Title: Spatial Analysis of Positron Emission Tomography Images Using 3D Moment Invariants

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Abstract: 3D moment invariants (3DMIs) are mathematical spatial descriptors designed to be invariant to scaling, translation and rotation. We propose to characterize the spatial distribution of positron emission tomography (PET) images using 3DMIs. We have used 3DMIs to characterize the spatial distribution of PET brain images recorded from subjects with Parkinson's Disease (PD) and healthy controls. 3DMIs were found to accurately describe the 3D texture of PET images despite changes in the size and orientation of the participating subjects in the PET scanner. In addition, we were able to find differences in the 3DMIs of PD patients distinct from those of healthy volunteers. These changes suggest that disease-related variations in the spatial distribution measured using PET can be quantitatively described with the proposed method. Therefore, this method shows great promise to extract additional information from PET data with a wealth of potential applications to disease diagnosis, staging, treatment assessment and more. The quantification of the observed disease-related changes for PD subjects is currently under way.

Outline

- Medical Imaging
- Positron emission tomography (PET) :
  - Introduction
  - Applications
- 3D spatial analysis:
  - Moment invariants
  - Applications to PET data
  - Results
- Summary and future directions

Medical Imaging

- Medical physics:

"Medical physics is a division of Healthcare science concerning the application of physics to medicine. It generally concerns physics as applied to medical imaging and radiotherapy."

- Medical Imaging:

"Medical imaging is the technique and process used to create images of the human body (or parts and function thereof) for clinical purposes or medical science."

Medical Imaging

- X-rays
- Fluoroscopy
- Mammography
- X-ray Computed Tomography (CT = CAT)
- Ultrasound
- MRI
- **Positron Emission Tomography (PET)**
- Single Photon Emission Computed Tomography (SPECT)
- Magnetoencephalography (MEG)
- Electroencephalography (EEG)
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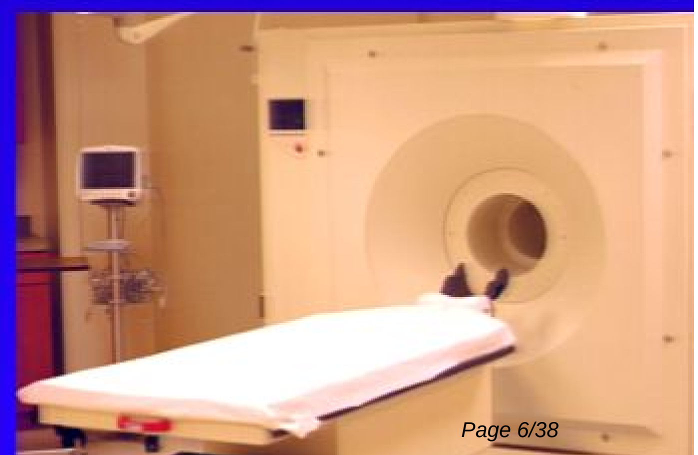
-

PET: Introduction

- Basic principles:
  - Inject radioactive substance (***radiotracer***) into subject
  - Substance accumulates in specific parts of the body
  - Emitted photons are detected and made into images

- PET = Positron Emission Tomography

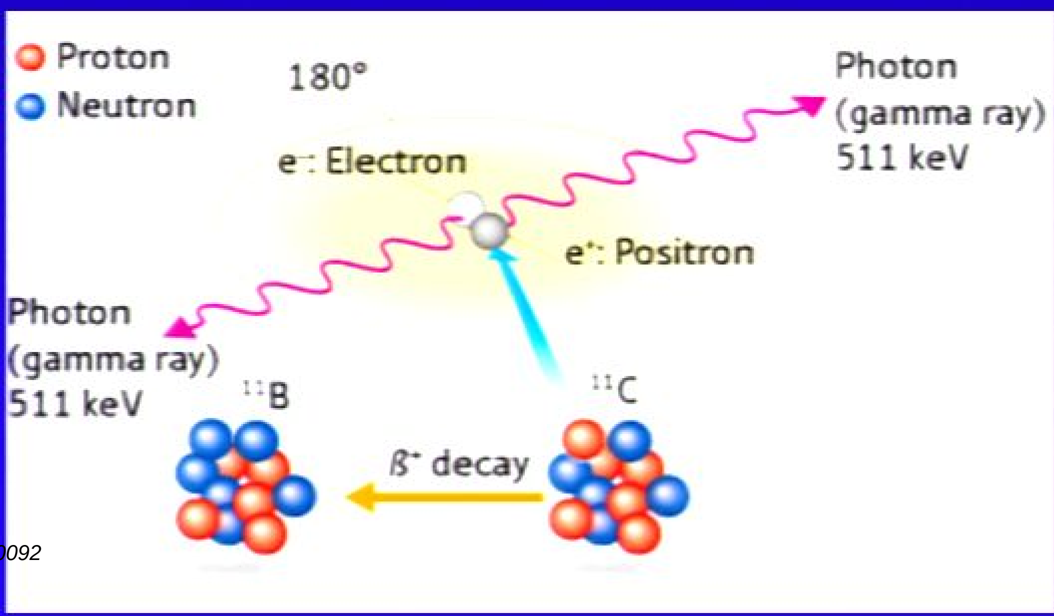
Radiotracer injection



PET Scanner

PET: Introduction

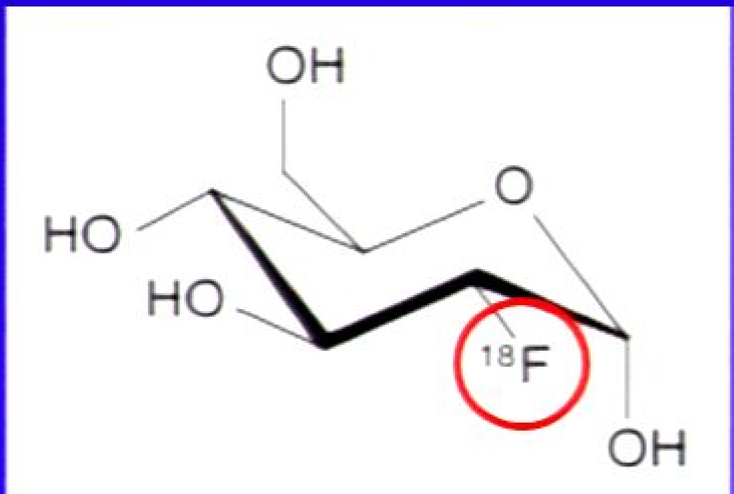
- PET:
  - Uses isotopes that decay mainly through positron emission (beta+ decay)
  - Positron travels through body until it annihilates with an electron and two 511 keV photons are produced



Isotope	Max. e+ Range	½ life
^{11}C	4.1 mm	20.4 min
^{15}O	5.4 mm	2 min
^{18}F	2.4 mm	110 min

PET: Introduction

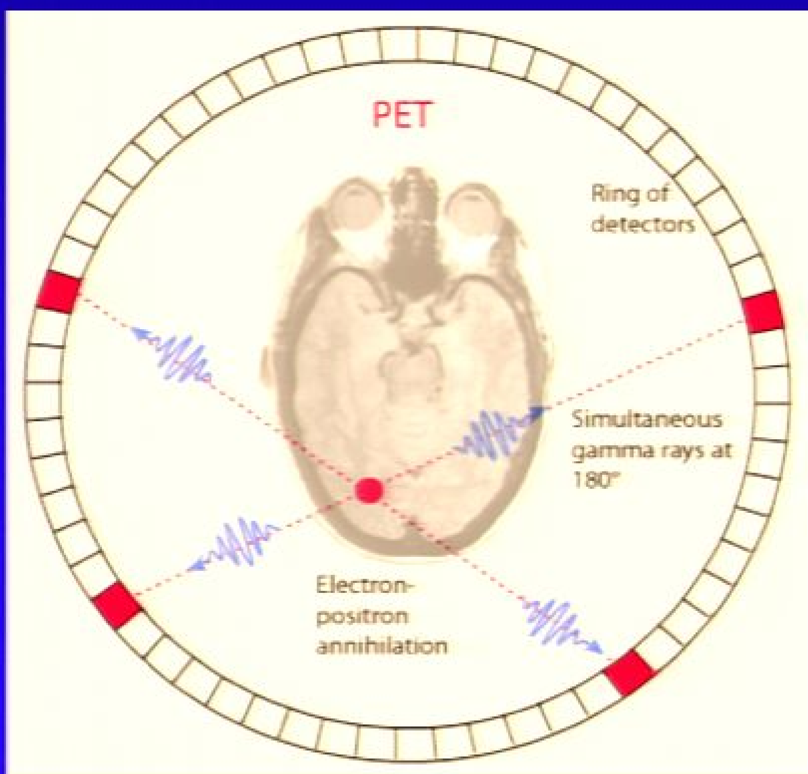
- Radioactive tracers:
  - Substances containing radioactive isotopes
  - Isotopes are combined with other elements or with pharmaceuticals to make radioactive tracers
  - Radiotracers can then accumulate in specific regions of the body

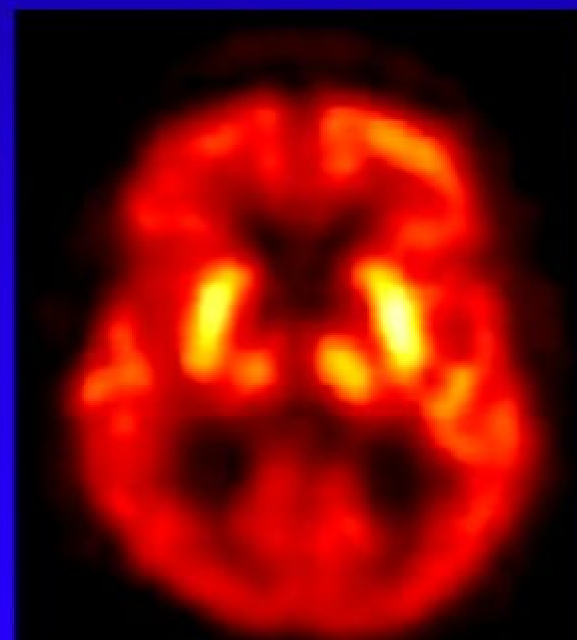


^{18}F-Flurodeoxyglucose (^{18}F-FDG)

PET: Introduction

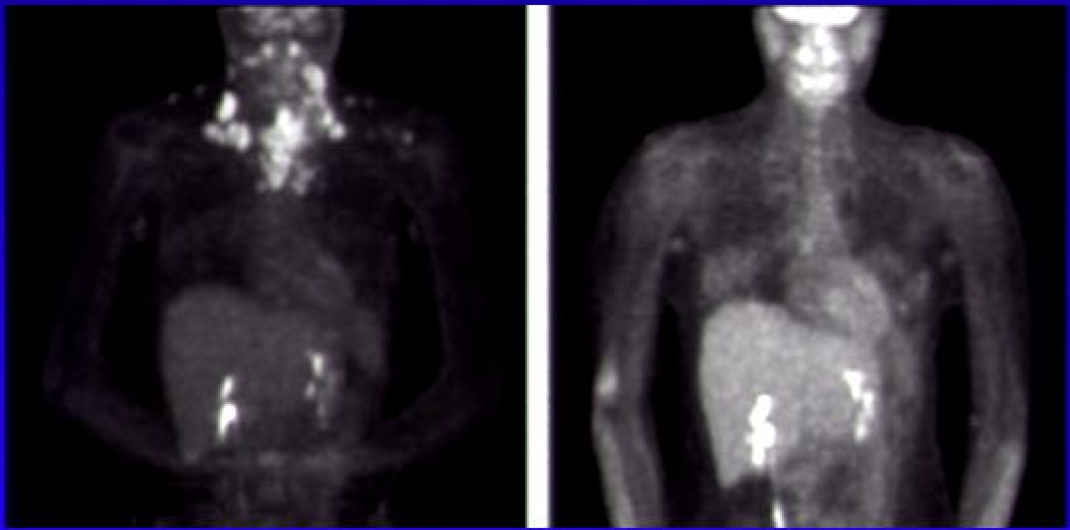
- PET:
  - Pair of photons detected by scintillators and photomultiplier tubes to produce image





PET image

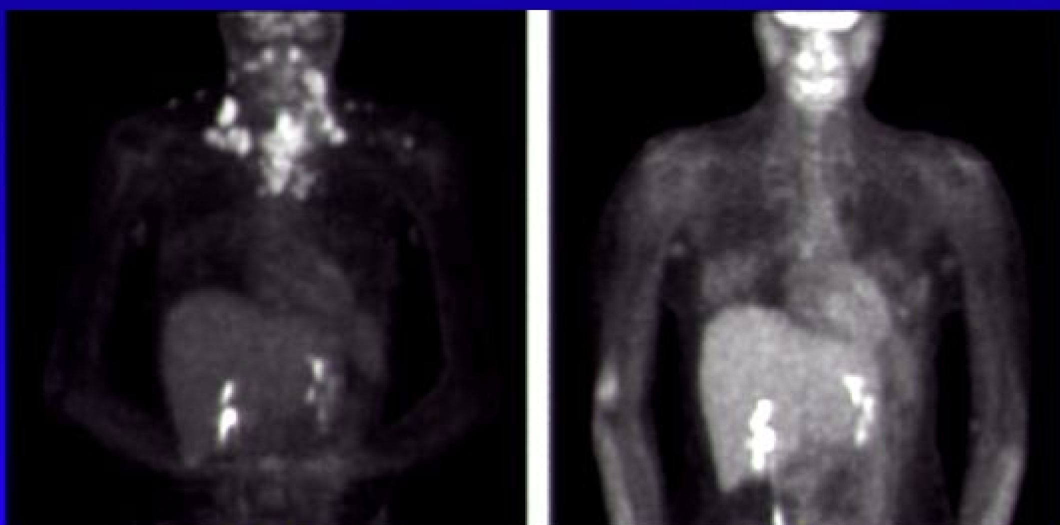
PET: Introduction



Before chemotherapy

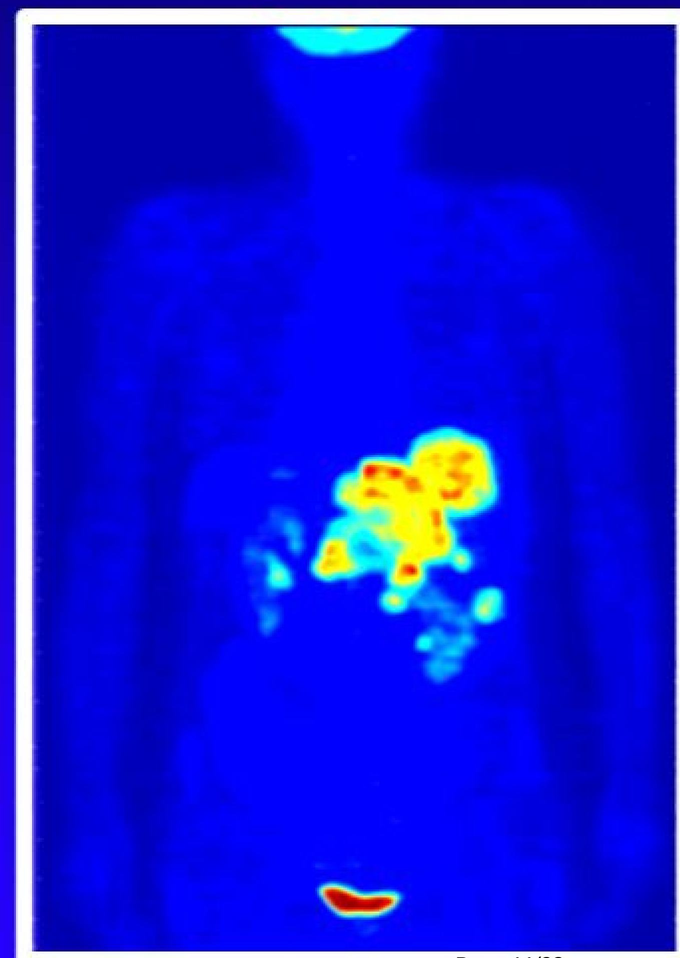
After chemotherapy

PET: Introduction



Before chemotherapy

After chemotherapy



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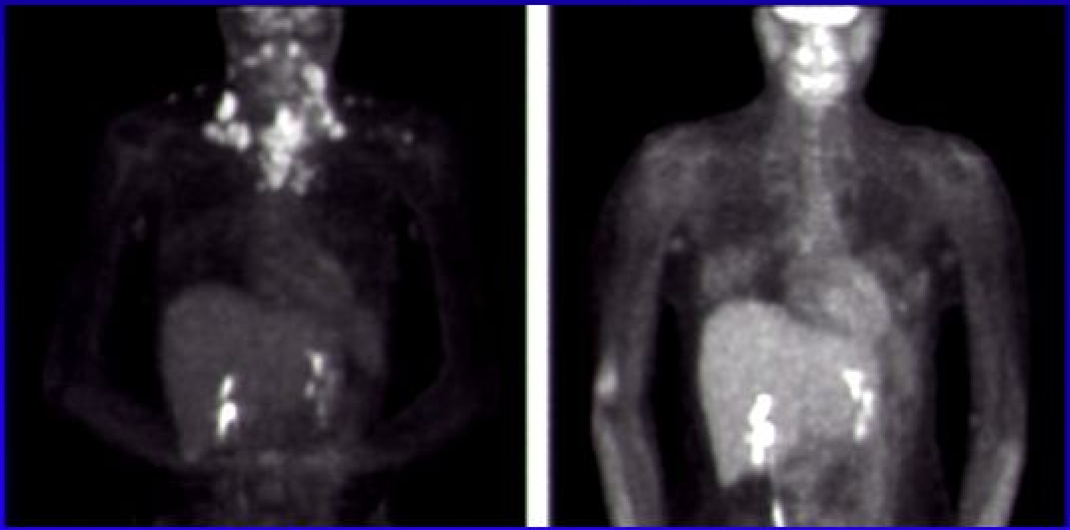

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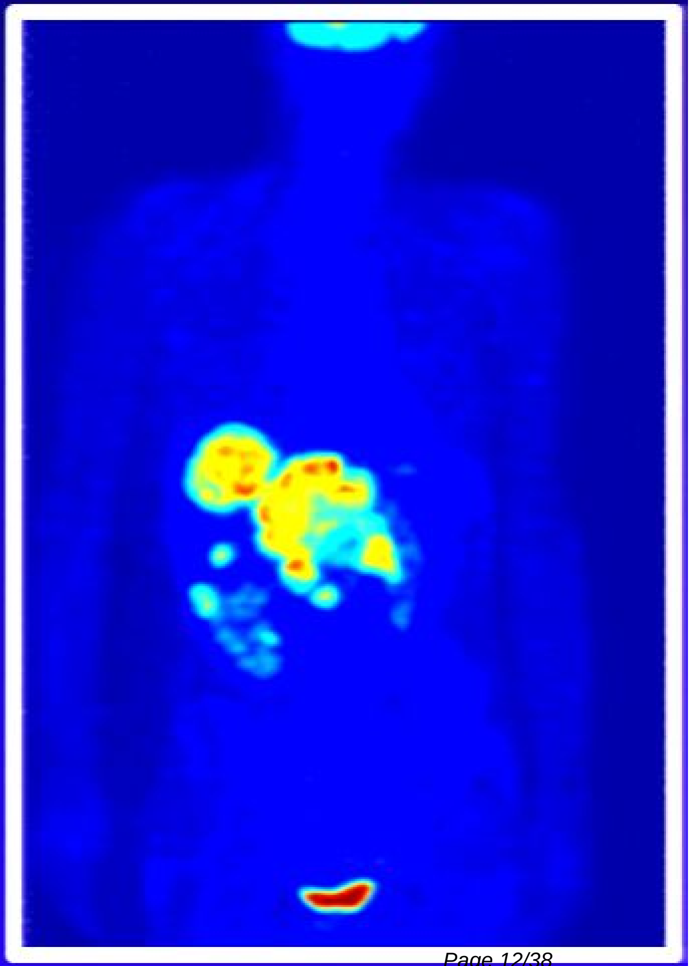
After chemotherapy



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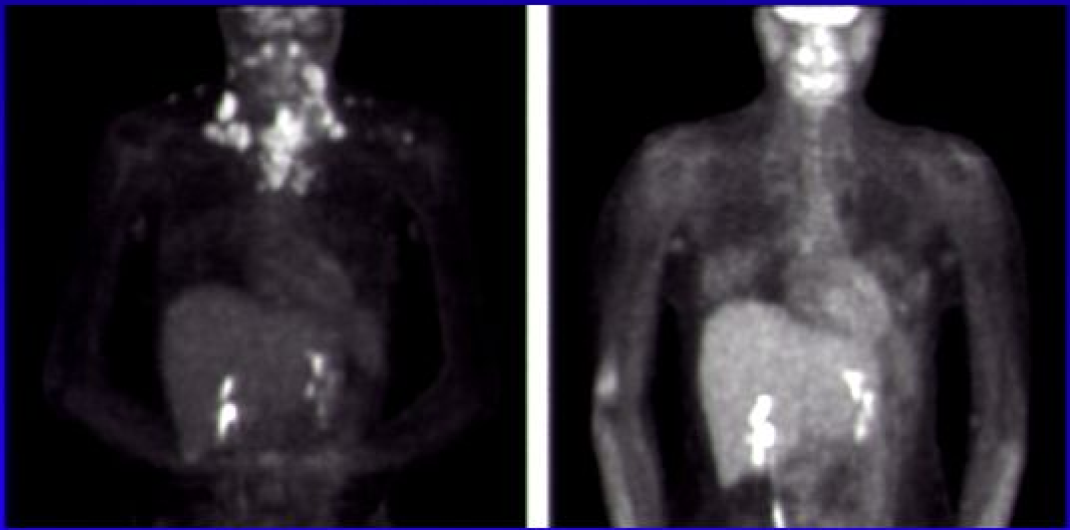

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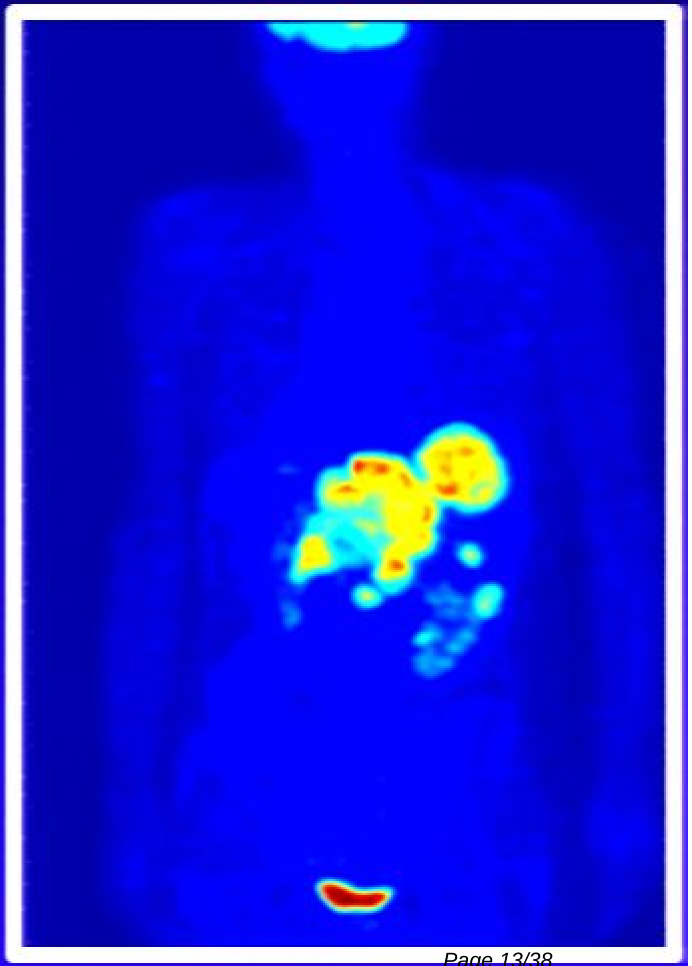

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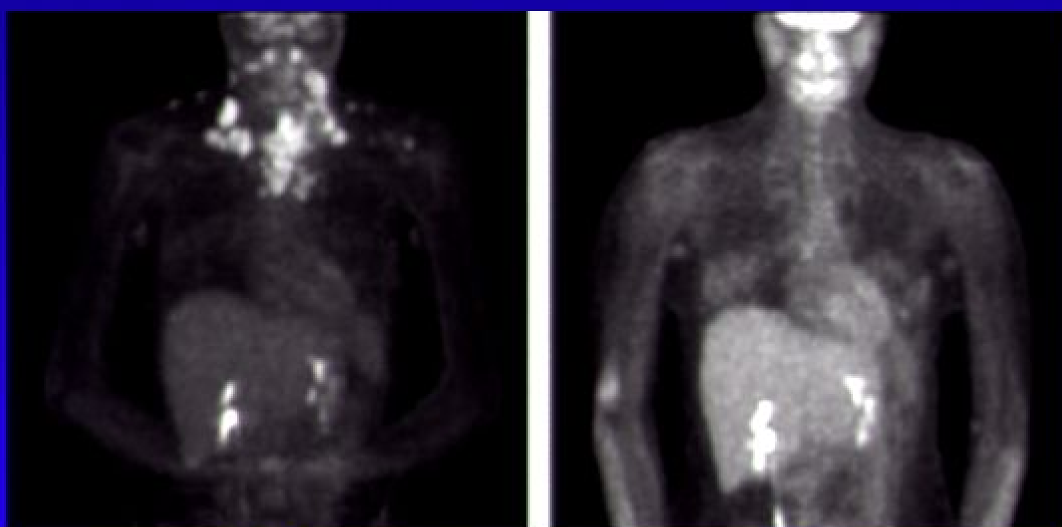

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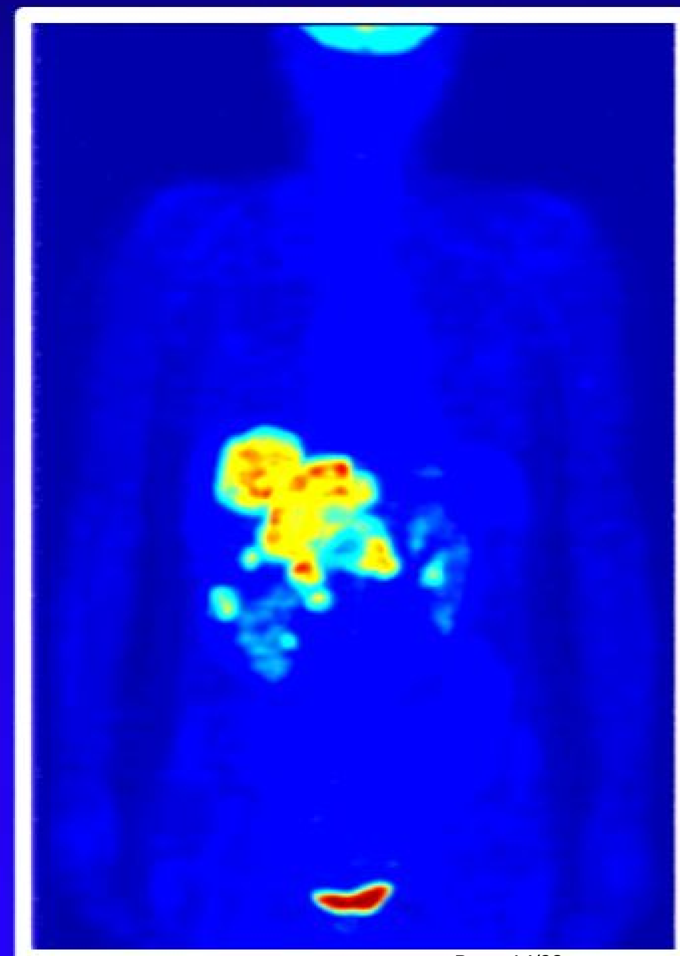
After chemotherapy



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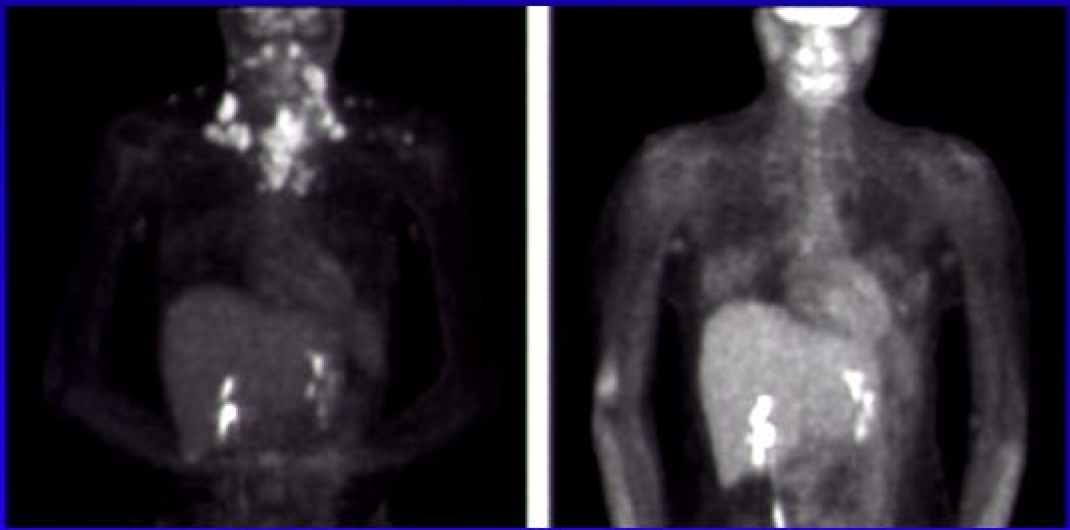

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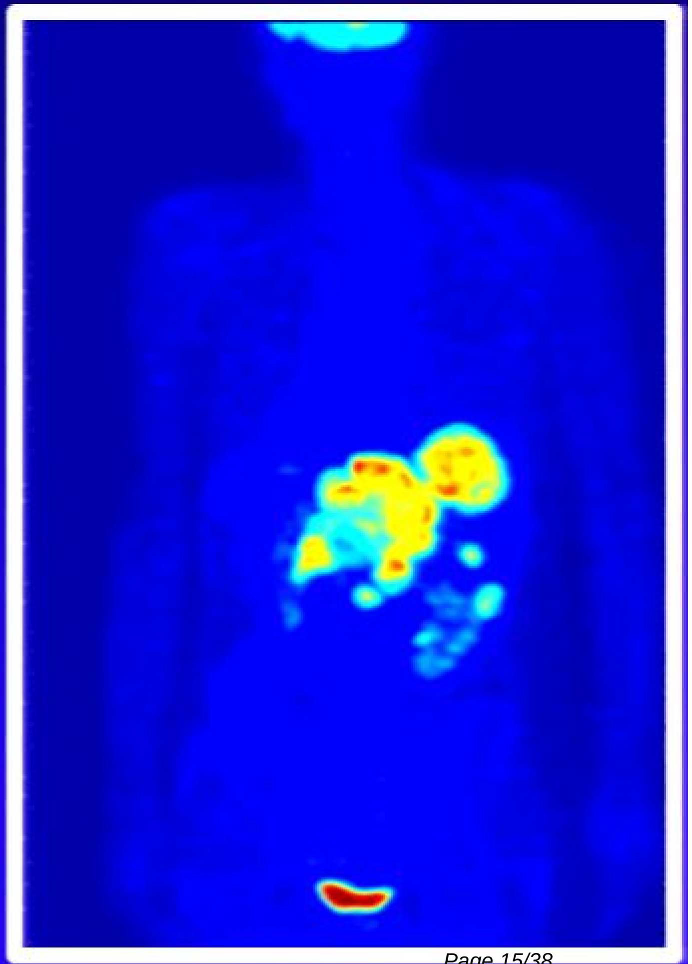

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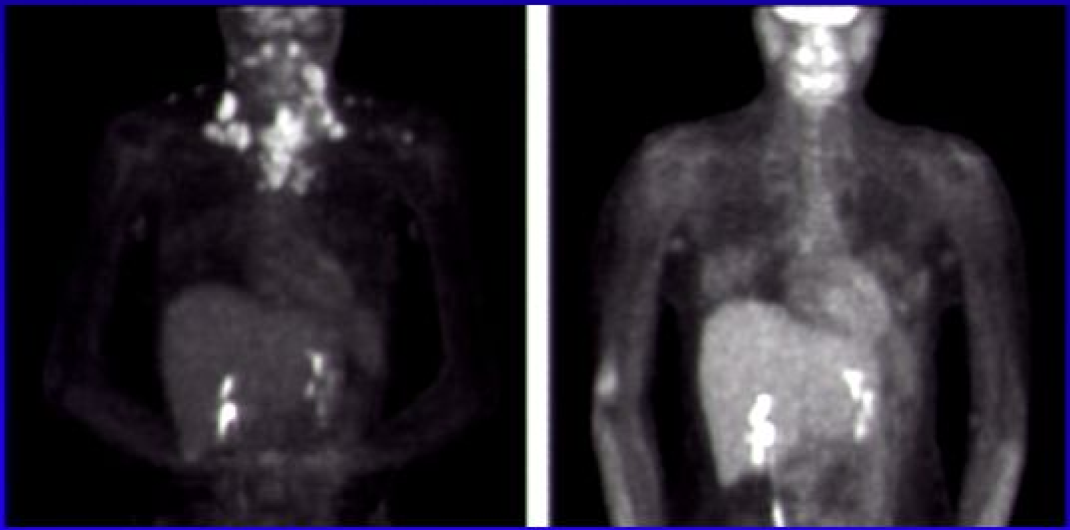

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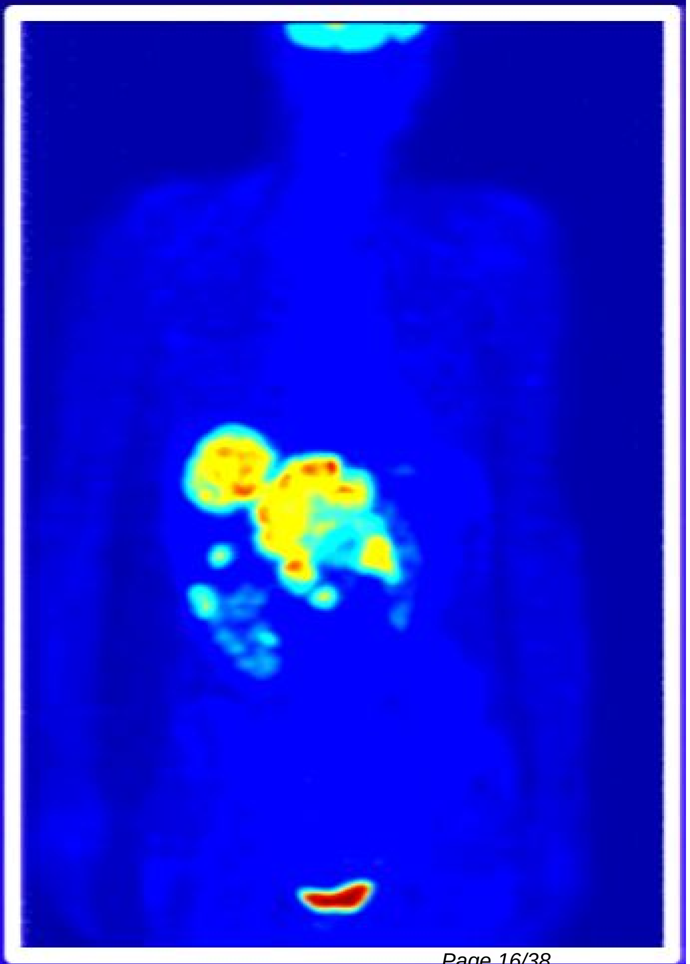

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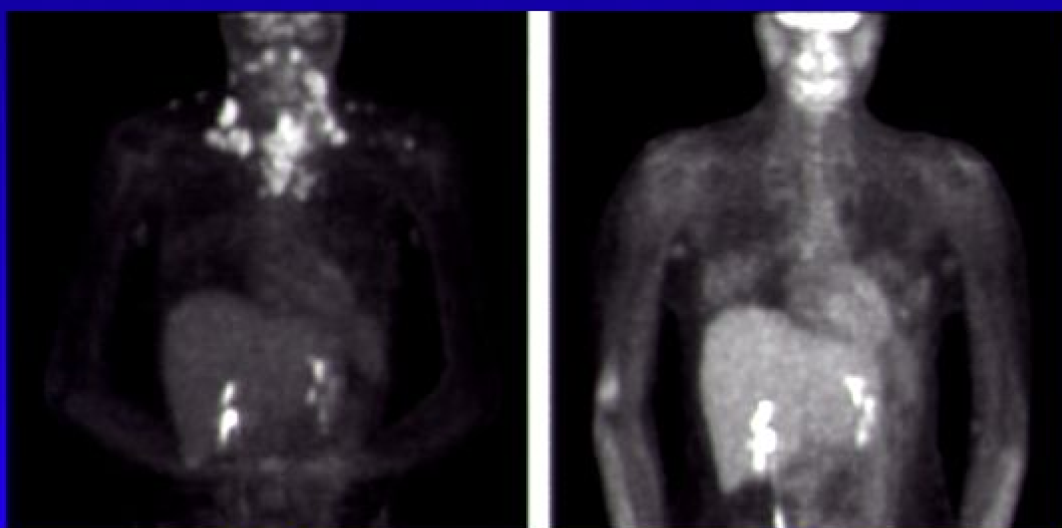

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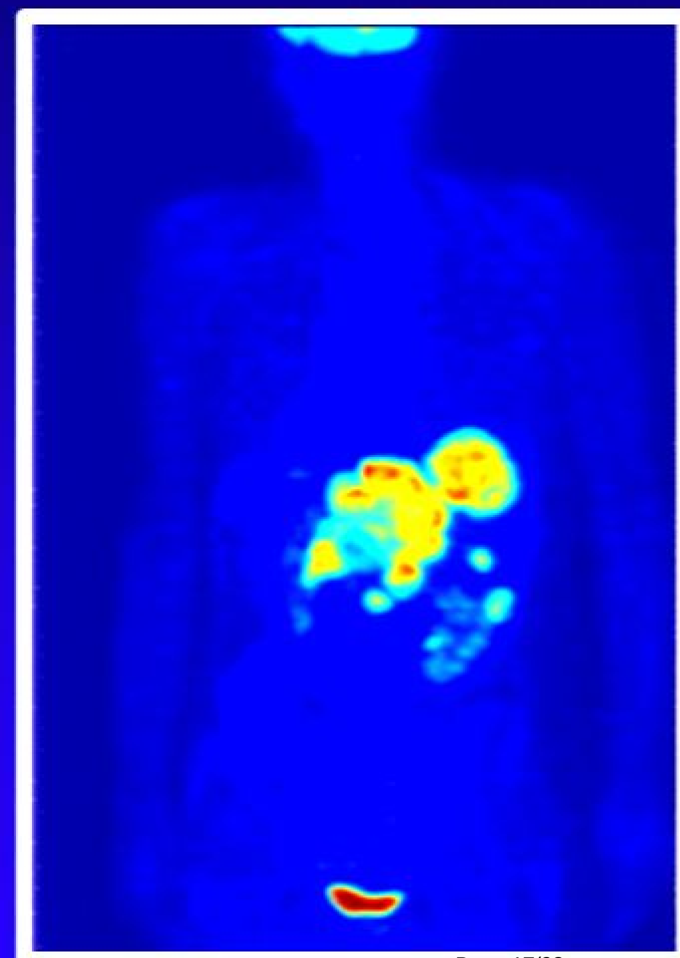
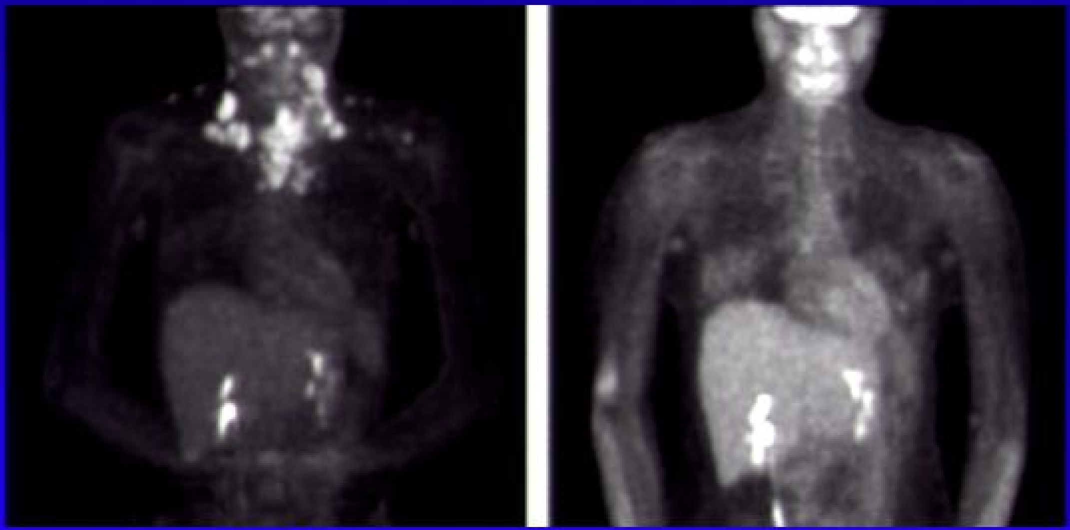


PET: Introduction



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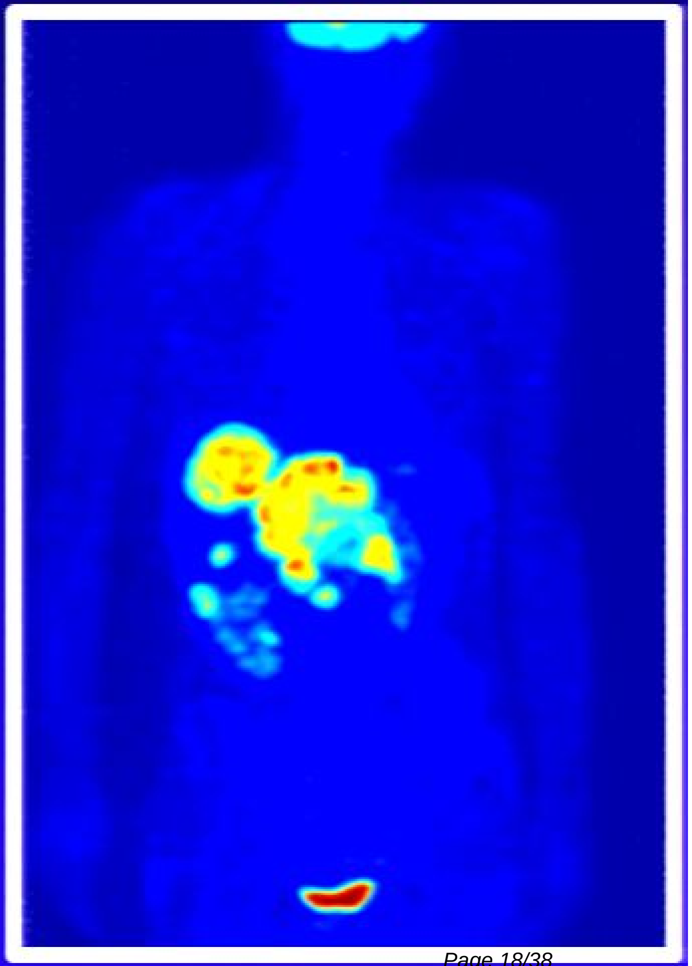
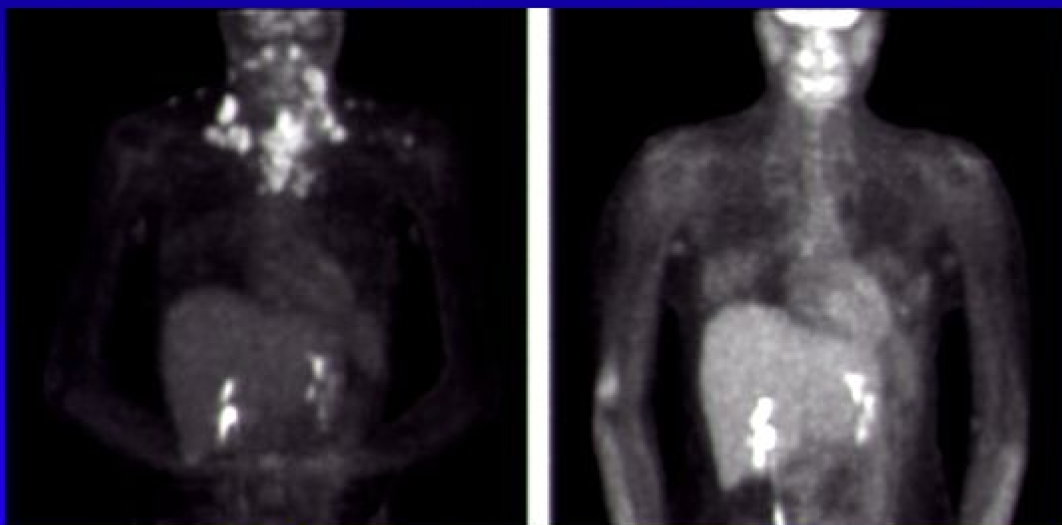
After chemotherapy



PET: Introduction



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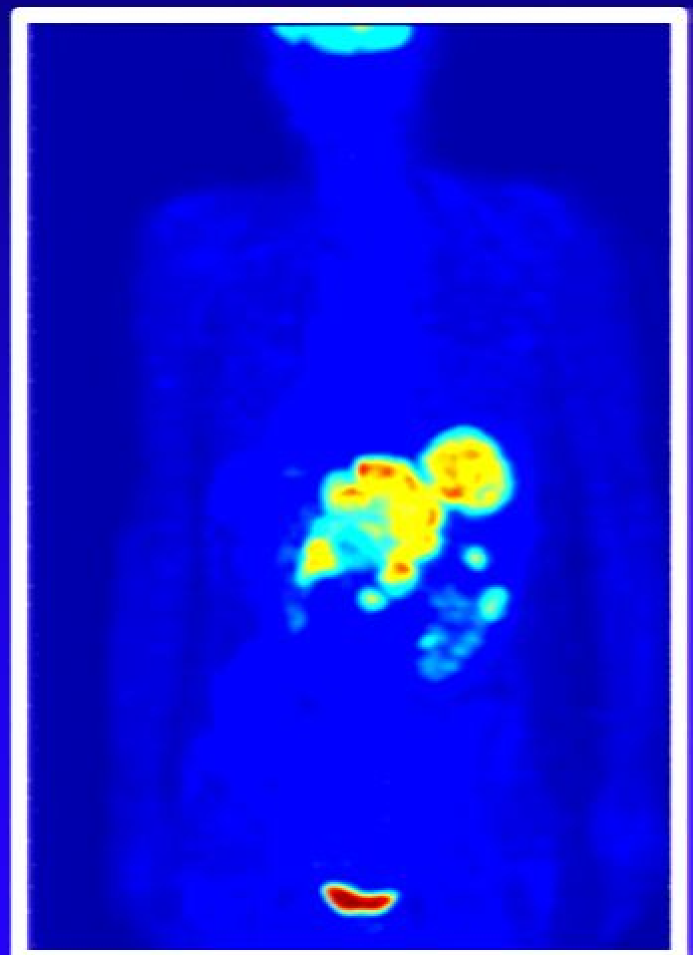
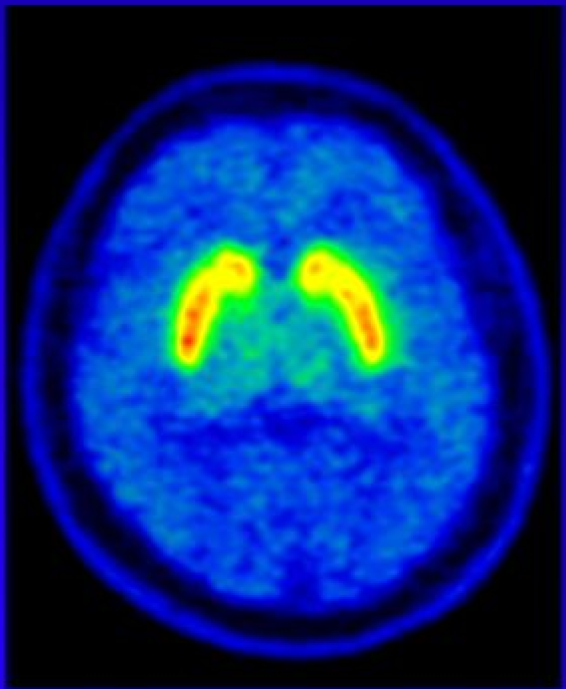


PET: Applications

- Brain imaging (neuroimaging):
  - Uses radiotracers that are associated with specific brain structures/functions



Healthy

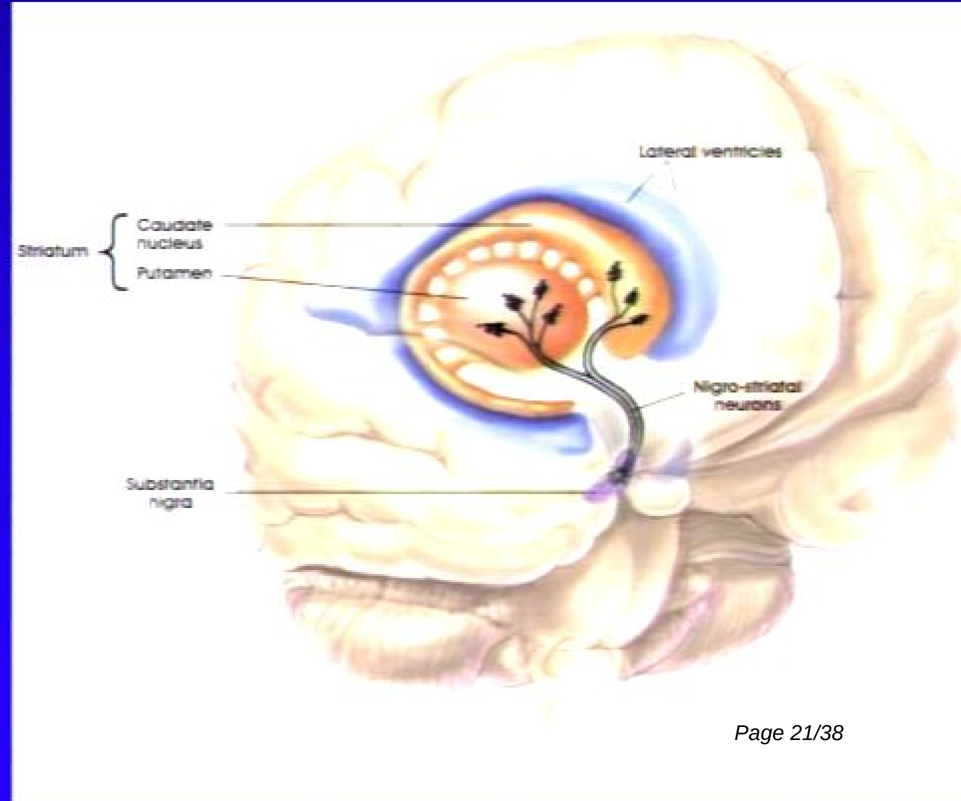
^{18}F-Fluoro-L-dopa PET:

- Simulates the neuro-transmitter dopamine.
- Dopamine is used to regulate movements, motivation, reward, learning, etc.

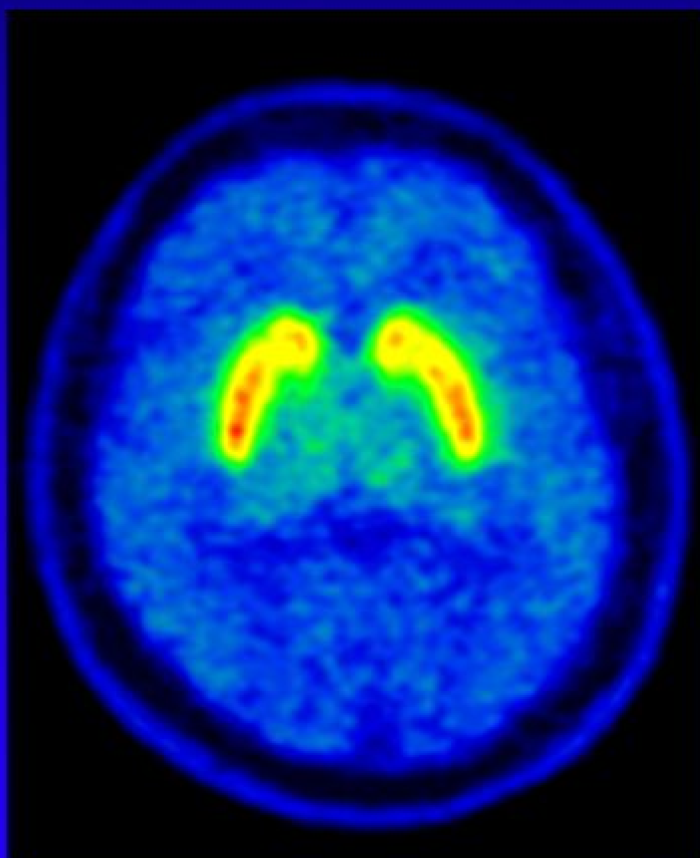
Parkinson's Disease (PD)

- Degenerative neurological disease: loss of neurons that produce dopamine.

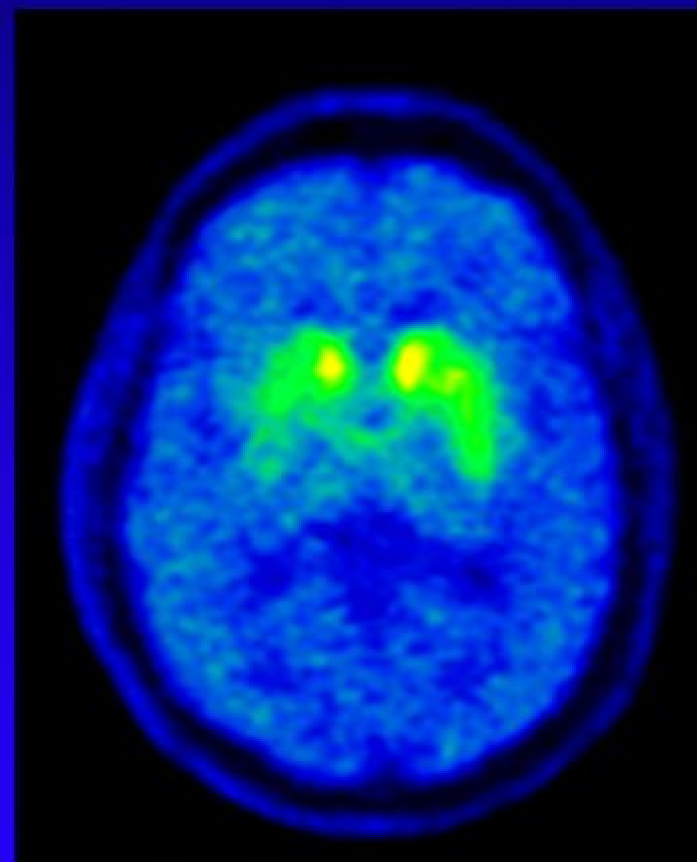
- Loss of dopamine affects the function of the brain structures that are important for movement control.



PET: Applications



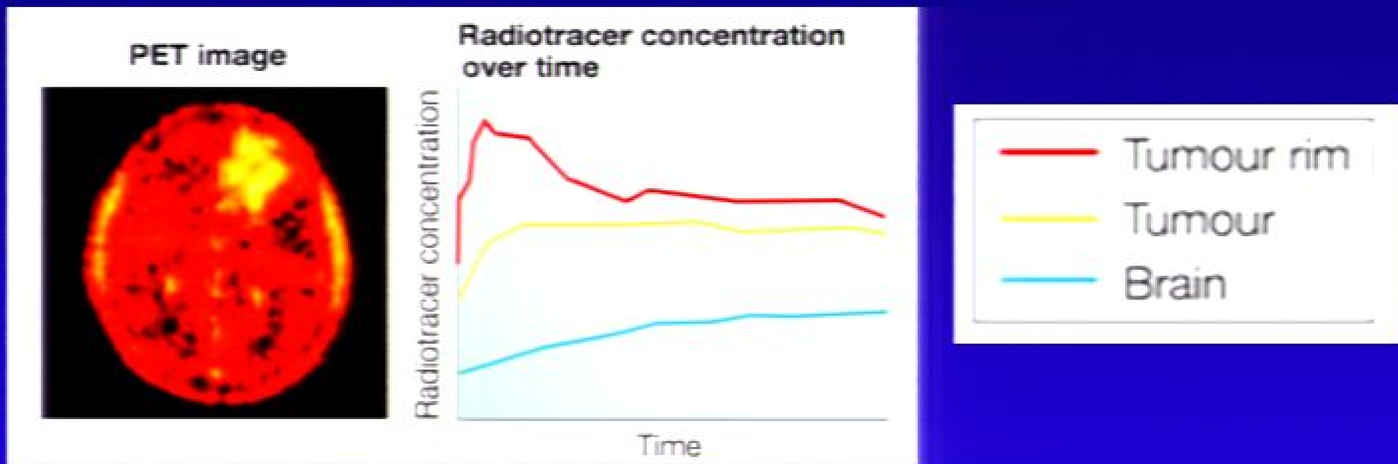
Healthy



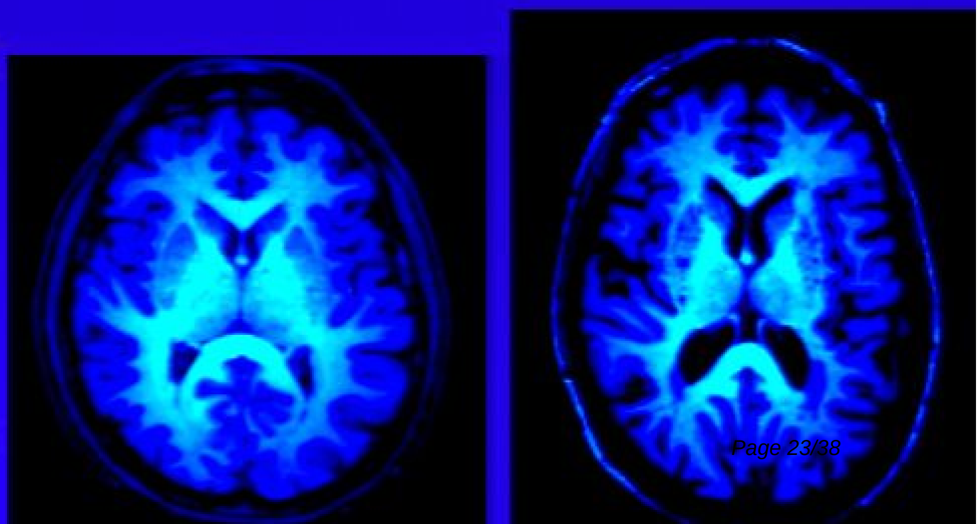
Parkinson's disease

PET: Analysis

- Time analysis: done routinely

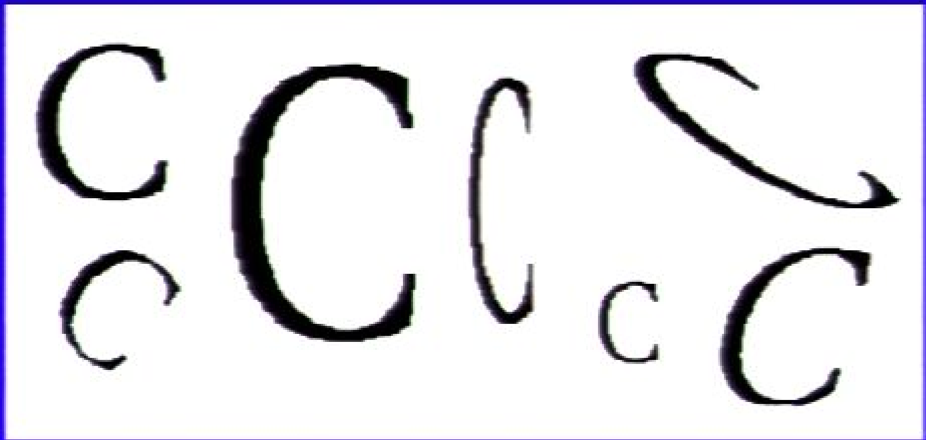


- **Spatial analysis: hasn't been done so far**
  - Everyone's brain is different!
  - Position in scanner is different



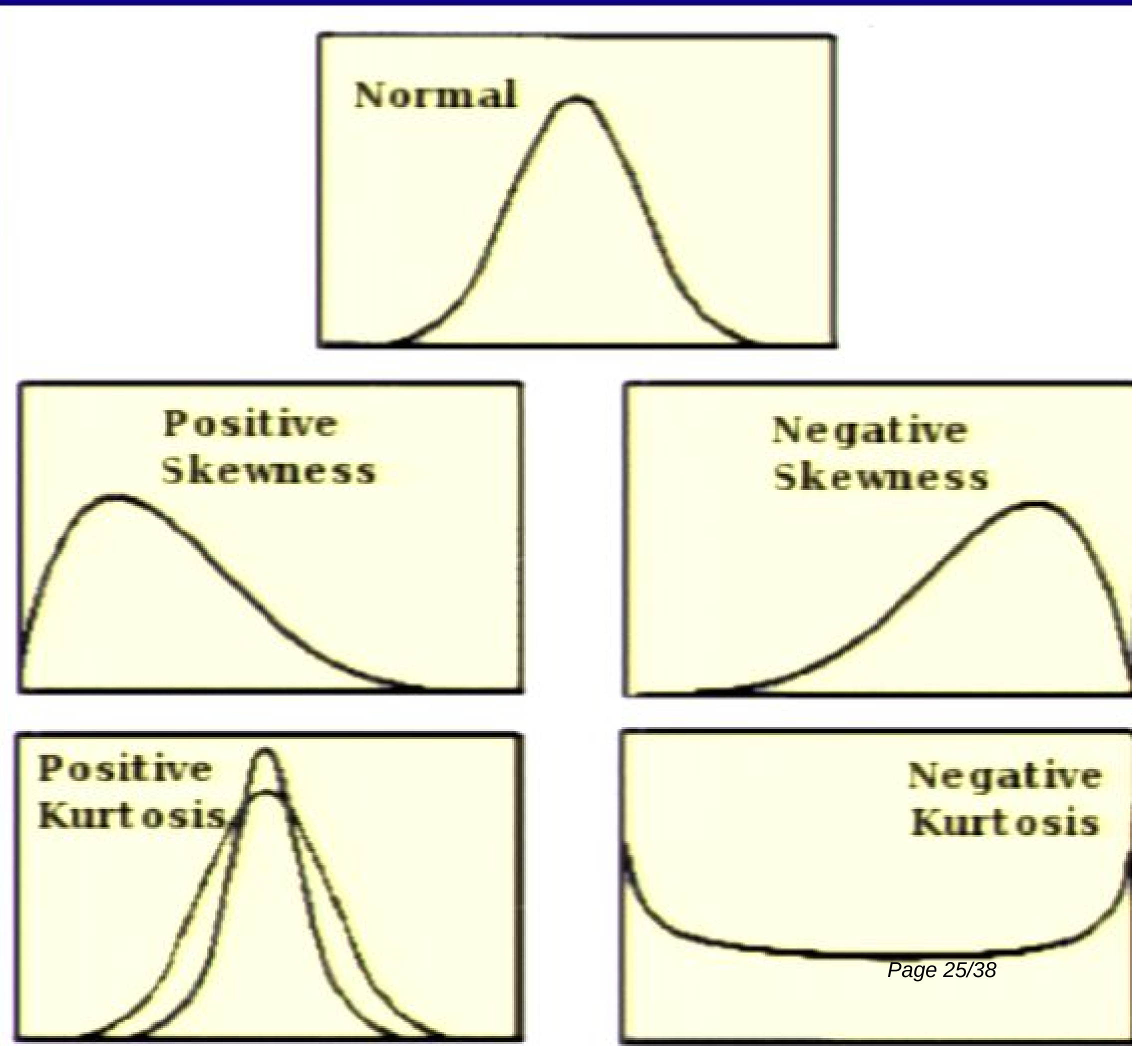
PET: Spatial Analysis

- We want to find a mathematical way of describing the 'shape' or spatial distribution of 2D and 3D objects




Shape descriptors: moment invariants

- Moments
  - Describe shapes of probability density functions, or
  - Describe mass distribution of a body.
  - Examples:
    - Variance = (Var) = (std dev)^2
    - Skewness
    - Kurtosis



3D Moment invariants (3DMIs)

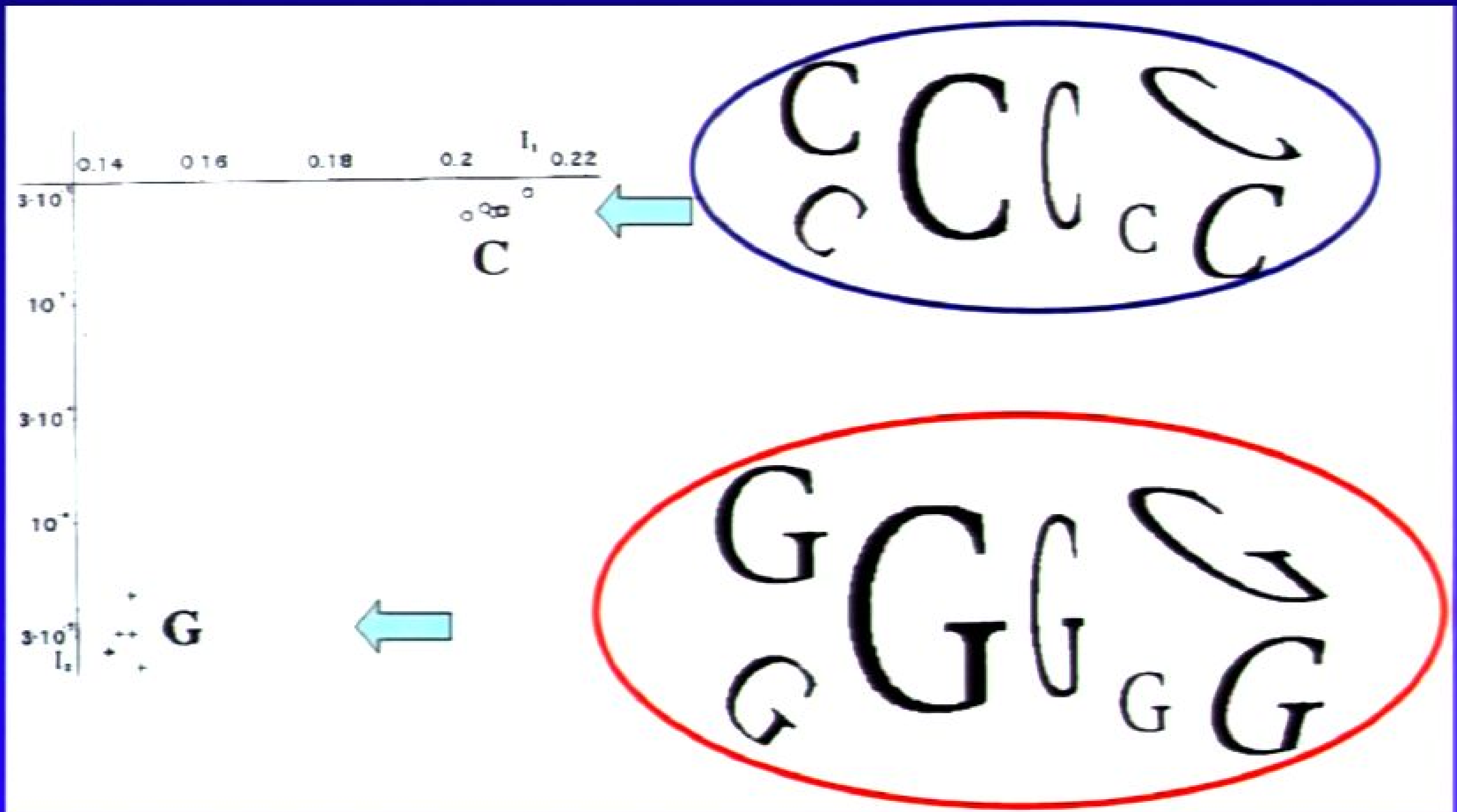
- 3D moment invariants:
  - Combinations of 3D moments
  - Invariant (=*unchanged*) to differences in size, orientation, etc
  - Sample moment invariants:

$$J1=(Var)_x+(Var)_y+(Var)_z$$

$$J2= (Var)_x(Var)_y+(Var)_x(Var)_z+(Var)_y(Var)_z-(Cov)^2_{xy}-(Cov)^2_{xz}-(Cov)^2_{yz}$$

- Lo and Don (1989) derived 12 invariants to rotation in 3D using complex moments and group theory.

3DMIs

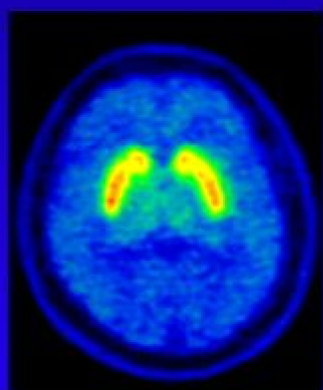


(Flusser et al. 2009)

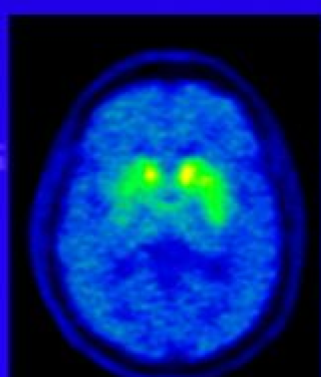
3DMIs: Results

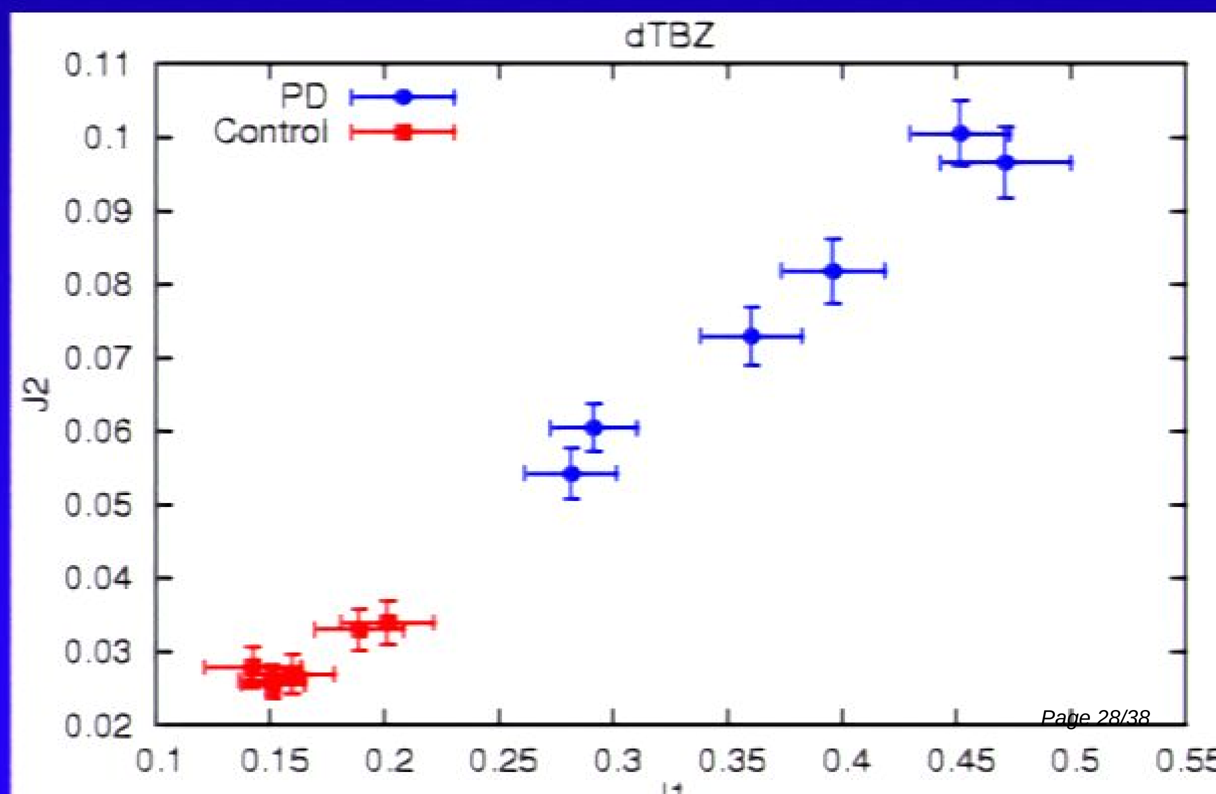
- 3DMIs: measure asymmetries, deviations from symmetric distribution
  - They are able to distinguish between healthy and PD!

Healthy



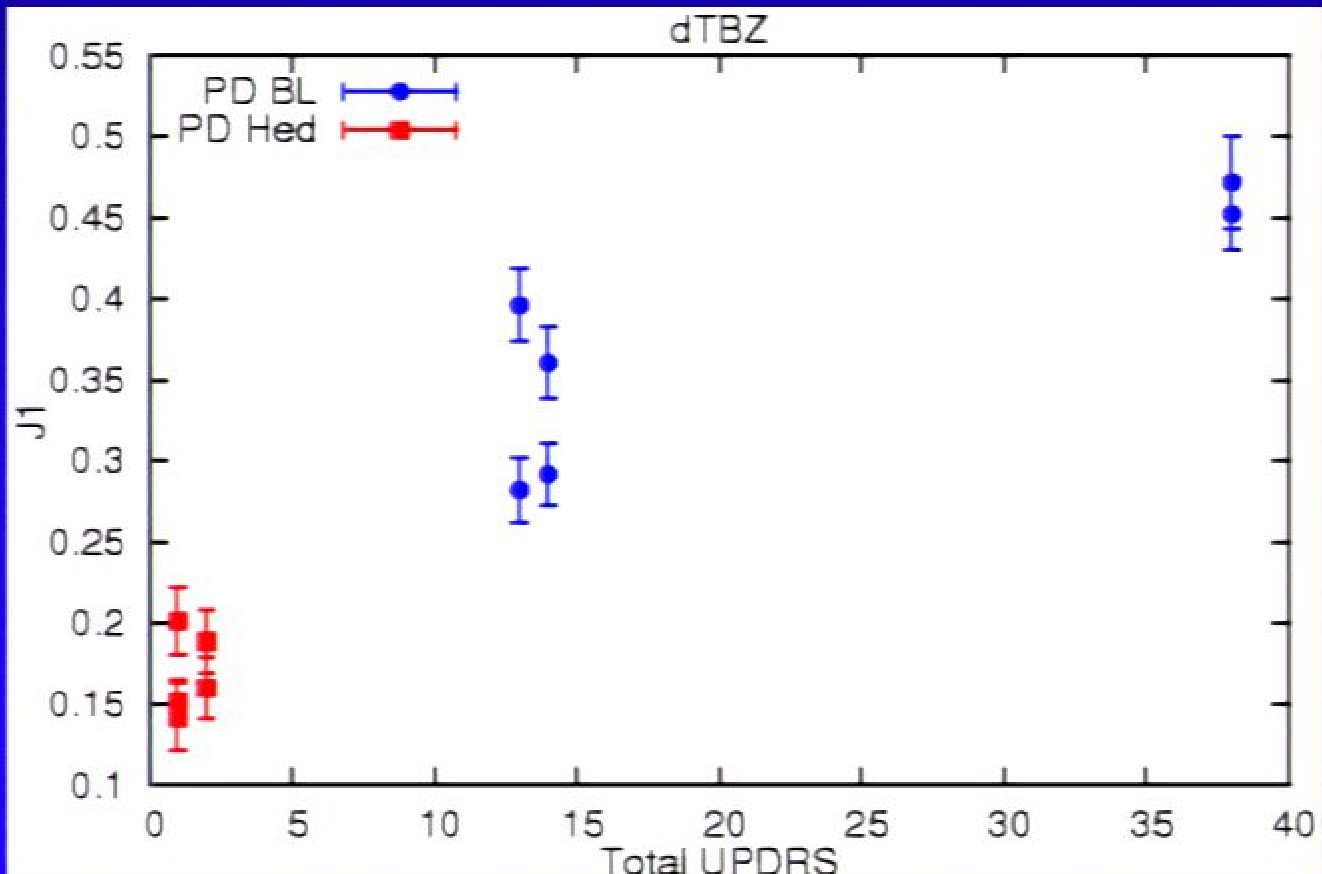
Parkinson's disease





3DMIs: Results

- 3DMIs are able to quantify spatial changes as a function of PD severity!



Summary

- Medical imaging offers a great opportunity to apply physical principles to medical applications.
- We have used 3DMIs to describe the spatial distribution of PET data:
  - We are able to distinguish between healthy and PD subjects.
  - We are able to track the severity of the disease.

Future Work

- Things to work on:
  - Characterize the method further.
  - Apply to other diseases/datasets.
  - Explore other applications: shorten scan time, assess treatment effectiveness, etc...

References

Flusser, J., Suk, T. and Zitova, B. (2009) “Moments and Moment Invariant in Pattern Recognition”. Sussex, UK: John Wiley & Sons.

Lo, C.-H. and Don, H.-S. (1989). “3-D moment forms: Their construction and application to object identification and positioning”. IEEE Transactions on Pattern Analysis and Machine Intelligence, vol. 11, no. 10, pp. 1053−1064.

Thanks....

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Stephan Blinder
Ryan Thomson

UBC - TRIUMF
Positron Emission Tomography

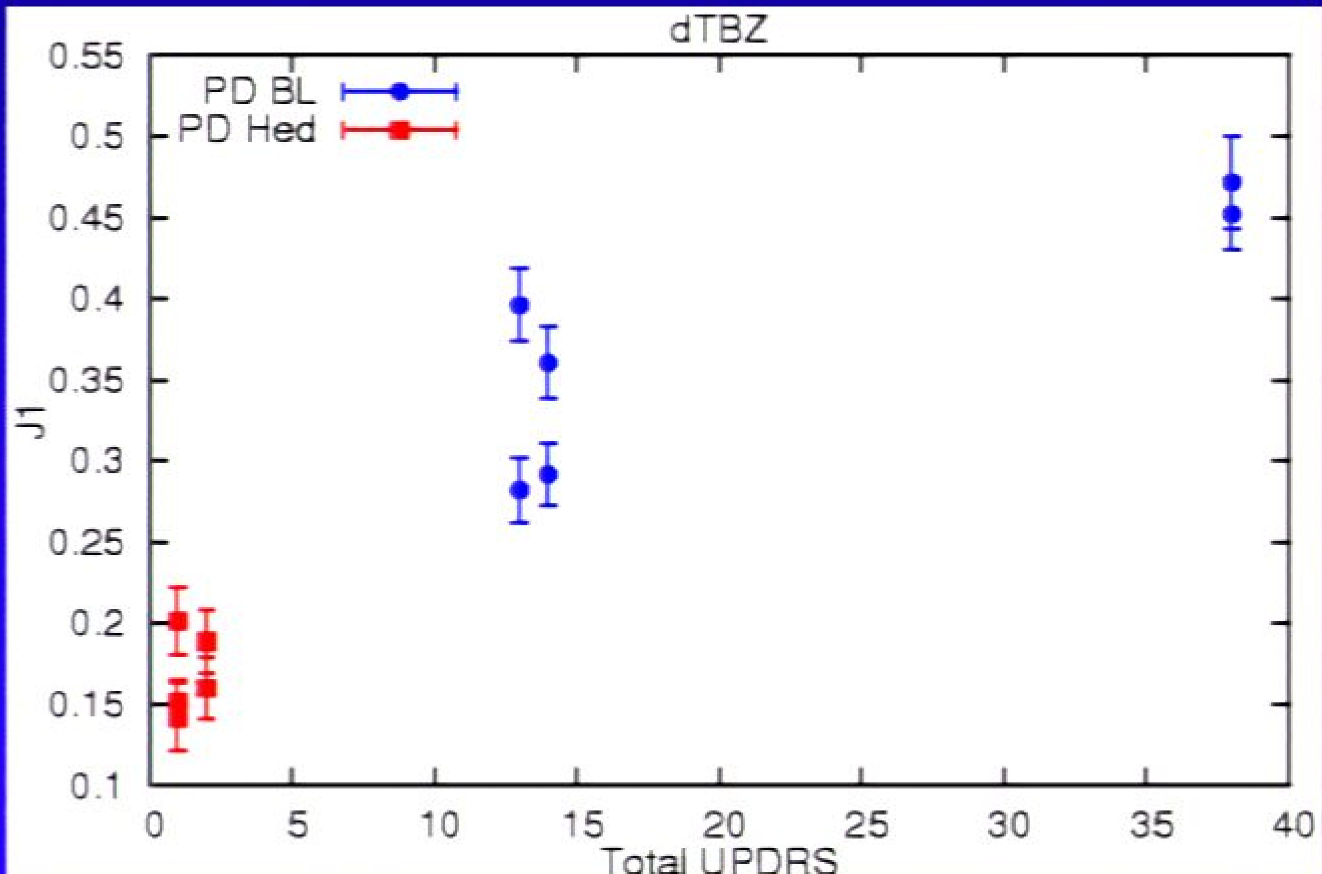
Pacific Parkinson's Research Centre, UBC

Martin McKeown
Silke Cresswell
Nicole Heffernan
Jess McKenzie

UBC
Pacific Parkinson's Research Centre
UBC Faculty of Medicine
Vancouver Coastal Health Authority

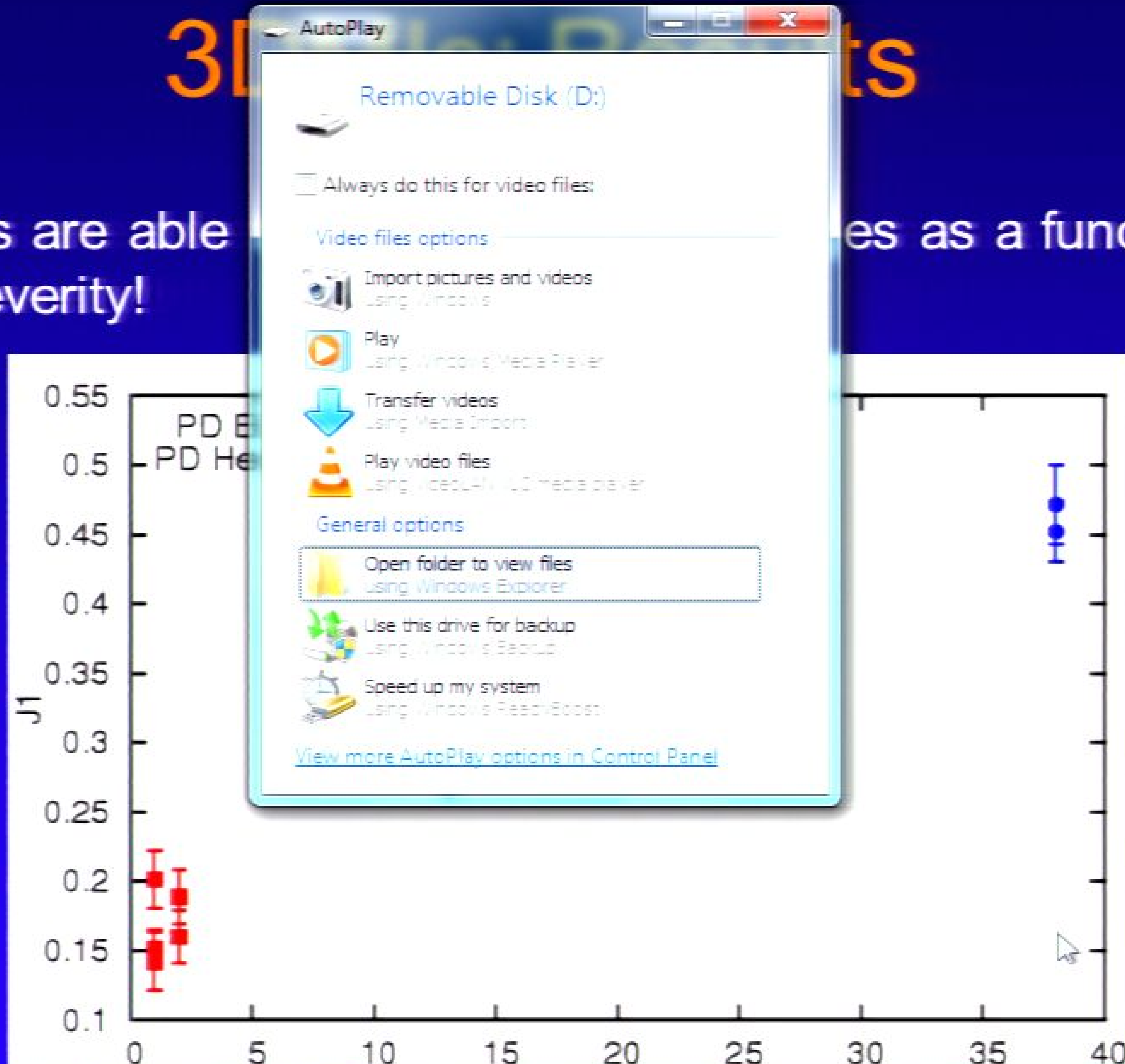
3DMIs: Results

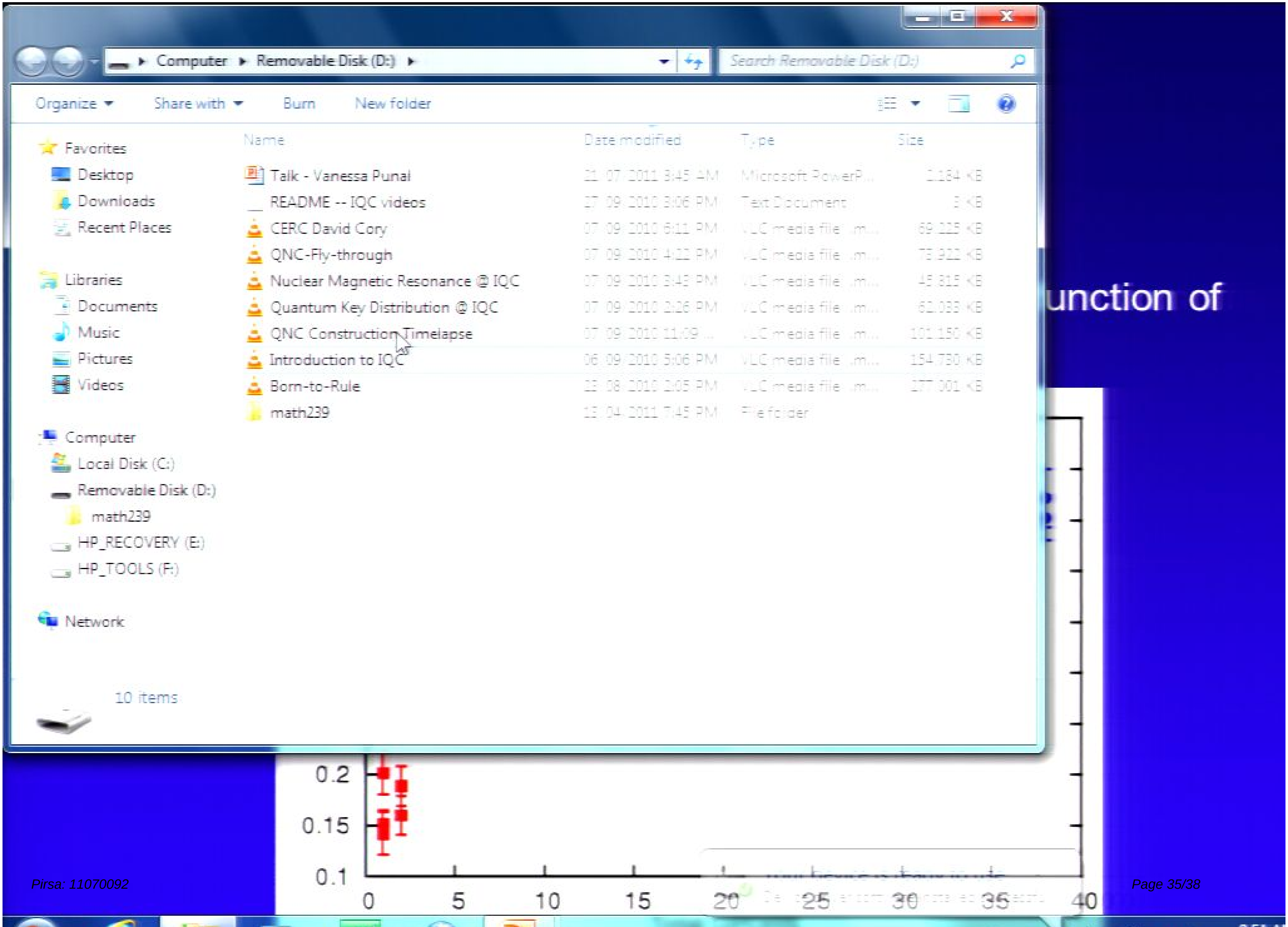
- 3DMIs are able to quantify spatial changes as a function of PD severity!



3D ts

- 3DMIs are able es as a function of PD severity!





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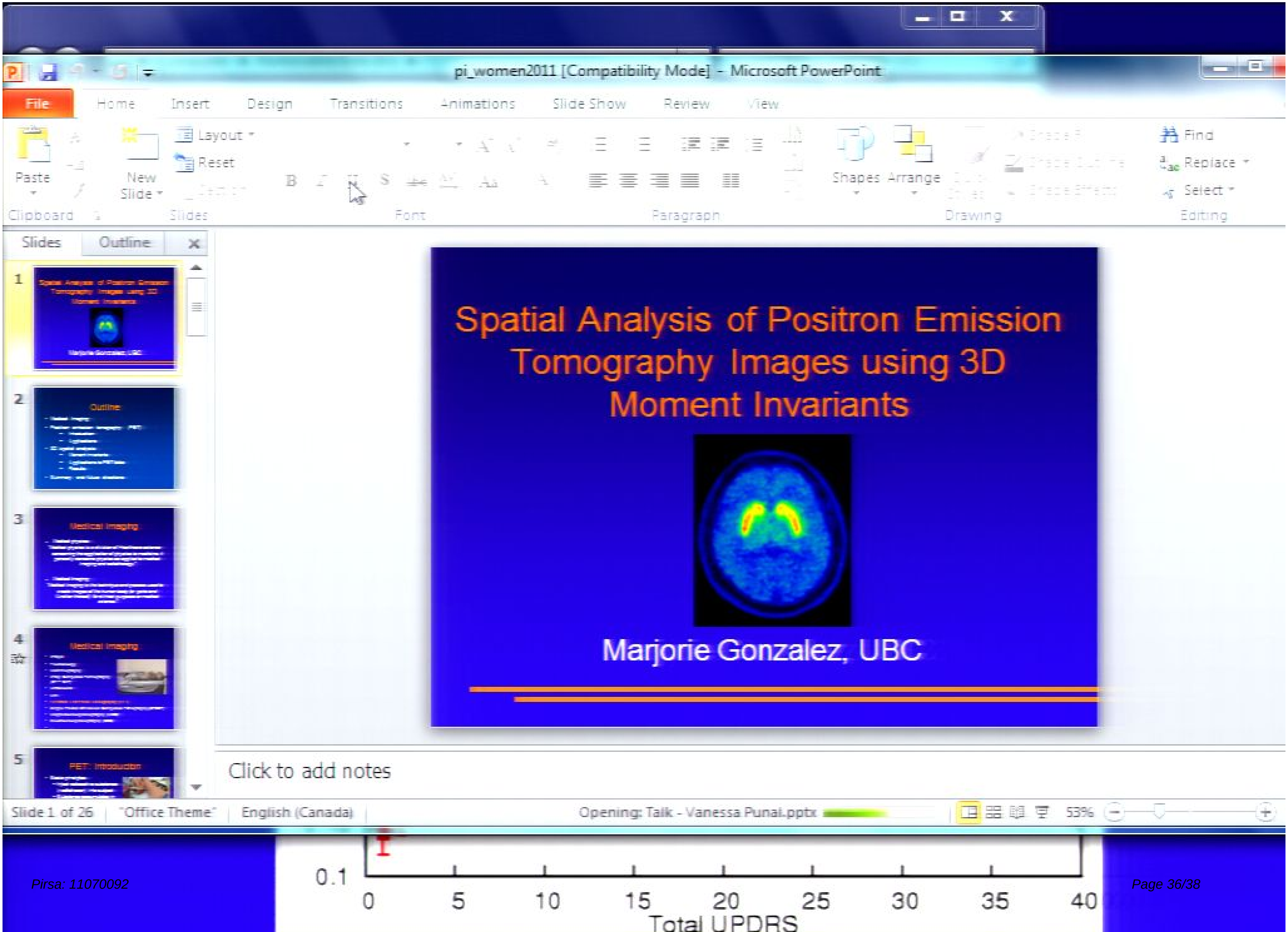
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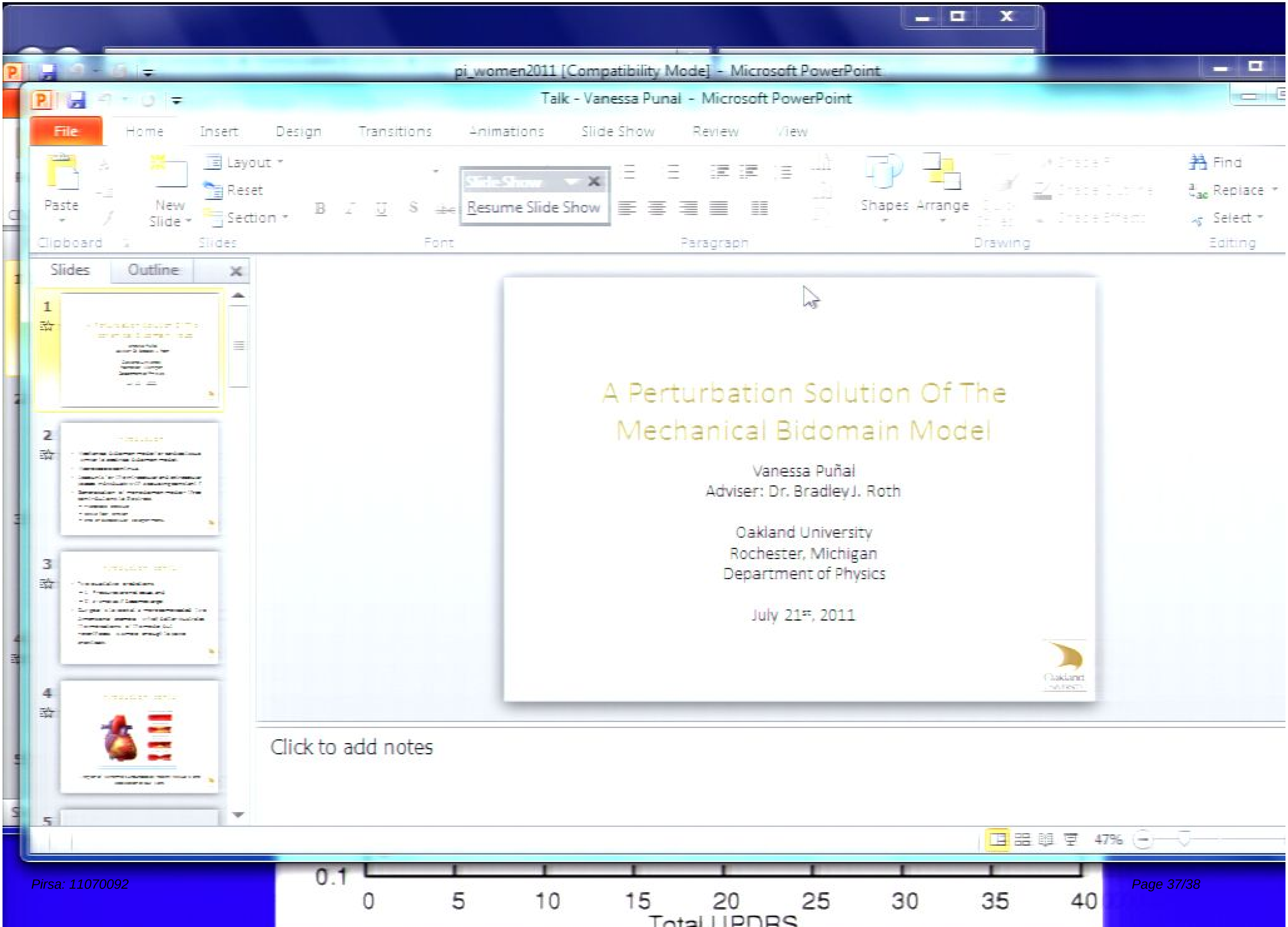
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July 21st, 2011
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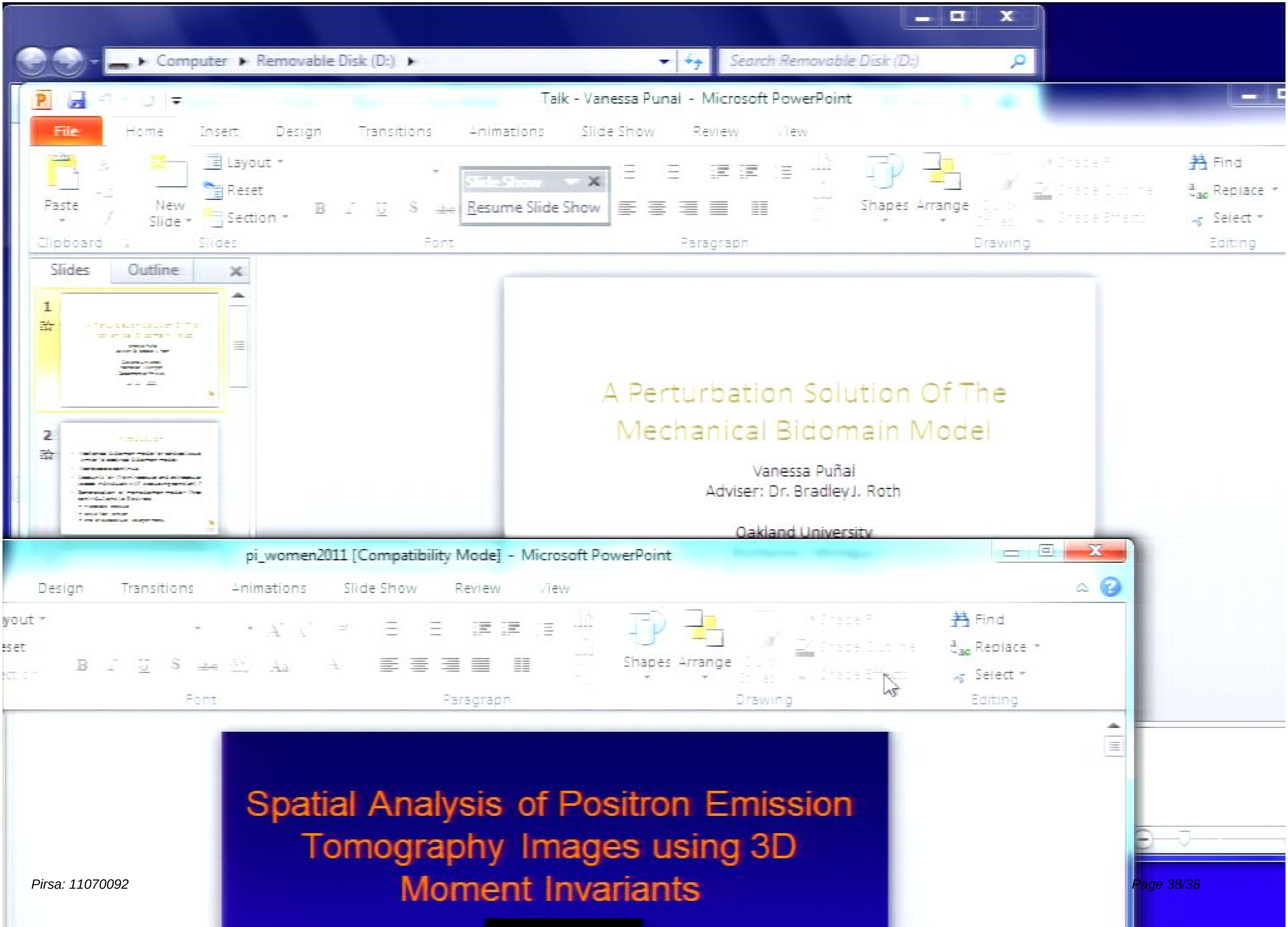
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