Immunogenicity of Therapeutic Proteins

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Causes of Immunogenicity

- Sequence differences between therapeutic protein and endogenous protein
- Structural alterations
  - Aggregation
  - Oxidation
  - Deamidation and degradation
  - Conformational changes
- Storage conditions
- Production/purification
- Formulation
- Route, dose and frequency of administration
- Immune status of patient
- Genetic background
Immunogenicity Prediction

- May play a role in future drug development
- Could be useful in early drug development and in design of second-generation products
- Could significantly reduce development costs
- The story is still building
Animal Models

- At this time, animal models cannot predict immunogenicity in humans

- Factors limiting predictive value
  - Immune system differences between humans, other primates, and other mammals
  - Lack of 100% homology between human therapeutic protein and non-human endogenous protein
Animal Models for Differential Immunogenicity

- Animal models can be useful for comparing immunogenicity of 2 similar products
  - Parent and second generation product
  - Original therapeutic and product after process changes have been made

NOTE: This will still not necessarily reflect what happens in humans, but may provide advance warning if comparator has different immunogenicity profile from original
Value of Preclinical Immunogenicity Assessment

- Interpret toxicology findings (was the animal exposed to the therapeutic protein or was the protein neutralized by the immune response)
- Provide insight into potential consequences of immunogenicity
- However, preclinical findings are not predictive for human immunogenicity
How Do T-Cells Boost an Immune Response?

- Initial immune response is typically IgM, low affinity, and low concentration
- T-cell help is needed for class switching and affinity maturation that is required for a robust immune response
- High affinity mature antibodies of the IgG class are more likely to neutralize effects of therapeutic proteins
Clinical Trials

- Immunogenicity is best determined through controlled clinical trials
  - Studies need to be powered to detect immunogenicity
  - Duration should be at least 6 months to 1 year
  - Ab samples taken at time when circulating drug has cleared or methods utilized to compensate for high levels of circulating drug
  - Assays should be robust, sensitive, specific, and validated
  - Binding and neutralizing Abs should both be measured
Significance of Antibody Results

- Factors effecting interpretation of results
  - Magnitude of response (titer)
  - Duration of response (continuous or sporadic)
  - Correlation with AE
  - Correlation with change in PK (sustaining or clearing)
  - Biologically neutralizing antibodies
Relevance of Antibody Response

- Examine relevance by patient
  - Determine effect of immune response on each patient

- Assess impact of immune response in patients on the project
  - Track rate of antigenicity
  - Track magnitude of immune response
  - Track rate of neutralizing antibody formation
Antibody Significance

Antibody Response = all antibodies generated in a patient in response to a drug

Clinically Relevant Ab =

1) Clearing Ab
2) Sustaining Ab
3) Neutralizing Ab
4) Allergic reaction
5) Cross-reacting with endogenous protein
“Clearing” Antibody

<table>
<thead>
<tr>
<th>Time (day)</th>
<th>Serum Concentration (ng/mL)</th>
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<tbody>
<tr>
<td>0</td>
<td>10000</td>
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<tr>
<td>7</td>
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<tr>
<td>21</td>
<td>1</td>
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</table>

- **1st Dose Ab Negative**
- **3rd Dose Ab Positive**
"Sustaining" Antibody

Antibody Positive (Day 28)

Antibody Negative (Day 28)
Drug Induces Neutralizing Antibody to Drug and to Endogenous Protein
Strategy for Immunogenicity Testing

- Tiered approach
  - Screening immunoassay
  - Confirmatory immunoassay
  - Bioassay for neutralizing antibodies

- Sensitive, specific, and robust methods required
- Validation of assays to allow interpretation of results
- Incorporate “risk-based” approach
How Should Antibodies be Tested?

- Many different formats available
- No “perfect” assay currently exists
Immunoassay Platforms for Detecting Antibodies

- ELISA
  - Bridging format
  - Direct format
  - Indirect format

- Radioimmune precipitation

- Surface plasmon resonance

- Electrochemiluminescence
ELISA Platforms

Coat Drug

Indirect

Direct

Bridging

Add Ab

Add detector

Measure Ab

Labeled Drug

Labeled Protein A
Pros and Cons - ELISA

- **Pros**
  - Established technology, equipment and expertise readily available
  - Sensitive
  - Inexpensive and high throughput
  - Bridging format is highly specific

- **Cons**
  - Can suffer from high background
  - Limited in ability to detect low-affinity antibodies
  - Difficult to confirm IgM antibodies in competition experiments
Radioimmune Precipitation Assay

1. Dilute sample
2. Add radioactive-labeled drug
3. Add Protein A, precipitate Ab, and measure labeled drug
Pros and Cons - RIA

- **Pros**
  - Highly sensitive
  - Established method

- **Cons**
  - Use of radioactivity
  - Not ideal at detecting low-affinity antibodies
  - May not detect early immune response
Surface Plasmon Resonance (Biacore)

Event

Immobilize Drug

Add Sample

Confirm binding is antibody

Inhibit binding w/ drug

Sensorogram
Pros and Cons - SPR

- **Pros**
  - Real-time detection is ideal for detection of low affinity Abs
  - Very good method for detecting early immune response
  - Ability to characterize detected Abs

- **Cons**
  - Equipment expense
  - Not as sensitive as other methods
  - Not as established as other methods
  - Throughput is moderate to low
Electrochemiluminescence Assay (ECL)

- Biotinylated TP
- Ruthenylated TP
- Anti-TP antibody
- Streptavidin

Diagram:
- Measured signal is light
- Luminescence: Emitting Light
- Chemi-: Chemical Energy
- Electro-: Electrochemically Initiated

Reaction:
- $\text{Ru(bpy)}_2^{2+}$
- $\text{Ru(bpy)}_3^{3+}$
- TPA
- $\text{TPA}^+$
- $\text{H}^+$

Electrode: $\text{E}^-$
Pros and Cons - ECL

**Pros**
- Highly sensitive
- Broad dynamic range
- Generally better than ELISA for detecting early immune response
- Can be automated for high throughput

**Cons**
- Limited availability, not yet well-established
- Can be subject to pronounced “hook effect”
- May not detect all low affinity Abs
Characterization of Antibodies

- Isotype determination
- Binding inhibition with soluble drug
- Determination of relative binding affinity
- Relative antibody concentration
- Specificity to native and second generation product
- Ability to neutralize in a cell-based system
Biacore: Determination of Antibody Isotype

Sample Injection

Sample Dissociation

Anti-IgE, Anti-IgA, and Anti-IgM Injection

Confirmatory Binding

Regeneration

Anti-IgG Injection

Time

0 10 20 30 40 50 60 70 80 90

Y-axis: concentrations
“High” and “Low” Affinity Antibodies

Low Affinity Antibody
(rapidly dissociating)

High Affinity Antibody
Bioassays for Neutralizing Antibodies

1. Culture cells
2. Add drug
3. Measure biological response (proliferation)

1. Culture cells
2. Add drug and Ab sample
3. Measure biological response (proliferation)
Receptor Tyrosine Kinase Activation

- Cell line untreated and treated with a growth factor for 20 minutes.
- Blue is Hoechst nuclear stain and green represents phosphorylated receptor antibody.

No treatment  + Growth Factor
Transcription Factor Activation

- Cell line untreated and treated with a growth factor for 30 minutes.
- Blue is Hoechst nuclear stain and green represents a transcription factor.
- In untreated cells, is inactive and remains primarily in the cytoplasm. Upon activation, a transcription factor translocates to the nucleus to mediate gene expression.
Neutralizing Antibodies

- Bioassay used to determine ability of the antibody to neutralize a biological effect of the drug in a cell-based system
  - Proliferation assay
  - Cytokine release assay
  - m-RNA measurement

- Bioassays typically more variable and less sensitive than immunoassays

- When a biological assay cannot be developed, can substitute a functional immunoassay
Unique Features of Bioassays

- Determines effect of an antibody in a cell-based system
- Only assay that determines if an antibody can neutralize the biological effect of the drug
- Results must be coupled with a specific immunoassay to verify neutralization is due to antibody
Antibody Response to Therapeutic Proteins

- Historically, many therapeutic proteins have induced antibody formation, effects of which range from minimal to significant
- Some of these antibodies are associated with serious adverse effects
- Both biopharmaceutical industry and regulatory agencies continue to partner for a better approach to antibody testing
Antibody-Mediated PRCA

- Professor Nicole Casadevall reported in NEJM in 2002 on cases of antibody-mediated pure red cell aplasia in patients treated with ESAs.
- These patients had neutralizing antibodies against erythropoietin.
- Very few reports in the literature of this phenomenon prior to the Casadevall manuscript.
- Focused attention on the analytical procedures used for detecting and characterizing antibodies against ESAs.
## Summary of Anti-EPO Results

<table>
<thead>
<tr>
<th>Subject</th>
<th>RIP*</th>
<th>ELISA</th>
<th>BIACORE</th>
<th>Bioassay</th>
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* RIP = Radioimmune precipitation assay
+ = Positive for anti-rHuEPO antibodies
– = Negative for anti-rHuEPO antibodies
## Characterization of PRCA Antibodies

<table>
<thead>
<tr>
<th>Relative Ab Concentration (mcg/ml)</th>
<th>Ab Dissociation Rate (RU/min)</th>
<th>Predominant Isotype</th>
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<tr>
<td>43.46</td>
<td>10.7</td>
<td>IgG4 (IgG1, 2)</td>
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<td>15.86</td>
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<td>14.57</td>
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<td>5.96</td>
<td>1.9</td>
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<td>4.10</td>
<td>1.6</td>
<td>IgG4 (IgG1)</td>
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Antibody Related Issues in Clinical Studies and Post-Approval Stage

**Patient safety**
- Cross reactivity with endogenous proteins
- Allergic reactions
- Immune complexes-complement activation

**Reduced efficacy**
- Neutralizing and/or clearing antibodies

**Altered PK**
- Enhanced drug clearance
- Drug accumulation
- Interference with PK assay
Conclusions

- Recombinant therapeutic proteins can be immunogenic.
- Antibodies to therapeutic proteins can cause difficulties in preclinical animal studies and occasionally, serious side effects in humans.
- Antibody testing method can greatly impact the results.
- Careful antibody monitoring with appropriate assays is necessary throughout preclinical and clinical development in order to ensure safety and efficacy of therapeutic proteins.
References


Acknowledgements

Amgen’s Clinical Immunology Department