Biomarkers of myocardial infarction

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Cardiovascular system, 2013
References

• This lecture
• Hand-outs
Acute Myocardial Infarction

- A rapid development of myocardial necrosis caused by prolonged ischemia (a critical imbalance between the oxygen supply and demand of the myocardium) resulting in an irreversible myocardial injury.
Biochemical Changes

ischemia to myocardial muscles (with low $O_2$ supply) →

anaerobic glycolysis →

increased accumulation of Lactate →

decrease in pH →

activate lysosomal enzymes →

disintegration of myocardial proteins →

cell death & necrosis →

clinical manifestations (chest pain)

BIOCHEMICAL MARKERS
release of intracellular contents to blood

ECG changes
What is a molecular biomarker?

A molecular alteration that is objectively measured and evaluated as an indicator of normal biological processes, pathogenic processes, or pharmacologic responses to a therapeutic intervention.
Criteria for ideal markers for MI

- **Specific**: no false positive *(present in the myocardium absent in nonmyocardial tissues)*
- **Sensitive**: no false negative *(produced at high concentrations that can be measurable)*
- **Prognostic**: relation between plasma level & extent of damage
- **Persists longer**: can diagnose delayed admission
- **Reproducible**
- **Simple, inexpensive**
- **Quick**
- **Acceptable** (by patient and clinician)
What are biomarkers good?

- Diagnostic (yes or no; infarct vs. reinfarct)
- Differentiating (AMI, skeletal muscle damage, other cardiac conditions, renal disease, etc.)
- Risk-stratifying (low- vs. high-risk)
- Prognostic (degree of severity; infarct size)
MI biomarkers

- Inflammation (C-reactive proteins)
- Oxidative stress (myeloperoxidase)
- Extracellular matrix remodeling (proteases)
- Neurohormones
- Myocyte injury (troponins, creatine kinase, heart-type fatty acid binding protein, myoglobin)
- Myocyte stress (Brain-natriuretic peptide)
- New biomarkers
Alterations of molecular profile
Myoglobin and CK isoforms

Troponin (large MI)

CKMB

Troponin (small MI)

Days after onset of AMI

Multiples of the upper limit of normal

10% CV/99th percentile
TROPONINS

THE GOLD STANDARD
Structure

- Associated with tropomyosin, which forms a continuous chain along each actin thin filament
- A complex of the three subunits:
  - TN-T: tropomyosin binding subunit
  - TN-I: myosin ATPase inhibiting subunit
  - TN-C: calcium binding subunit
Troponin isoforms

- Troponin I and T are highly specific for myocardial injury
  - Levels in a healthy person are negligible

- cTNI indicates only cardiac troponin
- cTNT may cross-react with troponin found in other muscles
  - non-cardiac injury such as skeletal myopathies and with renal failure
Troponins in MI

- Increase within 4-6 hours after onset of MI
- Stays elevated: 5–10 days (cTnI) or 5–14 days (cTnT)
Why is release of troponin prolonged?

- Most is bound to the contractile apparatus of the cardiomyocyte
- 3% of cTnI and 6% of cTnT exist free in the cytoplasm
- The initial elevation of cTnI or cTnT is thought to be a function of the free cytosolic form
- The prolonged elevation is caused by degradation of the contractile pool
Troponin Influence on Prognosis

- Since normal people have virtually nil levels of troponin in serum
- Positive results: MI or chronic disease
Advantages

• Higher sensitivity than CK-MB
• Fewer false-positive results in the setting of trauma, surgery, and renal failure as compared to CK-MB
• Prognostic of death from acute coronary syndrome
Troponin and death

Death or MI (%)

P = 0.05

- < 0.18: N = 120
- 0.19 - 1.3: N = 120
- 1.4 - 5.6: N = 121
- > 5.6: N = 120

cTnI Concentration (ng/ml)
Disadvantages

• It lacks sensitivity in the early hours of AMI

• Pulmonary embolism, congestive heart failure, and myocarditis can all lead to cardiac troponin elevation
Serial Sampling

- When initial results are negative
- Serial sampling at presentation, 6–9 h later, and after 12 h is recommended if the earlier results are negative and clinical suspicion remains high
What is troponin test is not present, then use that of creatine kinase
Sources of energy

**Phosphagen system**
- Sprinter
- 8-10 seconds (100 m)

**Glycogen-lactic acid system**
- Swimmer
- 1.3–1.6 minutes (400 m)

**Aerobic respiration**
- Marathon runner
- Unlimited time (15 Km)

Dominant Energy Pathways for Exercise of Differing Durations

- **Aerobic Glycolysis**
- **Anaerobic Glycolysis** (lactic acid)
- **Creatine**
- **ATP**

EXERCISE TIME → → → → →
Creatine phosphate

Creatine kinase

2.6% of PCr reserves per day

1.1% of creatine reserves per day
CK in MI

- Indicator of myocardial infarction
Total CK can be elevated

- AMI
- False positive (for MI) CK elevation can be seen in:
  - Significant skeletal muscle injury
  - Significant CNS damage (Stroke/Trauma)
  - Occasionally from GI, renal, urologic disease
  - Others: i.m. injection, hypothermia, exercise, intoxication and drug abuse
- Dose-related side effect in statin treatment
  - Statin-related increases in CK mainly affect MM isozyme
# CK Isozymes

<table>
<thead>
<tr>
<th></th>
<th>Serum</th>
<th>Skeletal Muscle</th>
<th>Cardiac Muscle</th>
<th>Brain</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 trace BB</td>
<td>0 trace BB</td>
<td>0% BB</td>
<td>97% BB</td>
<td></td>
</tr>
<tr>
<td>&lt;6% MB</td>
<td>1% MB</td>
<td>20% MB</td>
<td>3% MB</td>
<td></td>
</tr>
<tr>
<td>&gt;94% MM</td>
<td>99% MM</td>
<td>80% MM</td>
<td>0% MM</td>
<td></td>
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</tbody>
</table>
CK-MB

- Increase: 3 and 12 h after the onset of MI
- Peaks at 24 hr
- Reverts to normal values within 48–72 h

Useful for diagnosis of reinfarction
Cardiac relative index

- improves specificity, but may limit sensitivity

\[ RI = \frac{\text{CK-MB mass}}{\text{Total CK}} \times 100 \]

More than 5% is indicative for MI
Limitations of CK-MB

- Skeletal Muscle Involvement
- Duchenne Muscular Dystrophy
- Polymyositis
- Alcohol Myopathy
- Thermal or Electrical Burn Patients
- Carcinomas (Colon, Lung, Prostate, Endometrial..)
- Athletes (e.g. Marathon runners)
CK-MB isoforms and MI

- Two isoforms called 1 (plasma) and 2 (cellular)
- 2 to 1 ratio of > 1.5 can be useful for early MI detection
  - Requires a skilled technician
  - False positive results with congestive heart failure and other conditions can occur
MYOGLOBIN (Mb)

- Rapidly released to the circulation after muscle injury
  - An early marker that can be detected 1–2 hours after symptom onset, and remains elevated for up to 24 hours
- Sensitive in the absence of concomitant skeletal muscle trauma or renal failure
- Specimens collected serially every 1-2 hours during the first 2-10 hours after infarction
- Levels that double within 1-2 hours are highly suggestive of AMI
- Suited to excluding AMI at the earliest phase
But...

- low-specificity for MI
  - in patients with renal failure or skeletal muscle trauma
- Rises and falls rapidly in the setting of MI
- The level may normalize in patients that present >24 hours after symptom onset
  - indicated for the diagnosis of re-infarction
- Therefore,
  - potentially useful for ruling out but not for confirming the diagnosis of AMI
  - Is used in combination with CK-MB or cTn
SPECIFICITY OF CARDIAC MARKERS

- TROPONIN-I: 99%
- CK-MB: 92%
- TOTAL CK: 87%
- MYOGLOBIN: 70%
SUMMARY
<table>
<thead>
<tr>
<th>MARKER</th>
<th>TISSUE SOURCE</th>
<th>PHYSIOLOGIC FUNCTION</th>
<th>“DIAGNOSTIC WINDOW”</th>
<th>CLINICAL UTILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Creatine Kinase (CK)</td>
<td>Skeletal muscle, Cardiac muscle</td>
<td>Rephosphorylation of ADP, forming ATP in muscle contraction</td>
<td>Rise: 6-8 hr Peak: 24-36 hr Normal: 3-4 days</td>
<td>Limited diagnostic value since it is increased in various disease states.</td>
</tr>
<tr>
<td>Total Activity</td>
<td>Skeletal muscle</td>
<td></td>
<td></td>
<td>CK isoenzyme analysis is more useful for diagnosis</td>
</tr>
<tr>
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<tr>
<td>CK-MB Isoenzyme, Mass (amount, not activity)</td>
<td>Cardiac muscle Skeletal muscle to a much lesser extent</td>
<td>Same as above</td>
<td>Rise: 4-6 hr Peak: 12-24 hr Normal: &gt;48 hr</td>
<td>Mass assay of CK-MB isoenzyme, the current “gold standard” for early diagnosis of AMI</td>
</tr>
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<tr>
<td>CK-MB Isoforms and Isoforms ratio</td>
<td>Same as above</td>
<td>Same as above</td>
<td>Rise: 2-6 hr Peak: 6-12 hr Normal: 24-36 hr</td>
<td>Early marker of AMI, more specific than myoglobin</td>
</tr>
<tr>
<td>Myoglobin</td>
<td>Cardiac muscle Skeletal muscle</td>
<td>Oxygen binding protein</td>
<td>Rise: 2-3 hr Peak: 6-9 hr Normal: 24-36 hr</td>
<td>Non-specific early marker to rule in/rule out AMI</td>
</tr>
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</table>
| Cardiac Troponin I     | Cardiac muscle| Muscle contraction regulatory protein; bound to tropomyosin and actin                  | Rise 4-8 hr Peak: 14- 18 hr Normal: 5-9 days       | Highly specific for myocardial injury  
Useful for patients with atypical symptoms or those who delay seeking medical attention  
Potential to diagnose AMI in patients who also have concomitant skeletal muscle trauma/disease  
Potential usage to risk stratify angina pectoris                                      |
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</thead>
<tbody>
<tr>
<td>Cardiac Troponin T (cTnT)</td>
<td>Cardiac muscle; regenerating skeletal muscle</td>
<td>Same as above</td>
<td>Rise: 4-8 hr</td>
<td>As above for cTnI</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Peak: 14-18 hr</td>
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<td></td>
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<td>Normal: &gt;14 days</td>
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OLD BIOMARKERS

Aspartate aminotransferase
Lactate dehydrogenase
Aspartate aminotransferase

Time course of myocardial enzymes appearing in the blood after myocardial infarction
Lactate dehydrogenase in MI

- Rises in 12 to 24 hours following MI,
- Peaks in 2 to 3 days
- Gradually disappearing in 5 to 14 days
## Tissue distribution of LDH

<table>
<thead>
<tr>
<th>Isoenzyme</th>
<th>Composition</th>
<th>Present in</th>
</tr>
</thead>
<tbody>
<tr>
<td>LDH1</td>
<td>(H₄)</td>
<td>Myocardium, RBC, kidney</td>
</tr>
<tr>
<td>LDH2</td>
<td>(H₃M₁)</td>
<td>Myocardium, RBC, serum, kidney</td>
</tr>
<tr>
<td>LDH3</td>
<td>(H₂M₂)</td>
<td>Kidney, Skeletal muscle</td>
</tr>
<tr>
<td>LDH4</td>
<td>(H₁M₃)</td>
<td>Kidney, Skeletal muscle</td>
</tr>
<tr>
<td>LDH5</td>
<td>(M₄)</td>
<td>Skeletal muscle, Liver</td>
</tr>
</tbody>
</table>
Normal vs. MI

**Normal**
LD1:LD2 = 0.5-0.75

**MI**
LD1:LD2 > 1

LD isoenzyme electrophoresis
(normal)
LD-2 > LD-1 > LD-3 > LD-4 > LD-5

LD isoenzyme electrophoresis
(abnormal)
LD-1 > LD-2
Conditions causing flipped LD1/LD2 without AMI

- Hemolysis
- Megoblastic & Pernicious Anemia
- Renal Cortex Infarction
- Testicular Germ Cell Tumors
- Small Cell Lung Carcinoma
- Adenocarcinoma of the Ovary
- Acute Coronary Insufficiency (Unstable Angina)
- Exercise Induced Myocardial Ischemia
- Polymyositis
- Muscular Dystrophies
- Well Trained Athletes
- Rhabdomyolysis
Example

1. MI
2. MI (hrs post)
3. Control
4. Liver disease
5. MI (2d post)
6. MI (1d post)
7. Liver + HF
8. Normal
Interpretation

- **Sample #3** represent results for a control
- **Sample #8** results are from a normal specimen.
- **Sample #1** MI patient. The specimen was collected at a time when the activity of both LDH and CK were elevated. Note the LDH flip and the high relative activity of the MB isoenzyme.
- **Sample #2** MI patient who experienced chest pain only several hours previously. Total CK is significantly elevated with a high relative MB isoenzyme activity.
- **Sample #6** MI patient (the 1st day post MI); CK activity is definitely elevated with a high relative MB isoenzyme activity and the LDH flip is evident.
- **Sample #5** MI patient (2 days post MI) so that CK has almost returned to normal activity and the LDH flip is definite.
- **Sample #7** MI patient with complications of heart failure and passive liver congestion or the patient was involved in an accident as a consequence of the MI, and suffered a crushing muscle injury.
- **Sample #4** a patient with liver disease. Although the LDH isoenzyme pattern is indistinguishable from muscle disease or injury, the absence of at least a trace of CK-MB isoenzyme is inconsistent with the muscle CPK isoenzyme distribution as is the apparently normal total activity.
FUTURE MARKERS
Natriuretic peptides

- Atrial natriuretic peptide (ANP)
- B type natriuretic peptide (BNP)
- C type natriuretic peptide
- D type natriuretic peptide

- All hormones function in the homeostasis of sodium and water retention
The Natriuretic Peptide System

ET inhibition, Vasodilation, CNP, Antiproliferation effect

Sympathoinhibitory

ANP, BNP, Antifibrotic, Lusitropic

ANP, BNP, Aldosterone inhibition

ANP, BNP, Natriuresis, Renin inhibition

Physiological actions of NPs

- ANP
- BNP
- Circulating hormone
- Inhibition of hypertrophy and fibrosis
- Local hormone
- GC-A
- GC-B
- CNP
- Local hormone
- Growth inhibition
- Vasodilation
- Natriuresis
- Reduction in blood pressure and cardiac load
- Inhibition of remodeling (Cardioprotective effect)
B-type Natriuretic Peptide (BNP)

- Secreted by the ventricles in response to tension
- BNP binds and activates receptors causing reduction in systemic vascular resistance, central venous pressure and natriuresis
Synthesis and secretion of BNP
Clinical utilization

• A prognostic indicator of death, heart failure, risk prediction of AMI recurrence (Higher BNP suggests higher chance of AMI recurrence)

• May also guide treatment

• Not useful relative to other biomarkers

• However, it is useful in risk stratification
## Illustrations of risk stratification

<table>
<thead>
<tr>
<th>Risk category</th>
<th>Low (n=18) mean (SD)</th>
<th>Moderate (n=64) mean (SD)</th>
<th>High (n=18) mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BNP (pg/ml)</td>
<td>80 (90)</td>
<td>194 (247)</td>
<td>374 (272)</td>
</tr>
<tr>
<td>Age (years)</td>
<td>58.8 (11.2)</td>
<td>62.4 (10.2)</td>
<td>68.5 (7.9)</td>
</tr>
<tr>
<td>Peak VO₂ (ml/min/kg)</td>
<td>31.7 (8.5)</td>
<td>22.7 (8.2)</td>
<td>14.6 (5.9)</td>
</tr>
<tr>
<td>Troponin (µg/L)</td>
<td>9.1 (12.4)</td>
<td>15.3 (16.0)</td>
<td>15.4 (18.1)</td>
</tr>
</tbody>
</table>

Key: SD = standard deviation

Source: Br J Cardiol © 2008 Sherbourne Gibbs, Ltd.
BNP and Mortality

**N-BNP predicts survival after acute MI** Kaplan-Meier survival curves of 121 patients with an acute myocardial infarction show that patients with serum concentrations of N-BNP that are above the group median of 122 pmol/L had a poorer survival compared to those with N-PNP concentrations below the median (P<0.00001). (Redrawn from Richards, AM, Nicholes, MG, Yandle, TG, et al. Circulation 1998; 97:1921.)
Limitations

• The proper cutoff values has not been determined
• BNP and NT-proBNP levels are higher in women and increase with age
• Biologic variability
• Assays lack precision
Glycogen phosphorylase BB (GPBB)

- Heart and brain tissue
  - Because of the blood–brain barrier, GP-BB can be heart muscle specific
- A rapid rise in blood levels can be seen in myocardial infarction and unstable angina.
- GP-BB elevated 1–3 hours after process of ischemia.
  - Early diagnosis in acute coronary syndrome.
- High specificity and sensitivity
Heart-type fatty acid binding protein (H-FABP)

Not heart-specific, but can identify patients at high-risk
Profile of GPBB and H-FABP release after MI
C-Reactive Protein

• Pentameric structure consisting of five 23-kDa identical subunits
• Produced primarily in hepatocytes
• Plasma levels can increase rapidly to 1000x baseline levels in response to acute inflammation
• “Positive acute phase reactant”
CRP and CV Risk

• Elevated levels predictive of:
  – Long-term risk of first MI
  – Ischemic stroke
  – All-cause mortality
Limitations to CRP in Screening

- Low specificity
- Gender and racial differences exist
- Affected by physiologic conditions, lifestyle behaviors (smoking, obesity, exercise, and alcohol use), and drugs
- Clinical value??

  - No evidence that lowering CRP levels decreases CV risk
Ischemia-Modified Albumin (IMA)
Ischemia-Modified Albumin (IMA)

• Under conditions of ischemia, albumin undergoes a conformational change, so that it can no longer bind to transitional metals such as copper or cobalt
  – Albumin cobalt binding (ACB) test
• Using the albumin cobalt binding test, the proportion of albumin modified by ischemia can be estimated
  – But, low specificity and sensitivity

• A predictor of long-term outcome in patients with acute myocardial infarction
IMA is a marker of ischemia, not necrosis.
Myeloperoxidase (MPO)

• MPO appears to participate in the initiation and progression of plaque formation
• Elevated early after ACS
• Appears to identify patients with ACS earlier than biomarkers like troponin and CK-MB
• Also appears to provide risk stratification for patients who are troponin negative
  – For patients who present with chest pain and negative troponin levels are at increased risk for readmission if MPO is elevated
Note

“Despite the multitude of cardiac biomarkers in production and under investigation, none have convincingly demonstrated their incremental utility beyond that of cTn.”

SJ Aldous

International Journal of Cardiology 164 (2013) 282–294
The Future of Cardiac Biomarkers

- Many experts are advocating the move towards a *multimarker strategy* for the purposes of diagnosis, prognosis, and treatment design.
Why do we need multiple Markers?

- No single ideal marker exists for ACS
- Complicated diseases are not likely to be associated with single markers
- Multiple markers define disease categories
- Multi-marker panels can aid in differential diagnosis
It all goes back to $\$

“Conversely, multi-marker assessment has been shown to be associated with higher Emergency Department, coronary care and cardiac intervention costs but...[it] has not been shown to reduce overall costs despite reducing admissions.”

SJ Aldous

International Journal of Cardiology 164 (2013) 282–294