Positron Emission Tomography: Tool to Facilitate Drug Development and to Study Pharmacokinetics

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Outline of Talk

PET has high sensitivity and specificity
PET used in therapeutic drug development
Pharmacokinetic modeling of plasma concentration and tissue uptake can measure receptor density
Study drug distribution: block distribution to periphery and increase distribution to brain
Study drug metabolism: inhibit defluorination
Imaging Receptors with PET

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Positron Emission Tomography
Title slide for a talk on this topic by Simon R. Cherry at the University of California - Davis
PET vs. MRI

Chart comparing PET and MRI
Radionuclide ($^{11}$C): high sensitivity
Ligand (raclopride): high selectivity
Radioligand $[^{11}]$C]raclopride: high sensitivity & selectivity

PET provides greater sensitivity but less spatial resolution than MRI.
Radioligand = Drug + Radioactivity

Drug administered at tracer doses
  No pharm effects
  Labels <1% receptors
  Labeled subset reflects entire population

Radioligand disposed like all drugs
  Metabolism & distribution

Radiation exposure
NIH Rodent PET Camera
$^{18}$F bone uptake rat

PET scan image.

Developed By: Mike Green & Jurgen Seidel
PET: Tool in Therapeutic Drug Development
Determine dose and dosing interval
Identify homogeneous group
Biomarker for drug efficacy
Monitor gene or stem cell therapy
Lazaemide blocks $[^{11}\text{C}]$deprenyl
Binding to monoamine-oxidase-B (MAO-B)

Images of baseline, 25 mg bid, 50 mg bid, and 36 hours later.

Selegilene is more potent and longer acting than lazabemide

Images at baseline, 5 mg bid, 1 week later and 3 weeks later.
PET: Tool in Therapeutic Drug Development

- Determine dose and dosing interval
- Identify homogeneous group
- Biomarker for drug efficacy
- Monitor gene or stem cell therapy
Dopamine Transporter: Located on DA Terminals
Removes DA from Synapse

Illustration of this process at synapse.
SPECT Imaging of Dopamine Transporter in Caudate and Putamen of Human Brain

MRI   SPECT

Illustration of imaging differences in MRI vs. SPECT.
$^{123}\text{-}\beta$-CIT Dopamine Transporter SPECT: Decreased in Parkinson’s Disease

Healthy Parkinson’s Stage 1

Images of a health individual vs. a Parkinson Stage 1 patient.
PET: Tool in Therapeutic Drug Development

Determine dose and dosing interval
Identify homogeneous group
Biomarker for drug efficacy
Monitor gene or stem cell therapy
Serial Dopamine Transporter Imaging in a Parkinson Patient

Images comparing baseline with 22 months, 34 months, and 46 months with progressive reduction in dopamine transporter.

Institute for Neurodegenerative Disorders
Pet Imaging of Amyloid: Biomarker for Alzheimer’s Disease

University of Pittsburgh
PET Amyloid Imaging Group
PET: Tool in Therapeutic Drug Development
Determine dose and dosing interval
Identify homogeneous group
Biomarker for drug efficacy
Monitor gene or stem cell therapy
Gene Therapy Using Viral Vectors

Viral vectors deliver gene that synthesizes dopamine (DA)

Infuse virus into striatum (target cells)

Illustration of gene therapy.
PET Dopamine Imaging in Hemi-Parkinson Monkey: Monitors gene for DA synthesis in right striatum

Images:
Pre post – Control Gene: Lac-Z
DA Synthesis Gene: AADA
Pet Imaging to Monitor Embryonic Stem Cell Treatment of “Parkinson Disease” in Rats

Pet images of normal, unilateral and embryonic stem cells in Pet & MRI.
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Pharmacokinetic modeling: plasma concentration and tissue uptake

Study drug distribution: “peripheral” benzodiazepine receptor

Study drug metabolism: inhibit defluorination
Brain Uptake of $[^{18}\text{F}]$Flooxetine: Measures Density of Serotonin Transporters & Affinity of Fluoxetine

Illustration of brain drug levels in a patient compared with a brain drug levels in a healthy subject over time.
Brain Uptake of $[^{18}\text{F}]$ Fluoxetine: Measures Density of Serotonin Transporters & Affinity of Fluoxetine

Illustration of brain drug levels in a patient compared to brain drug levels in a healthy subject over time. Effect of injected activity (dose).
Brain Uptake of $[^{18}\text{F}]$FluoetineL Measures Density of Serotonin Transporters & Affinity of Fluoxetine

Illustration of a brain drug levels in a patient compared to brain drug levels in a healthy subject over time at different doses. Equal doses but different AUCs.
Brain Uptake $[^{18}\text{F}]$Fluoxetine: Measures Density of Serotonin Transporters & Affinity of Fluoxetine

Illustration of brain drug in patient compared to brain drug in a healthy subject over time. Equal weight but different AUCs.
Brain Uptake of $[^{18}F]F$Fluoxetine: Measures Density of Serotonin Transporters

Illustration of brain drug in patient compared to brain drug in a healthy subject over time. Effects of liver disease.
Binding Potential (BP): Receptor Density*Affinity
BP equals uptake in brain relative to how much drug is delivered via arterial plasma.

Chart illustrating the binding potential in the brain comparing drug in plasma with drug in brain.
Binding Potential: Independent on Injected Dose*

Double Plasma Input => Double Brain Response

*If ligand does not saturate receptors – i.e., if tracer doses used

Charts illustrating this.
BP can be calculated from the Area Under Curve (math integral) as well as rate constants (math differential).

From curves of plasma and brain radioactivity over time, estimate rate constants of entry and removal to/from tissue.

Formula for this calculation.
Tissue uptake is proportional to density of receptors and the affinity of the drug.

Formula for binding potential.
SUMMARY PET KINETICS

Organ uptake is proportional to receptor density and affinity of drug

Binding Potential (BP) = density X affinity

“Drug Exposure” to tissue is AUC of: plasma concentration vs. time

“Response” (uptake) of tissue is AUC of: tissue concentration vs. time

BP also equals ratio of rate constants of entry and removal to/from tissue

Formulas to illustrate
Major Point of PET Pharmacokinetics (in words)

Plasma pharmacokinetics provides a limited view of what’s happening to drug in plasma.

PET provides a limited view of what’s happening to drug in tissue.

Concurrent measurement of drug in plasma and of drug in tissue allows quantitation of the target of drug action – i.e., receptor.
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Translocator Protein (18 kDa)  
a.k.a. “peripheral benzodiazepine receptor”
Mitochondrial protein highly expressed in macrophages and activated microglia

Exists in periphery and brain

Multiple potential functions: steroid synthesis, nucleotide transport

Distinct from typical benzodiazepine GABA_A receptor in brain

Marker for cellular inflammation
Receptor Blockade [$^{11}$C]PBR28 in Monkey Brain: more radioligand in plasma and brain

Chart illustrating this and comparing baseline with receptors blocked
Receptor blockade displaces from lung and kidney. Drives more to brain but doesn’t bind there.
Human with low uptake is similar to monkey with receptor blockade

Compares A) regular healthy subject with B) odd healthy subject.

Graphic illustration
Some HEALTHY subjects May have No Receptor Binding of $[^{11}\text{C}]\text{PBR28}$

Images of organs that demonstrate this occurrence.

Nonbinders showed a trend of higher plasma $[^{11}\text{C}]\text{PBR28}$
Focal and Global Increase of Inflammation

Inflammation imaging
Brain scans of the effects of healthy vs. diseased Disease
Epilepsy
   Focal increase in epileptogenic focus
Alzheimer’s Disease
   Global increase of inflammation
TSPO identifies gliosis in epileptogenic focus

Brain images
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[^18F]FCWAY: Defluorination
Bone uptake: human skull at 2 h

Brain images
[^18]FCWAY: Defluorination

$^{18}$F-flouride ion accumulates in bone

Image
Miconazole inhibits Defluorination & Bone Uptake

Images of defluorination and bone uptake at various times.
Disulfiram: Decreases Skull Activity & Increases Brain Uptake

Images of this at baseline and with Disulfram
Disulfiram: Decreases skill uptake of flourise and increase brain uptake of $[^{18}\text{F}]\text{FCWAY}$

Charts comparing this uptake in skull and the temporal cortex.
Disulfiram: Decreases plasma fluoride and Increases plasma radiotracer $[^{18}\text{F}]\text{FCWAY}$

Charts that illustrate this activity.
Summary
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Self-Assessment Quiz: True or False?

Imaging with positron emission tomography (PET) involves the injection of a radioactively labeled drug that emits a particle called a positron.

PET shows the location of radioactivity in a cross section (or tomograph) of the body.

PET can be used to quantify the density of specific proteins in the body.

Compartmental modeling of PET data typically uses measurements over time of 1) PET images of the target tissue and 2) concentrations of unchanged parent radioligand in plasma.
FDA Critical Path Initiative

Approvals for new drugs declining

R&D funding by industry and NIH is increasing

Problem: tools are inadequate for efficient evaluation of new drugs in the “critical path” of development

Still using old tools like liver enzymes and hematocrit to evaluate safety and efficacy

Need new Product Development Toolkit
There is currently an urgent need for additional public-private collaborative work on applying technologies such as new imaging technologies.

Opportunity: Imaging technologies, such as molecular imaging tools in neuropsychiatric diseases or as measures of drug absorption and distribution, may provide powerful insights into the distribution, binding, and other biological effects of pharmaceuticals.”
Copy of website for the Foundation for the NIH

http://www.fnih.org/
The website of the Biomarkers Consortium

Information for this initiative can be found at http://www.cancer.gov/ncicancerbulletin/NCI_Cancer_Bulletin_101006/page3
Quantification of receptor density
Distribution volume

Uptake in brain relative to how much drug is delivered via arterial plasma
$^{18}$F-SP203 in Human: Quantification went well

Calculation for regions, temporal cortex and cerebellum

Illustrations to show this.
Quantification of receptor density
Equilbriums method
Distribution volume

Concentration ratio of tissue to plasma under equilibrium
Advantages of equilibrium method

Determine VT directly from concentration ratio of tissue to plasma under equilibrium
Rapid equilibrium can be achieved with bolus and constant infusion

From pharmacokinetic course 2009 by R.E. Carson
Radioactivity became stable in plasma and brain with bolus plus constant infusion

Temporal cortex