Biomarkers and Surrogate Endpoints in Clinical Trials

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Lecture Objectives

~ Recognize strong correlation of a biomarker (replacement) endpoint with a direct measure of how a patient feels, functions or survives doesn’t justify a conclusion that treatment effect on biomarker status reliably predicts treatment effect on the direct measure of how a patient feels, functions or survives.

~ Explain the integral importance, to the rigorous validation of a biomarker as a replacement (or surrogate) endpoint, of:

  ─ An in depth clinical understanding of
    ✓ the causal pathways of the disease process; and
    ✓ intervention’s intended & *unintended* mechanisms of action;
  ─ Meta-analyses of clinical trials showing the relationship between:
    ✓ the *net* effect of treatment on the biomarker, and
    ✓ the *net* effect of treatment on direct measures of how a patient feels, functions and survives
Issues in Replacement (Surrogate) Endpoints

- Criteria for Choosing Endpoints
- “A Correlate does not a Surrogate Make”
- Validation of Replacement (Surrogate) Endpoints
Some Characteristics for Study Endpoints in Phase 3 Clinical Trials

- Consistently & readily measurable
- Sensitive
- Well defined & reliable
- Clinically meaningful

A “Clinically Meaningful Endpoint”:
...a direct measure of how a patient “feels, functions or survives”...

... Robert Temple, FDA

Invasive Procedures:
E.g., Biopsy, RHC
Biomarkers & ‘Feels, Functions, Survives’ Endpoints

• **Biological Activity:** Hemodynamic Measures in PAH: $PVRI$, $mPAP$, $CO$, $SBP$, $DBP$, $NT$-proBNP

• **Clinical Meaningful Benefit**
  
  ~ **Functions:** Ability to conduct normal activities
  ~ Ability to walk, Ability to engage in recreational activities, Ability for self care, Risk of syncope
  ~ Time in hospital or missing school (overall, or cause specific)

  ~ **Feels:**
  ~ Chest pain, breathlessness, fatigue, dizziness

  ~ **Survives**
  ...Physician or Observer administered & PROs...
Potential ‘Feels, Functions, Survives’ Endpoints

Patient Reported Outcomes (PROs):

“Any report of the status of a patient’s health condition that comes directly from the patient, without interpretation of the patient’s response by a clinician or anyone else”.

Patient Reported Outcomes (PROs)

...Direct Measures of ‘Feels’, but with need to confirm:

Reliability, Sensitivity, Validity (Content, Construct, etc)
Clinical Relevance, Interpretability

Integrity, including need for:
blinded assessment & control of missing data…

…Mobilize disease specific interest groups,
before sponsors plan clinical trials…

Biomarkers & ‘Feels, Functions, Survives’ Endpoints

• **Biological Activity:** Hemodynamic Measures in PAH: $PVRI, \ mPAP, \ CO, \ SBP, \ DBP, \ NT$-proBNP

• **Clinical Meaningful Benefit**

  ~ **Functions:** Ability to conduct normal activities
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  - Chest pain, breathlessness, fatigue, dizziness

  ~ **Survives**
  ...Physician or Observer administered & PROs...
Biomarkers as Replacement Endpoints

“Biomarkers are measurements of biological processes. Biomarkers include physiological measurements, blood tests and other chemical analyses of tissue or bodily fluids, genetic or metabolic data, and measurements from images.

Cholesterol and blood sugar levels are biomarkers, as are blood pressure, enzyme levels, measurements of tumor size from MRI or CT, and the biochemical and genetic variations observed in age-related macular degeneration...”

Direct Measures of Patient “Functions, Feels, Survives”

- Patient (symptoms: chest pain, dyspnea, fatigue, dizziness)
- Clinician (PANNS for schizophrenia syndrome, Clinician Global Measures)
- Observer (seizures, infant behavior, stroke, death)

Indirect Measures

- Measures depending on patient motivation or clinician judgment to perform the test

Biomarkers

- e.g. $H_b A_1c$, CD-4, PSA, PVRI, NT-proBNP, CO HR, Blood Pressure Pulm Arterial Pressure TIMI-III flow HDL, LDL, body temperature, urine GAG, urine KS cardiac rhythm, blood cultures, PCR, quantitative measures from radiology imaging.

Categorization of Nomenclature

Outcome Assessments

# John Powers, Dave DeMets, Marc Walton, Laurie Burke, Bob Temple...
Biomarkers (as Replacement Endpoints)

...“Post hoc, ergo, Propter hoc”...

Treatment effects on Biomarkers:

- Establish *Biological Activity*
- But not necessarily the net effects on
  - How a patient feels
  - The ability to conduct normal activities
  - Overall Survival
Issues in Replacement (Surrogate) Endpoints

~ Criteria for Choosing Endpoints

~ “A Correlate does not a Surrogate Make”

~ Validation of Replacement (Surrogate) Endpoints
The Biomarker Endpoint is not in the Causal Pathway of Disease Process

Disease

Biomarker Endpoint

Causal Pathway

Feels, Functions, or Survives Endpoint
The Biomarker Endpoint is not in the Causal Pathway of the Disease Process.

Disease → Biomarker
e.g., CD4  → Mother-to-Child
   Trans of HIV

HIV Viral Load

Disease → Biomarker
e.g., CEA, PSA  → Ca. Symptoms & Death

Tumor Burden  → NT-proBNP in PAH

• “Correlates”: Useful for Disease Diagnosis, or Assessing Prognosis
• “Valid Surrogates”: Replacement Endpoints
Multiple Pathways of the Disease Process

Intervention

Disease → Biomarker Endpoint → Feels, Functions or Survives Endpoint

Intervention

Disease → Biomarker Endpoint → Feels, Functions or Survives Endpoint
Biomarker (as a Surrogate) in Chronic Granulomatous Disease

- CGD $\rightarrow$ Recurrent Serious Infections
- Interferon $\gamma$ ...Increase Bacterial Killing and Superoxide Production?

- International CGD Study Group Trial

Interferon $\gamma$:
- 70% Reduction in Recurrent Serious Infections
- Essentially No Effect on Biological Markers
Multiple Pathways of the Disease Process

- **Intervention**
  - **Disease**
    - **CGD**
  - **Interferon γ**
    - **Bacterial Killing**
  - **Surrogate Endpoint**
    - **Feels, Functions or Survives Endpoint**
      - **Recurrent Serious Infections**
Biomarkers in Acellular Pertussis Vaccines

(Sweden I Trial with DT control: 10,000 subjects)

• **VE**

<table>
<thead>
<tr>
<th>Vaccine</th>
<th>VE</th>
<th>95% CI</th>
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</thead>
<tbody>
<tr>
<td>SKB</td>
<td>58%</td>
<td>(51%, 66%)</td>
</tr>
<tr>
<td>Aventis Pasteur</td>
<td>85%</td>
<td>(81%, 89%)</td>
</tr>
</tbody>
</table>

• **Biomarkers**

*Filamentous Haemagglutinin (FHA)* and *Pertussis Toxoid (PT)* antibody responses were superior with the SKB vaccine
• Other Immune Responses, including those resulting from additional antigens in the vaccines:
  ~ Pertactin
  ~ Fimbriae (types 2 and 3)

• Durability of effect
Multiple Pathways of the Disease Process

Thrombolytic

M.I. (Rapid II / Gusto III)

TIMI III

What magnitude and what duration is needed?

30-Day Mortality

Intervention

CGD

Biomarker Endpoint

Recurrent Serious Infections
Interventions having Mechanisms of Action Independent of the Disease Process
Illustration:
Ventricular Arrhythmia after M.I.

- Arrhythmia:
  - Risk factor for Sudden Death
- Antiarrhythmic Drugs:
  - Class IC antiarrhythmic agents
    ...Strong Sodium-Channel Blockade
Illustration:
Ventricular Arrhythmia after M.I.

- Arrhythmia:
  - Risk factor for Sudden Death
- Antiarrhythmic Drugs:
  - Class IC antiarrhythmic agents
    - Strong Sodium-Channel Blockade

Cardiac Arrhythmia Suppression Trial:
The drugs, relative to placebo,
TRIPLE the death rate.
Interventions having Mechanisms of Action Independent of the Disease Process

"Deadly Medicine" by Thomas Moore
Interventions having Mechanisms of Action Independent of the Disease Process

ESAs: ↑ Thrombosis ⇒ ↑ Mortality
Cox-2s, Muraglitazar, Rosiglitazone: ↑ CV Risk Factors ⇒ ↑ CV Death/ MI /Stroke
Troglitazone: ↑ Serious Hepatic Risks ⇒ ↑ Morbidity
Natalizumab: ↑ Prog. Multifocal Leukoencephalopathy ⇒ ↑ Morbidity / Mortality
Ezetimibe/Simvastatin: Block pathways linked to CA prot. ⇒ ↑ Cancer Mortality?
Long Acting β-Agonists: ↑ Asthma-related deaths
Torcetrapib: Activates renin angiotensin system ⇒ ↑ BP ⇒ ↑ Mortality
Revatio in Pediatric PAH: ↑ doses ⇒ Improved hemodynamics yet ⇒ ↑ Mortality
“FDA Drug Safety Communication: FDA recommends against use of Revatio in children with pulmonary hypertension”

“The hazard ratio for high dose compared to low dose was 3.5 ($p=0.015$)”
Issues in Replacement (Surrogate) Endpoints

~ Criteria for Choosing Endpoints

~ “A Correlate does not a Surrogate Make”

~ Validation of Replacement (Surrogate) Endpoints
End Stage Renal Disease

- Standard Dose ESA* ⇒ Hematocrit 30%
- High Dose ESA* ⇒ Hematocrit 42%

Goal: Normalize Hematocrit Values
⇒ reduce Death and MI

* Erythropoietin stimulating agent
Patient Distribution & Percent Deaths by Hematocrit %

STANDARD DOSE ESA

- 30% ↓ death RR for 10 pt ↑ in hem.
- ↑ in hematocrit

HIGH DOSE ESA

- 30% ↓ death RR for 10 pt ↑ in hem.
- ↑ in hematocrit
Patient Distribution & Percent Deaths by Hematocrit %

STANDARD DOSE ESA

- 30% \( \downarrow \) death RR for 10 pt \( \uparrow \) in hem.
- \( \uparrow \) in hematocrit
- 30% \( \uparrow \) in death RR

HIGH DOSE ESA

- 30% \( \downarrow \) death RR for 10 pt \( \uparrow \) in hem.
- \( \uparrow \) in hematocrit
- 30% \( \uparrow \) in death RR
End Stage Renal Disease

Results (Interim at 1/2 planned endpoints)

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>Death/MI</th>
<th>Death</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard Dose</td>
<td>615</td>
<td>164</td>
<td>160</td>
</tr>
<tr>
<td>High Dose</td>
<td>618</td>
<td>202</td>
<td>195</td>
</tr>
</tbody>
</table>

Death / MI relative risk: 1.30 (0.94, 1.79)

Besarab et al, NEJM 339:584-590, 1998:

“↑ in incidence of thrombosis of vascular access sites”
Validation of Replacement (Surrogate) Endpoints

Property of a Valid Replacement (Surrogage) Endpoint:

- **Net effect of the Intervention on the Replacement (Surrogate) Endpoint reliably predicts the Net effect of the Intervention on the ‘Feels, Functions, or Survives’ Endpoint**
Using Replacement (Surrogate) Endpoints for Direct Measures of ‘Feels, Functions, Survives’

Clinical

• Comprehensive understanding of the
  ~ Causal pathways of the disease process
  ~ Intervention’s intended and unintended mechanisms of action

Statistical

• Meta-analyses of clinical trials data
Mechanisms of Action of the Intervention & Causal Pathways of the Disease Process

Torcetrapib

CHD

HDL Cholesterol

LDL Cholesterol

SBP / DBP

CV Morbidity & Mortality
Using Replacement (Surrogate) Endpoints for Direct Measures of ‘Feels, Functions, Survives’

Clinical

• Comprehensive understanding of the
  ~ Causal pathways of the disease process
  ~ Intervention’s intended and unintended mechanisms of action

Statistical

• Meta-analyses of clinical trials data
Illustration of Validating a Surrogate

- **Anti-Hypertensives**
  (>500,000 patients from rand trials)

  …β-blockers, low dose diuretics, ACE-I, CCBs, ARBs …

  FDA Cardio-Renal Advisory Committee: 6/15/2005

  - Effects on *Blood Pressure* predicting effects on each of the following, considered individually:

    ✓ Stroke, MI, CVD, Mortality, Heart Failure
Odds Ratio for CV Events and Systolic BP Difference: Recent and Older Trials


Recent trials

Older trials placebo

Older trials active

Recent

Older

AASK L vs. H
ABCD/NT L vs. H
ALLHAT/Aml
ALLHAT/Lis
ALLHAT/Lis ≥65
ALLHAT/Lis Blacks
ANBP2
CONVINCER
DIABHYCAR
ELSA
IDNT2
LIFE/ALL
LIFE/DM
NICOLE
PREVENT
SCOPE

ALLHAT/Dox
ATMH
EWPHE
HEP
HOPE
HOT
HOT M vs. H
INSIGHT
MIDAS/NICS/VHAS
L vs. H
MRC
MRC2
PART2/SCAT
PATS
PROGRESS/Per
PROGRESSION/Com
RCT70-80
RENAAL
SHEP
STONE
STOP 1
STOP2/CCBs
STOP2/ACEIs
Syst-China
Syst-Eur
UKPDS C vs. A
UKPDS L vs. H

P < .0001

Difference (reference minus experimental) in Systolic BP (mm Hg)

Slide: Henry Black’s lecture
Illustration of Validating a Surrogate

➢ Anti-Hypertensives
   (>500,000 patients from rand trials)
   …β-blockers, low dose diuretics, ACE-I, CCBs, ARBs…

FDA Cardio-Renal Advisory Committee: 6/15/2005

• Effects on *Blood Pressure* predicting effects on each of the following, considered individually:
  ✓ *Stroke, MI, CVD, Mortality, Heart Failure*
Colon Adjuvant: Hazard Ratios for DFS vs. Overall Survival
Validation of Surrogate Endpoints

Illustration:

HPTN 015 Trial (EXPLORE)

- Clinical Endpoint
  - HIV Infection

- Behavioral Surrogate Endpoints
  - Serodiscordant Unprotected Anal
  - Unprotected Anal
<table>
<thead>
<tr>
<th>Site</th>
<th>N</th>
</tr>
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<tbody>
<tr>
<td>Boston</td>
<td>729</td>
</tr>
<tr>
<td>Chicago</td>
<td>624</td>
</tr>
<tr>
<td>Denver</td>
<td>726</td>
</tr>
<tr>
<td>New York</td>
<td>737</td>
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<td>San Francisco</td>
<td>736</td>
</tr>
<tr>
<td>Seattle</td>
<td>743</td>
</tr>
<tr>
<td>TOTAL</td>
<td>4295</td>
</tr>
</tbody>
</table>
Site-specific Intervention Effects: HIV vs. SDUA/UA
• **Addressing Assay Performance**
  …analysis of analytical performance of an assay…
  e.g., limit of quantitation, across lab reproducibility, etc

• **Evidentiary Assessment**
  …relationship between biomarker & disease state
  …data regarding effects of interventions on both
  biomarker and clinically meaningful outcomes…

• **Justifying the Proposed Use**
  …determining whether available evidence provides
  sufficient justification for the context of use proposed…
Some Uses of Biomarkers

As “Correlates”…

• Disease Diagnosis

• Assessing Prognosis

• In Patient-specific Therapeutic Strategies

• Primary Endpoints in Screening or Proof of Concept Trials

• Measures of Biologic Activity in Confirmatory (registrational) trials
Uses of Biological Markers: High Clinical Utility

• As Replacement or “Surrogate” Endpoints…
  ...*When one can fully capture effects on the principle causal mechanism of disease process (w treatment lacking key unintended mech)*

• In Identifying Enriched Populations…
  ...*When the key mechanism(s) of Rx effect on the causal factor(s) of the disease process are specific to a targeted population (eg, gene) (w treatment possibly having unintended mech)*

  ...*EGFR Inhibitors: KRAS Wild Type vs. Mutation*
Categorization of Nomenclature
Outcome Assessments

Direct Measures of Patient “Functions, Feels, Survives”
- Patient (symptoms: chest pain, dyspnea, fatigue, dizziness)
- Clinician (PANNS for schizophrenia syndrome, Clinician Global Measures)
- Observer (seizures, infant behavior, stroke, death)

Indirect Measures
- Measures depending on patient motivation or clinician judgment to perform the test
- Observer (rescue meds for pain)

Biomarkers
- e.g. $H_bA_1c$, CD-4, PSA, PVRI, NT-proBNP, CO HR, Blood Pressure Pulm Arterial Pressure TIMI-III flow HDL, LDL, body temperature, urine GAG, urine KS cardiac rhythm, blood cultures, PCR, quantitative measures from radiology imaging.

# John Powers, Dave DeMets, Marc Walton, Laurie Burke, Bob Temple...
Chest Pain
Dyspnea
Fatigue
Hospitalization
L.T., Death

6-MWD
3-MSC
Exercise testing

PVRI
NT-proBNP
HR, BP
m-PAP

Direct Measures

Indirect Measures Continuum in PAH
IOM, 2010 “Evaluation of Biomarkers & Surrogate Endpoints in Chronic Disease”

• **Addressing Assay Performance**
  
  ...analysis of analytical performance of an assay... e.g., limit of quantitation, across lab reproducibility, etc

• **Evidentiary Assessment**
  
  ...relationship between biomarker & disease state
  ...data regarding effects of interventions on both biomarker and clinically meaningful outcomes...

• **Justifying the Proposed Use**
  
  ...determining whether available evidence provides sufficient justification for the context of use proposed...
Replacement Endpoints

➢ A replacement endpoint cannot be deemed to be a generic surrogate endpoint for a particular disease

Reasons why use needs setting-specific justification:

- Multiple causal pathways of the disease process
- Magnitude and duration of effect matters
- Intended and unintended effects of interventions

➢ How does evaluating replacement endpoints impact the public?

Response: Need “reliable” as well as “timely” evaluation …not simply “a choice”; rather, “an informed choice”
Biomarkers & ‘Feels, Functions, Survives’ Endpoints

- **Biological Activity**: Hemodynamic Measures:
  - PVRI, mPAP, CO
  - NT-proBNP

- **Clinical Meaningful Benefit**

  ~ **Functions**: Ability to conduct normal activities
    - Ability to walk, Ability to engage in recreational activities,
      Ability for self care, Risk of syncope
    - Time in hospital or missing school (overall, or cause specific)

  ~ **Feels**:  
    - Chest pain, breathlessness, fatigue, dizziness

  ~ **Survives**
    ...Physician or Observer administered & PROs...
Direct Measures of ‘Feels, Functions, Survives’ in PAH

~ Overall survival ~ 6MWD @ 48 wks ~ Syncope (freq. & severity)
~ NYHA Functional Class (1-2 vs. 3-4) ~ Clinician Global Measures
~ Level of successful social interaction with peers (mod. CAMPHOR)
~ Days school missed for health-related reasons; Everyday living skills
~ Symptoms: SF-36, Borg Dyspnea Score, Pain Measures

Composites of measures of ‘Feels, Functions and Survives’:

~ (E.g. Acute Coronary Syndrome: CV Death, Stroke, MI)
  ✓ PAH: Death, L.T., PAH Hosp, (NYHA↑ & 6MWT↓)
~ (E.g. CABP: Cough, Pleuritic chest pain, Dyspnea, Sputum Prod)
  ✓ PAH: Chest pain, Dyspnea, Fatigue, Dizziness/Syncpe

…..scored as Absent, Mild, Moderate, and Severe…..

The endpoint: a) one-point improvement in at least two symptoms
  & b) no worsening of any other symptoms, at day TBD
Principles & Insights


* Fleming TR, Powers JH: Biomarkers and Surrogate Endpoints in Clinical Trials *Statistics in Medicine* 2012; 31: 2973-2984
“A Correlate does not A Surrogate Make”


* Fleming TR, Powers JH: Biomarkers and Surrogate Endpoints in Clinical Trials *Statistics in Medicine* 2012; 31: 2973-2984