Drug Discovery and Development

Target Validation

&

Druggability
Outline

• Background on the issues
  – What is involved in establishing a discovery project
  – Biological relevance and chemical tractability
    • Focus on small molecules
• Validated target
  – What is a validated target and how do you make that determination
  – Examples
• Druggable target
  – What this means and how it is used
  – Druglikeness
• Conclusion – Viability for drug discovery
  – Biological relevance and chemical tractability
Drug Discovery & Development

- Target Identification
- Target Prioritization/Validation
- Lead Identification
- Lead Optimization
- Preclinical Testing
- Chemical Manufacturing Controls (CMC)/Pharmaceutics
- Pharmacology/Toxicology
- Investigational New Drug (IND)/CTX/CTA
- Phase I
- Phase II
- Phase III
- New Drug Approval (NDA)/MAA
- Phase IIIb/IV
- Post Market
Drug Discovery and Development
A Long Process

Drug development takes about 15 years

- 6.5 years Discovery and preclinical testing
- 1.5 years Phase I
- 2 years Phase II
- 3.5 years Phase III
- 1.5 years FDA review (postmarketing testing)

Clinical trials

$800 MM to 1.3 billion to develop a drug
Why is it so expensive?
- More regulations and requirements
- Large failure Rate
  - 1 in 10 compounds entering Phase 1 make it to a drug
- How many drug discovery programs are needed
Typical Large Pharma Averages

- Start 100 new screening programs/assays
  - New targets
- About 50 programs find leads or acceptable chemotypes to pursue
  - Limited chemotypes is a liability
  - Backup compounds
- 20 - 25 Advance into late stage lead optimization
- Only 10 programs/compounds proceed into Phase 1
- Why?
Why Compounds Fail
“A Changing Paradigm”

- Pharmacokinetics
  - Human ADME properties
    - Adsorption, distribution, metabolism, excretion
  - Rodent vs. dog vs. monkey vs. human
- Toxicology
  - Not predicted by animal studies
- Adverse effects in man
- Lack of efficacy
  - Biological rationale is incorrect
  - Relevance of animal models
    - Arthritis model in rats vs. rheumatoid arthritis in patients
    - Oncology models
- Commercial reasons
Preclinical Drug Discovery

- Target identification and validation
  - High throughput screening and lead identification
- In vitro activity
  - IC$_{50}$, EC$_{50}$, chemical tractability
  - Liability targets
    - CNS, cardiovascular,
- Medicinal chemistry and lead optimization
- In vitro ADME
  - Stability, solubility, cytochrome p450 enzymes, plasma protein binding, transporters
- Toxicology and additional liabilities
- In vivo assessment
  - In vivo optimization
    - Disease models, in vivo pharmacokinetics, bioavailability, safety
- Nomination candidate
Target Identification

- Key steps for a target
  - Is the target validated and druggable
    - Small molecule
  - How will you screen for modulators?
    - Agonist, antagonist, inhibitor
    - Outcome looking for
    - Where is the target!!
  - Secondary assays and species differences
  - Animal models to test hypothesis
    - Standards or known compounds
    - Predictability of the model
    - Biomarkers
  - Clinical outcome
Failure Rate Alzheimer's Disease

- Higher clinical failure rate than other therapeutic areas
- Not a single disease modifying drug approved
- Lack of a clear animal model that recreates the histopathological and neurodegeneration hallmarks of AD
- May have to target particular areas of the brain
- Targets not validated or better animal model?
What is a Drug Discovery Target

- Proteins
- Receptors and enzymes
  - Either inside the cell or on the surface
    - G-protein coupled receptors
    - Protease or kinase
- Transcription factors
  - Gene regulation
- Ion channels and transporters
- Infectious diseases and cancer
  - Direct cell-based assays
- Protein-protein interactions
Senicapoc

- Potassium channel inhibitor for the treatment of sickle-cell anemia
  - IK1 (KCa3.1) inhibitor in RBC’s to maintain hydration
  - In vivo efficacy in a mouse sickle cell model
- Advanced to a phase III clinical trial in sickle-cell patients
  - Positive Phase II trials
  - Phase III - Vaso-occlusive crisis rate was the approvable end-point
  - Three arms to the study
    - Senicapoc alone, hydroxyurea and combination
- Independent review board analyzed the data and concluded there would be no benefit
- The trial was stopped
  - There was an improvement in several hematological factors indicating biological activity
- Is this a validated/druggable target?
Therapeutic Need
Where do Discovery Ideas (targets) Come From?

• Historically from natural products
  – Medicine man, old wives tale?
  – Herbal medicines, snake venom
  – Observed in vivo effects in animals
    • Chemist made compounds and found someone to test them

• Clinical observation
  – Side-effects or desired effect

• Rationale approaches based upon biochemistry/biology

• Screening, systems biology

• Understanding genetic mutations in people
New Target Identification

• Newer approaches have identified more targets
• Genomics, proteomics, pharmacogenomics
• RNA interference and related technologies
  – Small interfering RNA (gene silencing)
  – Interference with the expression of a specific gene
• Pathway analysis
• Transgenic mice

• Key Question - Target Validation
  – Modulate a target and what effect does it have?
What constitutes a validated target

- Genetic mutations in a protein leading to or associated with a disease
  - Alzheimer's and amyloid precursor protein and secretase
  - Human epidermal growth factor receptor 2 (HER2) amplified in breast cancer promotes cancer cell growth

- Up-regulation during a disease process
  - Inflammation and Cyclooxygenase 2

- Proteome
  - Kinome- kinases
    - 518 Kinases
    - Gene family
KCNQ2/3 – Validated Targets

- Present at high levels in neurons including dorsal root ganglia (DRG). No significant expression in major peripheral organs.
- Mutations in KCNQ2 and KCNQ3 associated with a congenital seizure disorder in humans – Benign Familial Neonatal Convulsions
- Targeted deletion of KCNQ2 in mice increases sensitivity to chemoconvulsant induced seizures.
- KCNQ channels represent molecular correlates of the neuronal M-current – control resting membrane potential, integration of synaptic inputs and spike frequency adaptation.
- KCNQ/M-current activators are efficacious in animal models and human diseases associated with excessive neuronal excitability.
KCNQ Family

- **KCNQ1/KCNE1** contributes to cardiac action potential repolarization. Mutation can result in Long QT Syndrome.
- **KCNQ2** - Forms heterotetramers with KCNQ3. Mutations in KCNQ2 cause the congenital seizure disorder benign familial neonatal convulsions (BFNC).
- **KCNQ3** - Expresses poorly as a homomultimer. Co-assembles with other KCNQ channels such as KCNQ2 and KCNQ5. Mutations in KCNQ3 also linked to BFNC.
- **KCNQ4** - Expressed primarily in inner ear. Mutation linked to one form of hereditary deafness.
- **KCNQ5** - Expressed in nervous system and co-assembles with KCNQ3.
Cyclooxygenase Inhibitors
Validated Target

- The classical COX inhibitors are not selective and inhibit all types of COX. The resulting inhibition of prostaglandin and thromboxane synthesis has the effect of reduced inflammation, as well as antipyretic, antithrombotic and analgesic effects.

- The most frequent adverse effect of NSAIDs is irritation of the gastric mucosa as prostaglandins normally have a protective role in the gastrointestinal tract.

- Some NSAIDs are also acidic which may cause additional damage to the gastrointestinal tract.
Cyclooxygenase Inhibitors

COX 1 and COX2

• In the 1990s, researchers discovered that two different COX enzymes existed, now known as COX-1 and COX-2

• COX-1 is known to be present in most tissues.
  – In the GI tract, COX-1 maintains the normal lining of the stomach. The enzyme is also involved in kidney and platelet function

• COX-2 is primarily present at sites of inflammation

• COX-1 and COX-2 convert arachidonic acid to prostaglandin, resulting in pain and inflammation, their other functions make inhibition of COX-1 undesirable while inhibition of COX-2 is considered desirable
COX-2 Inhibitors

- **Celecoxib, Rofecoxib,**
  - COX-2 is usually specific to inflamed tissue, there is much less gastric irritation associated with COX-2 inhibitors, with a decreased risk of peptic ulceration.

- **COX-2 inhibitors have been found to increase the risk of atherothrombosis**
  - A 2006 analysis of 138 randomized trials and almost 150,000 participants showed that selective COX-2 inhibitors are associated with a moderately increased risk of vascular events, mainly due to a twofold increased risk of myocardial infarction

- **Validated, druggable**
  - Viable
<table>
<thead>
<tr>
<th>Protein name</th>
<th>Gene</th>
<th>Expression profile</th>
<th>Associated human channelopathies</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Na(_{1.1})</strong></td>
<td>SCN1A</td>
<td><strong>Central neurons, [peripheral neurons] and cardiac myocytes</strong></td>
<td>febrile epilepsy, GEFS+, Dravet syndrome (also known as severe myclonic epilepsy of infancy or SMEI), borderline SMEI (SMEB), West syndrome (also known as infantile spasms), Doose syndrome (also known as myoclonic astatic epilepsy), intractable childhood epilepsy with generalized tonic-clonic seizures (ICGTC), Panayiotopoulos syndrome, familial hemiplegic migraine (FHM), familial autism, Rasmussens's encephalitis and Lennox-Gastaut syndrome[7]</td>
</tr>
<tr>
<td><strong>Na(_{1.2})</strong></td>
<td>SCN2A</td>
<td>Central neurons, peripheral neurons</td>
<td>inherited febrile seizures and epilepsy</td>
</tr>
<tr>
<td><strong>Na(_{1.3})</strong></td>
<td>SCN3A</td>
<td>Central neurons, peripheral neurons and cardiac myocytes</td>
<td>none known</td>
</tr>
<tr>
<td><strong>Na(_{1.4})</strong></td>
<td>SCN4A</td>
<td><strong>Skeletal muscle</strong></td>
<td>hyperkalemic periodic paralysis, paramyotonia congenita, and potassium-aggravated myotonia</td>
</tr>
<tr>
<td><strong>Na(_{1.5})</strong></td>
<td>SCN5A</td>
<td>Cardiac myocytes, uninnervated skeletal muscle, central neurons</td>
<td>Long QT syndrome, Brugada syndrome, and idiopathic ventricular fibrillation</td>
</tr>
<tr>
<td><strong>Na(_{1.6})</strong></td>
<td>SCN8A</td>
<td><strong>Central neurons, dorsal root ganglia, peripheral neurons, heart, glia cells</strong></td>
<td>none known</td>
</tr>
<tr>
<td><strong>Na(_{1.7})</strong></td>
<td>SCN9A</td>
<td>Dorsal root ganglia, sympathetic neurons, Schwann cells, and neuroendocrine cells</td>
<td>erythromelalgia, PEPD, channelopathy-associated insensitivity to pain and recently discovered a disabling form of fibromyalgia (rs6754031 polymorphism - PMID: 22348792).</td>
</tr>
<tr>
<td><strong>Na(_{1.8})</strong></td>
<td>SCN10A</td>
<td>Dorsal root ganglia</td>
<td>none known</td>
</tr>
<tr>
<td><strong>Na(_{1.9})</strong></td>
<td>SCN11A</td>
<td>Dorsal root ganglia</td>
<td>none known</td>
</tr>
<tr>
<td><strong>Na(_x)</strong></td>
<td>SCN7A</td>
<td>heart, uterus, skeletal muscle, astrocytes, dorsal root ganglion cells</td>
<td>none known</td>
</tr>
</tbody>
</table>
Sodium Channel Inhibitors
Therapeutic Applications

- Local anesthetic
  - Lidocaine or Procaine
    - Short acting
- Epilepsy
  - Phenytoin
- Antiarrythmics
  - TAMBOCOR™ (flecainide), Mexitil
- Neuropathic pain
- All are non-selective
  - Affect multiple channels
- Validated targets?

Mexilitene
Congenital Insensitivity to Pain: Novel SCN9A Missense and In-Frame Deletion Mutations

• SCN9A encodes the voltage-gated sodium channel Na\textsubscript{v}1.7, a protein highly expressed in pain-sensing neurons.

• Mutations in SCN9A cause three human pain disorders
  – bi-allelic loss of function mutations result in Channelopathy-associated Insensitivity to Pain (CIP)
  – whereas activating mutations cause severe episodic pain in Paroxysmal Extreme Pain Disorder (PEPD) and Primary Erythermalgia (PE).

• To date, all mutations in SCN9A that cause a complete inability to experience pain are protein truncating and presumably lead to no protein being produced.
When is a Target Validated?

- Mechanistic studies – in vitro
  - Over expression, anti-sense, mutations
- Cell based activity
- Animal studies – knockout studies
  - Disease phenotype
- Therapeutic intervention
  - Small molecule or biological
- Phase 2 clinical results
- NDA approval
Discussion

• Validated target vs. “druggable target”

• Is there a difference?

• A druggable target is?
Types of Drugs

- Natural products
- Steroids, antibiotics
- Peptides (smaller)
- Biologicals
  - Antibodies, proteins, antisense
- Small molecules
  - Oral bioavailability, ease of manufacture, stability, cost
A New “Validated” Drug Target
Issues to Consider

• Is the target “druggable”
  – What evidence is there to support initiating a drug
discovery program?
  – Small molecule inhibitors, animal models, species
differences, biomarker (Phase 1)
  – Related to other known targets - Gene Families
    • Kinases, phosphatases, nuclear receptors

• Structural information
  – Protein crystallographic data, NMR structure

• Intellectual property
  – Competition
Gene Families

• A gene family is a group of genes that share important characteristics. In many cases, genes in a family share a similar sequence of DNA building blocks (nucleotides).
  – In other cases, dissimilar genes are grouped together in a family because proteins produced from these genes work together as a unit or participate in the same process.

• Gene family drug discovery - Programs and expertise directed toward certain sets of targets
  – For example, assays, chemistry, modeling
  – Success in drug discovery
Types of Gene Families
Druggable Targets

• G-protein coupled receptors
• Kinases
• Proteases
• Nuclear receptors
• Phosphatases
• Phosphodiesterases
• Ion channels
The KCNQ Gene Family

Interesting epilepsy and pain targets based on: Function, Distribution and Pharmacology

The IUPHAR name for the KCNQ family is Kv7.x
G-Protein Coupled Receptors

- World Market for G-Protein-Coupled Receptors (GPCRs) Targeting Drugs to Reach US$120.5 Billion By 2017, According to New Report by Global Industry Analysts, Inc.

- GIA announces the release of a comprehensive global report on the ‘G-Protein-Coupled-Receptors (GPCRs)’ market. Global market for G-Protein-Coupled Receptors (GPCRs) is projected to reach US$120.5 billion by the year 2017. Major factors driving growth in the market include rising interest among researchers for GPCR drug targets, increased know-how of membrane structures of GPCR, and advancements in identification as well as crystallization of newer structures. In addition to these, emergence of efficient and powerful technologies used in GPCR screening is expected to stimulate market growth.
GPCR drugs

- H2 antagonists – Zantac
  - Ulcers
- Beta-blockers – Bystolic
  - Hypertension
- Beta-agonists – Symbicort
  - Asthma
- Serotonin Agonists – Sumatriptan
  - Migraine

Focused libraries – GPCR’s
Develop an expertise
Chemical structure of hERG channel blockers.

Perry M et al. J Physiol 2010;588:3157-3167
### Calcium Channel Gene Family

- **Complex Problem** But **Druggable Targets**

#### Representative drugs that target different calcium channels

- **L-type**: nifedipine, verapamil, diltiazem for cardiovascular indications
- **N-type**: ziconitide for cancer pain (i.t. administration)
- **T-type**: zonisamide, ethosuximide, mibefradil (epilepsy, pain)

#### Table: Calcium Channel Gene Family

<table>
<thead>
<tr>
<th>Clone</th>
<th>Ca&lt;sub&gt;y&lt;/sub&gt;</th>
<th>Gene</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>a1S</td>
<td>1.1</td>
<td>CACNA1S</td>
<td>L-type</td>
</tr>
<tr>
<td>a1C</td>
<td>1.2</td>
<td>CACNA1C</td>
<td>L-type</td>
</tr>
<tr>
<td>a1D</td>
<td>1.3</td>
<td>CACNA1D</td>
<td>L-type</td>
</tr>
<tr>
<td>a1F</td>
<td>1.4</td>
<td>CACNA1F</td>
<td>L-type</td>
</tr>
<tr>
<td>a1A</td>
<td>2.1</td>
<td>CACNA1A</td>
<td>P/Q type</td>
</tr>
<tr>
<td>a1B</td>
<td>2.2</td>
<td>CACNA1B</td>
<td>N-type</td>
</tr>
<tr>
<td>a1E</td>
<td>2.3</td>
<td>CACNA1E</td>
<td>R-type</td>
</tr>
<tr>
<td>a1G</td>
<td>3.1</td>
<td>CACNA1G</td>
<td>T-type</td>
</tr>
<tr>
<td>a1H</td>
<td>3.2</td>
<td>CACNA1H</td>
<td>T-type</td>
</tr>
<tr>
<td>a1I</td>
<td>3.3</td>
<td>CACNA1I</td>
<td>T-type</td>
</tr>
</tbody>
</table>
T-Type Calcium Channel Antagonists- Target Validation

- Literature evidence suggests that T-type calcium channels are involved in certain pain and CNS disorders
  - i.e., small molecules, antisense, rodent knockout studies

- Identify a novel series of T-type calcium channel antagonists and evaluate in rodent models of pain
  - Target validation – IC$_{50}$ vs. plasma (brain?) concentrations
    - T-type IC$_{50}$<50nM, 30-40-fold selective vs. L-type
    - Selective versus other relevant targets
    - Orally bioavailable, $t_{1/2}$ >1 hr (i.v. rat)
    - $\sim$5-10-fold over IC$_{50}$ at Cmax (1-2h)
**T-type Calcium Channel Blockers**

**Druggable - Small Molecules Antagonists**

- **Pain**
  - T-type calcium channel inhibitor ethosuximide reverses dorsal horn responses to mechanical and cold allodynia in Chung model and reverses paclitaxel (taxol) and vincristine-evoked neuropathy (Flatters S.J. et al, 2004, *Pain* 109:150-161)
  - “T-Type calcium channel inhibitors” mibebradil and ethosuximide reduce tactile and thermal hypersensitivity in Chung model of neuropathic pain (Dogrul A. et al, 2003, *Pain* 105:159-68)

- **Epilepsy**

- **Arousal states**

- **Oncology**
Summary

- Identified novel, potent, small molecule T-type antagonists
  - Pan antagonists
    - No selectivity versus T-type family sub-types
  - Selective versus related gene family ion channels and cardiac channels
- Good in vitro properties can be achieved
  - Permeability, solubility, stability
- Oral bioavailability can be achieved
  - Caco2 - permeability assays used to guide synthesis
- Limited CNS exposure
- Plasma concentrations vs. T-type IC$_{50}$ insufficient for pain indications
Other Indications – T-Type Inhibitors

- Parkinson’s disease
- Neuroprotection
- Sleep disorders

- Druggable, yes, validated, maybe
Drug-like Molecules

- Rule of 5
  - Rule of 4.5?
- MW 500, ClogP 5, H-bond donors, 5 H-bond acceptors (sum of N and O atoms) 10
- Remarks: No more than one violation; not applicable for substrates of transporters and natural products
- Extensions:
- Polar surface area 140, sum of H-bond donors, and acceptors 12, rotatable bonds 10
Druglikeness

- Optimal solubility to both water and fat
  - Orally administered drug has to go through the intestinal lining, carried in aqueous blood and penetrate the lipid cellular membrane to reach the inside of a cell.
    - cLogP, is used to estimate solubility.

- High potency (IC$_{50}$ or EC$_{50}$)
  - Reduces the risk of non-specific, off-target pharmacology at a given concentration
  - Low clearance, high potency also allows for low total dose, which lowers the risk of idiosyncratic drug reactions
  - The less you give the better
Guiding Lead Optimization

- Several scoring methods can be used to express druglikeness as a function of potency and physicochemical properties, for example **ligand efficiency** and **lipophilic efficiency**.
  - Potency vs. lipophilicity

- Avoid substructures that have known chemical or pharmacological properties.
  - Alkyl nitro and aryl nitro compounds and Michael acceptors, such as **enones**, are **alkylating agents** and thus potentially **mutagenic** and **carcinogenic**
Natural Products

• Very effective as drugs
• Optimized by nature
• Don’t fit the drug-like concept
  – Very complex
  – Many stereocenters
• More difficult to work with
• Making a comeback
Streptomycin

**Formula**  \( \text{C}_{21}\text{H}_{39}\text{N}_{7}\text{O}_{12} \)

**Mol. mass**  581.574 g/mol
Predicting Druggability

- Identified a new protein
  - Druggable
- Computational approaches developed
  - Druggability software
  - Journal of Chemical Information and Modeling
    - 2012, 52, 1027
- Rules that govern druggability
- Algorithm to isolate and characterize binding pockets
  - Volume, depth enclosure, surface area, charged residues, aromatic, avg hydrophobic residues
- Remains to be tested
Validated, Druggable, Viable

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