndromes, Mihai Gheorghiade, J Am Coll Cardiol 2009;53:557–73
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Subclinical volume overload

43 non-edematous ambulatory HF pts studied with radiolabeled albumin technique

Hypo/normovolemia

Hypervolemia

Relan of Unrecognized Hypervolemia in Chronic Heart Failure to Clinical Status, Hemodynamics, and Patient Outcomes

Ana Silvia Androne, MD, Katarzyna Hryniewicz, MD, Alhakam Hudaihed, MD, Donna Mancini, MD, John Lamanca, PhD, and Stuart D. Katz, MD, MS

(Am J Cardiol 2004;93:1254–1259)
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Predischarge BNP Predicts Outcome in AHF

Death or Readmission (%)

Follow-Up (Days)

Predischarge BNP >700 ng/L
n=41, events=38

Predischarge BNP 350-700 ng/L
n=50, events=30

Predischarge BNP <350 ng/L
n=111, events=18

Hazard Ratios of 2nd and 3rd Versus 1st BNP Range

Plasma Brain Natriuretic Peptide-Guided Therapy to Improve Outcome in Heart Failure

The STARS-BNP Multicenter Study

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<th>BNP Group</th>
<th>Clinical Group</th>
<th>p</th>
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<tr>
<td>All cause hospitalizations</td>
<td>52</td>
<td>60</td>
<td>NS</td>
</tr>
<tr>
<td>HF-related hospitalizations</td>
<td>22</td>
<td>48</td>
<td>p&lt;0.00</td>
</tr>
<tr>
<td>Death all causes</td>
<td>7</td>
<td>11</td>
<td>NS</td>
</tr>
<tr>
<td>Death related to HF</td>
<td>3</td>
<td>9</td>
<td>p&lt;0.05</td>
</tr>
<tr>
<td>HF-related death and hospitalizations</td>
<td>25</td>
<td>57</td>
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Event-free survival improved with BNP group.

Jourdain P et al., JACC 2007
Caveats to BNP interpretation

- Obesity (associated with lower BNP levels)
- Renal failure (associated with elevated BNP levels)
- Wet / dry BNP: knowledge of patient’s historical trend
BNP Level = Baseline BNP (Dry) + Change Due To Increased Volume (Wet)

NYHA Class “Optivolemic” (Dry) BNP

- Class I: 1325 (Wet) + 175 (Dry) = 1500
- Class II: 1250 (Wet) + 250 (Dry) = 1500
- Class III: 1000 (Wet) + 500 (Dry) = 1500
- Class IV: 1200 (Wet) + 800 (Dry) = 2000

Bioelectrical Impedance Analysis

- Method for detecting whole body fluid overload and pulmonary congestion
- **Impedance** = measure of the degree a substance resists the flow of electrical current.
- **Principle**: Accumulation of fluid will better conduct an electrical current passing through the body
  → decrease in impedance
**BioImpedance Vector Analysis (BIVA)**

Correct patient position

- Patient should be:
  - Relaxed & supine for 2 mins
  - On a non-conductive surface
  - Legs abducted 45 degrees
  - Arms abducted by 30 degrees

- Important:
  - Avoid contact between the limbs and the trunk.
  - Any contact invalidates the resistance measurement by reducing the length of the circuit measured.
BioImpedance Vector Analysis (BIVA)

Reference population matched for age, sex, race
Livelli di idratazione classificati con nomogramma

- More impedance = Less fluid
- Less impedance = More fluid
BIVA Limitations

• Accurate body position is required
• Does not distinguish compartmentalized edema
  – pericardial, pleural, or abdominal effusion
• Standardized for western Europeans
  – No normals for African and Asian heritage
• Poor skin-electrode interface
  – diaphoresis, excessive hair
• Uncooperative patient
  – dementia, psychiatric disease
• Electrical ground or interference
  – metal bed frame
**Total Body Water in CHF**

- 22 CHF patients
- Body composition measured by
  - Dual-energy X-ray absorptiometry (DXA)
  - Deuterium dilution
  - BIVA

Can BNP and BIVA complement each other?

- 77/WM, admitted with CHF
- PMHx: Prior “heart condition”, NOS
- On admission: NHYA III, (+) peripheral edema
- Treated with diuretics, symptoms improved, UO>1000 ml/d
- BNP: from 689 pg/ml decreased to 580 pg/ml, (-16%)
BNP 418 pg/ml  
Crea 1.36 mg/dl  
06/10/08 11:08

BNP 291 pg/ml  
Crea 1.40 mg/dl  
06/10/08 17:09

BNP 189 pg/ml  
Crea 1.25 mg/dl  
06/10/08 21:36

Diuresis: 2050 cc

Diuresis: 3650 cc

Diuresis: 5300 cc

Diuresis: 8000 cc
Incidence and outcomes of acute kidney injury in intensive care units: A Veterans Administration study

Charuhas V. Thakar, MD, FASN; Annette Christianson, MS; Ron Freyberg, MS; Peter Almenoff, MD; Marta L. Render, MD

| CV + CV Surg = 42% of all AKI |

AKI frequency in the ICU 22%

n = 325,395 in 191 VAs

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<tr>
<th>Maximum AKIN Stage</th>
<th>Odds ratio for death in ICU</th>
<th>Frequency %</th>
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<tr>
<td>I</td>
<td>2.2</td>
<td>17.5</td>
</tr>
<tr>
<td>II</td>
<td>6.1</td>
<td>2.4</td>
</tr>
<tr>
<td>III</td>
<td>8.6</td>
<td>2.0</td>
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Thakar CV et al. Crit Care Med 2009
Acute Kidney Injury

• Contributes to impaired free water and solute excretion
• Translates into fluid accumulation
  – In septic patients (high risk for AKI), a degree of fluid overload is more the rule than the exception

![Graph showing fluid balance over time for early and late AKI patients.](image)

*Time course of the daily mean fluid balance during intensive care unit stay in patients without acute renal failure (ARF), with early-onset ARF, and with late-onset ARF. Analysis of variance for repeated measures: *P < 0.05 pairwise compared with each of the two other subgroups; †P < 0.05 compared with the previous time point. SEM, standard error of the mean.*
Consequences of Fluid overload

- Pulmonary edema, pleural effusions
- Skin breakdown, and delayed wound healing
- Atrial distension
- Gut mucosal edema (delayed nutrient and drug adsorption)
A positive fluid balance is associated with a worse outcome in patients with acute renal failure

Didier Payen¹, Anne Cornélie de Pont², Yasser Sakr³, Claudia Spies⁴, Konrad Reinhart³, Jean Louis Vincent⁵ for the Sepsis Occurrence in Acutely Ill Patients (SOAP) Investigators

• Sepsis Occurrence of Acutely Ill Patients (SOAP) study
• 3,147 pts in 198 ICUs
• Fluid balance = Intake - Output
A positive fluid balance is associated with a worse outcome in patients with acute renal failure

Didier Payen¹, Anne Cornélie de Pont², Yasser Sakr³, Claudia Spies⁴, Konrad Reinhart³, Jean Louis Vincent⁵ for the Sepsis Occurrence in Acutely Ill Patients (SOAP) Investigators

Adapted from Payen et al, Crit Care 2008
Fluid accumulation, survival and recovery of kidney function in critically ill patients with acute kidney injury

Josée Bouchard¹, Sharon B. Soroko¹, Glenn M. Chertow², Jonathan Himmelfarb³, T. Alp Ikizler⁴, Emil P. Paganini⁵ and Ravindra L. Mehta¹, Program to Improve Care in Acute Renal Disease (PICARD) Study Group

Fluid overload defined as >10% increase in body weight compared to baseline

Figure 2: Mortality rate by final fluid accumulation relative to baseline weight and stratified by dialysis status.
Fluid Accumulation in Critically Ill Children with AKI

![Bar chart showing fluid overload percentages for different studies.](chart.png)

- **Goldstein**: Survivors 16, Non-Survivors 34
- **Foland**: Survivors 9, Non-Survivors 16
- **Goldstein**: Survivors 14, Non-Survivors 25
- **Hayes**: Survivors 7, Non-Survivors 22
- **Sutherland**: Survivors 13, Non-Survivors 23
Fluid Overload and Mortality in Children Receiving Continuous Renal Replacement Therapy: The Prospective Pediatric Continuous Renal Replacement Therapy Registry

Scott M. Sutherland, MD,1 Michael Zappitelli, MD, MSc,2 Steven R. Alexander, MD,1 Annabelle N. Chua, MD,3 Patrick D. Brophy, MD,4 Timothy E. Bunchman, MD,5 Richard Hackbarth, MD,5 Michael J.G. Somers, MD,6 Michelle Baum, MD,6 Jordan M. Symons, MD,7 Francisco X. Flores, MD,9 Mark Benfield, MD,9 David Askenazi, MD,9 Deepa Chand, MD,10 James D. Fortenberry, MD,11 John D. Mahan, MD,12 Kevin McBryde, MD,13 Douglas Blowe, MD,14 and Stuart L. Goldstein, MD9

Sutherland et al AJKD: In Press
After initial resuscitation, attention to fluid balance has clinical relevance

Prevention of fluid overload may be an important and under-appreciated determinant of survival

Prevention or early control of fluid overload is evolving as a primary trigger for initiation of RRT/dialysis
Viewpoint

A proposed algorithm for initiation of renal replacement therapy in adult critically ill patients

Sean M Bagshaw¹, Dinna N Cruz², RT Noel Gibney¹ and Claudio Ronco²

Proposed Algorithm for Initiation of Renal Replacement Therapy in Critically Ill Patients

1. Patient admitted to ICU
2. Initiate RRT
3. AKI present?
   - NO: Potential non-renal indications?
     - Refractory fluid overload
     - Refractory septic shock
     - Acute liver failure
     - Severe tumor lysis syndrome
     - Severe electrolyte disturbances
     - Dysthermia
     - Selected toxins
     - Monitor and reassess clinical status
   - YES: Assess: AKI severity & trend, illness severity & trajectory, initial response to above therapy
4. Severe AKI? RIFLE-F/AKIN III or Anuria
   - YES: Rapidly worsening AKI
     - Rapidly worsening illness severity
     - Hypercatabolic state
     - Refractory fluid overload and/or accumulation
     - Permissive Hypercapnia
     - Reduced renal reserve
     - Low probability for early renal recovery
   - NO: Mild/Moderate AKI? RIFLE-R or I AKIN I or II
5. Consider adjuvant role of RRT
Consider initiating RRT

Any of the following?
- Rapidly worsening AKI
- Rapidly worsening illness severity
- Hypercatabolic state
- Refractory fluid overload and/or accumulation
- Sepsis
- Permissive Hypercapnea
- Reduced renal reserve
- Low probability for early renal recovery

Mild/Moderate AKI?
- RIFLE-R or -I
- AKIN I or II

YES
Summary

• Fluid accumulation and overload are common themes in the pathophysiology and clinical course of acute kidney injury and heart failure

• Fluid status represents an important “biomarker” which may provide therapeutic and prognostic information
  – AKI – fluid balance
  – HF – weight, P.E., BNP/ NT proBNP

• Novel technology (e.g. bioimpedance) may:
  – Provide more objective measure of fluid status
  – Complement existing biomarkers in clinical decision-making