

Medical Image Processing and Segmentation (with 3D Slicer)



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Champalimaud
Foundation

Automatic segmentation

- Manual segmentation by physicians is **time-consuming** and subject to **inter-reader variability** and **depends on experience**
- **AI** (in particular, deep learning – deep convolutional neural networks) allows for automatic segmentation – of tumors/lesions, organs, etc.

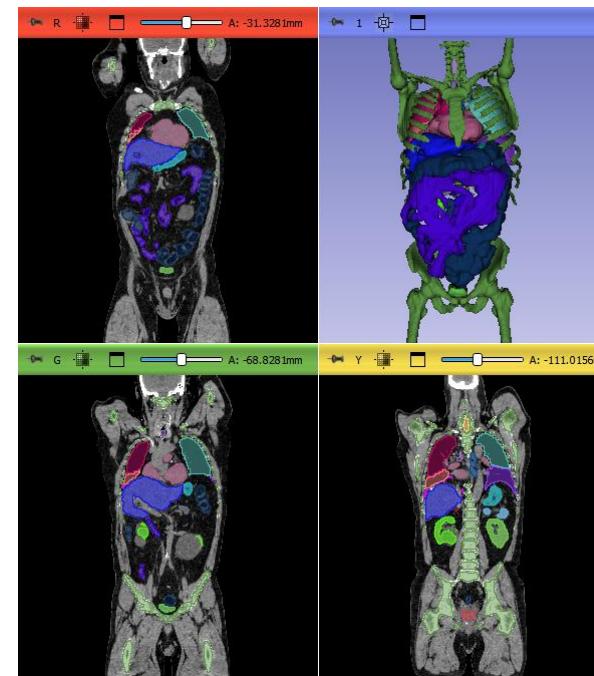
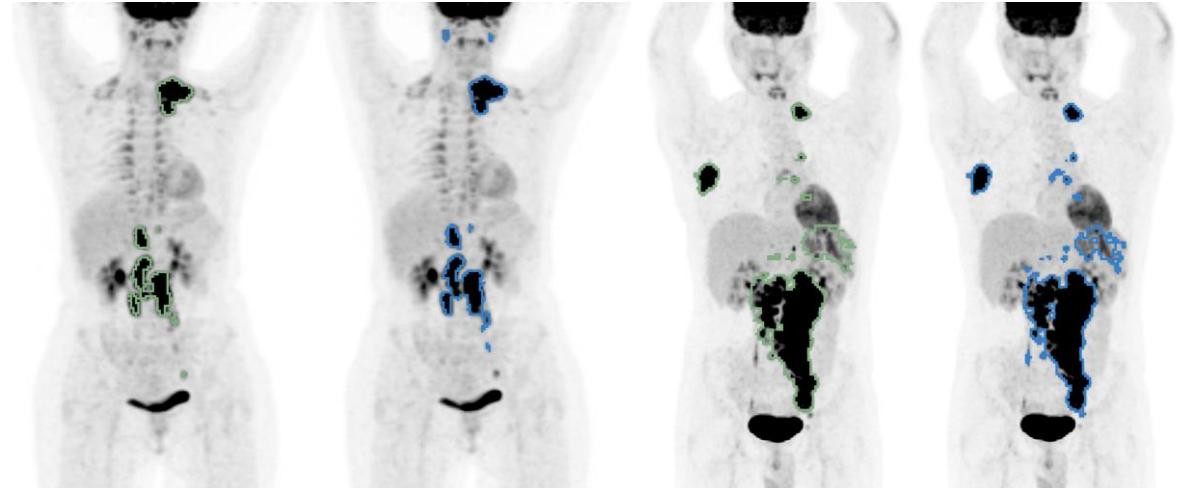
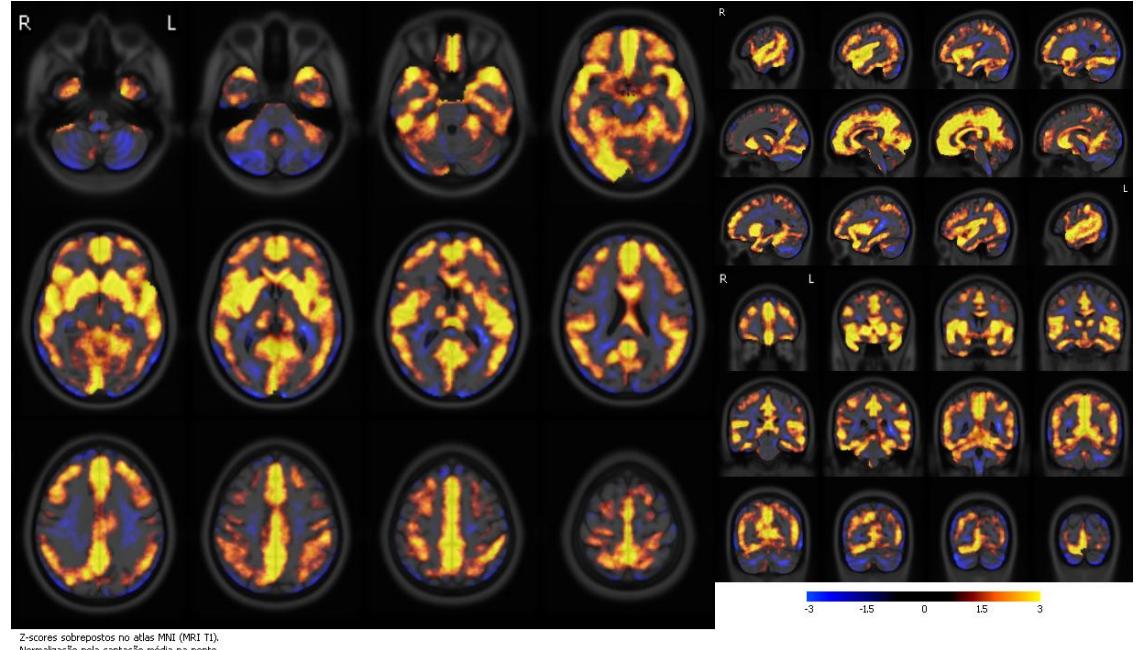
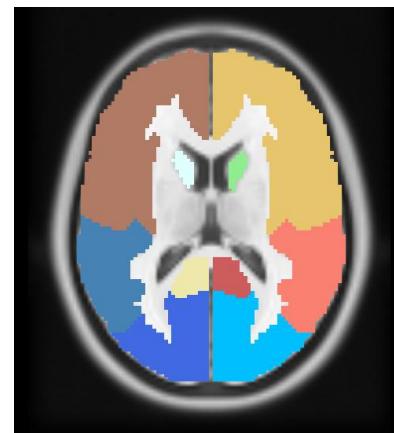


Image quantification

- Functional imaging modalities, such as PET and SPECT, allow for **interpretation in terms of function/activity**
- **Quantification in regions of interest** provides a **robust aid for interpretation**
- **Machine learning classifiers** based on quantitative measures **assist diagnosis**



Região	Doente (MeanSUVR)	Doente (MeanZscore)	Normal (MeanSUVR)
Frontal_esquerdo	1.39	1.32	1.12
Frontal_direito	1.43	1.32	1.15
Parietal_esquerdo	1.40	1.26	1.09
Parietal_direito	1.40	1.33	1.10
Ocipital_esquerdo	1.34	0.89	1.16
Ocipital_direito	1.34	1.11	1.13
Temporal_esquerdo	1.41	1.69	1.08
Temporal_direito	1.40	1.52	1.11
Putamen_esquerdo	1.84	4.75	1.08
Putamen_direito	1.89	4.61	1.13



Machine learning classifier: amyloid* positive

* Alzheimer's disease biomarker



Workflow optimization

- Reducing **acquisition duration** – medical image acquisition usually takes (a long) time!!
- AI-based **post-processing** allows for faster acquisitions:
 - **more patients** per day
 - **lower burden** for the patient
 - **lower susceptibility** for motion artifacts



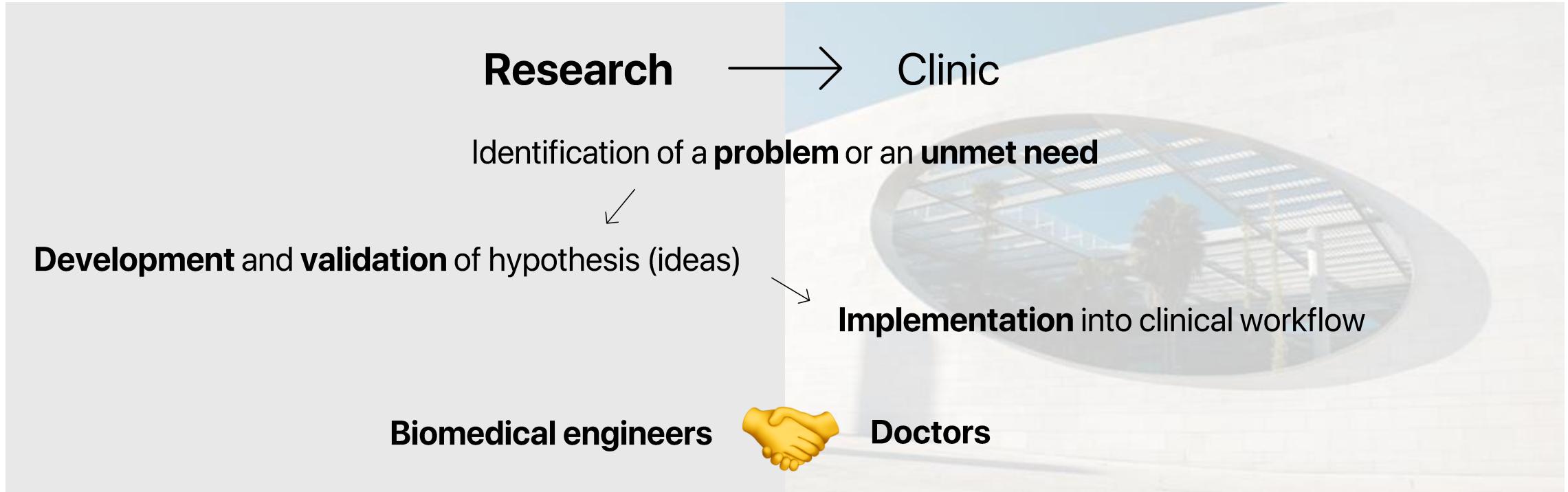
10 s acquisition
(x 10 bed positions)



10 s acquisition
(x 10 bed positions)
+ AI



Our work @ Champalimaud Foundation

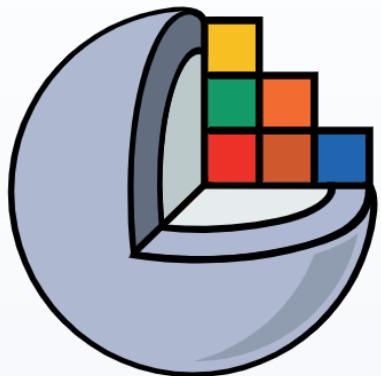


Translational research



Download 3D Slicer

<https://download.slicer.org/>



3D Slicer image computing platform

Download

Documentation

Developers

Training

Forum

LinkedIn

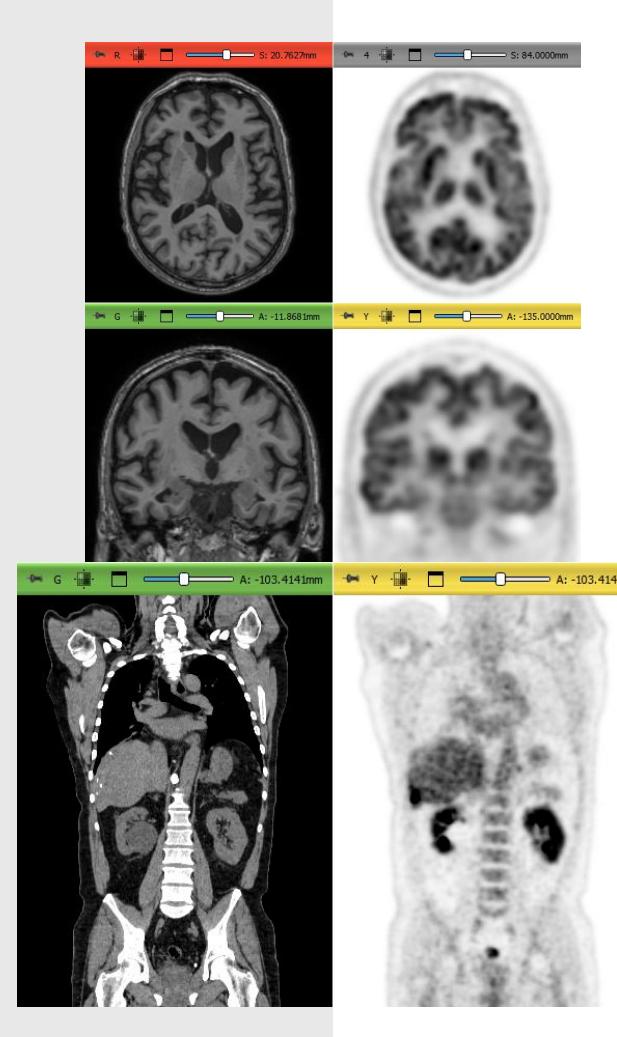
3D Slicer is a **free, open source** software for visualization, processing, segmentation, registration, and analysis of medical, biomedical, and other 3D images and meshes; and planning and navigating image-guided procedures.

Structural vs. Functional Imaging

Structural Imaging

E.g.: MRI, CT

- Provides **structural/spatial** information
- ↑ **spatial resolution** for visualizing anatomical details
- ↓ **functional/temporal** information



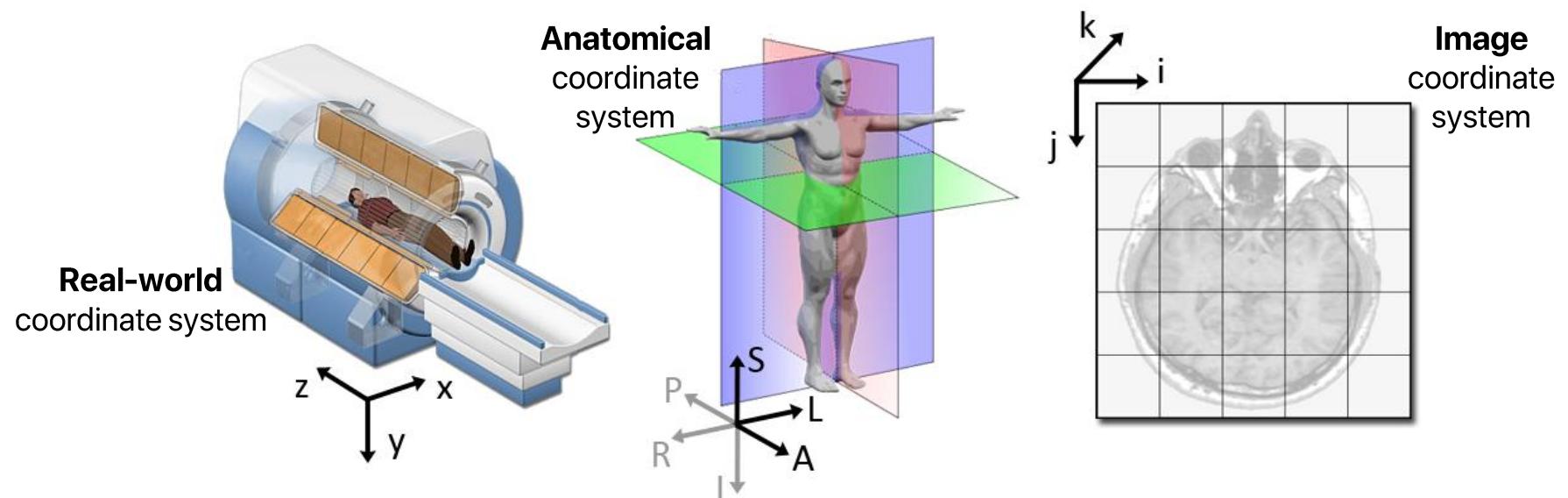
Functional Imaging

E.g.: PET, SPECT, fMRI

- Provides **functional** information (e.g. metabolic activity)
- ↑ **functional/temporal** information for translating tissue function/activity
- ↓ **spatial resolution**

Medical Image Basics

- Medical images are more than just an array!!!
- Each **point in the image** is mapped to a **location in the real world**:



How? By defining **origin**, **spacing**, **size** and **direction matrix**

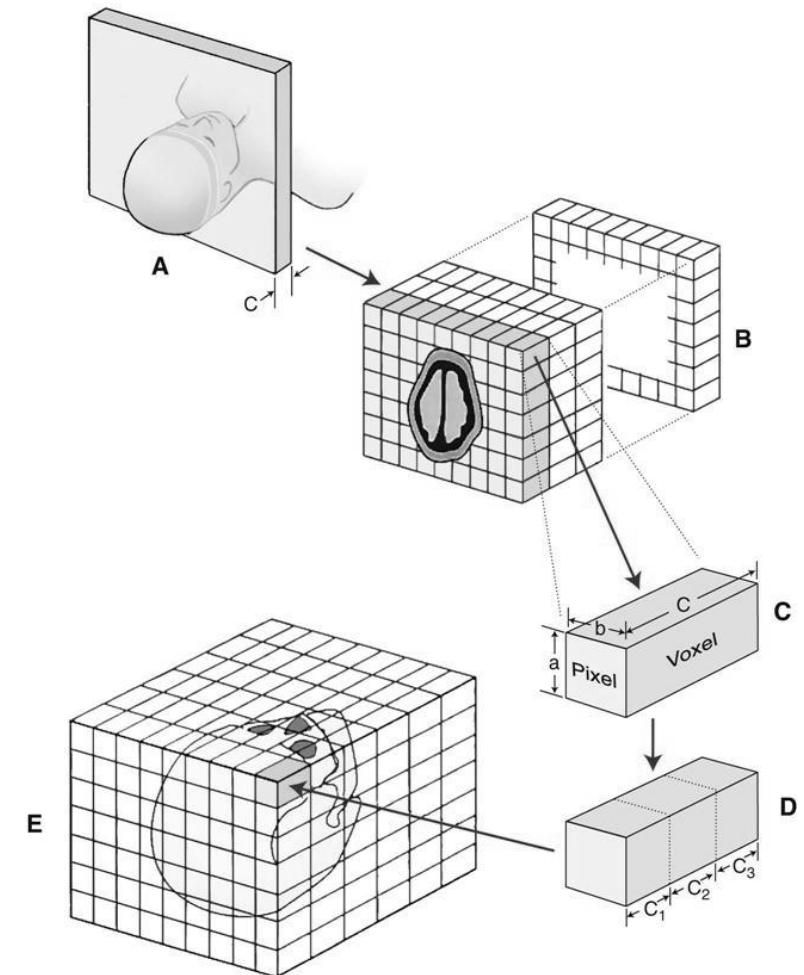
Medical Image Basics

Origin: location in the world coordinate system of the voxel with all zero indexes in the image coordinate system – e.g. $(0, 0, 0)$ for 3D space.

Spacing: real-world distance between pixels/voxels along each of the dimensions.

Size: number of pixels/voxels in each dimension.

Direction cosine matrix: orientation of the image coordinate system relative to a reference coordinate system (real-world coordinates).



Medical Image Basics

Image Origin: -106.5618mm | -166.7496mm | -98.8946mm

IJK to RAS Direction Matrix:

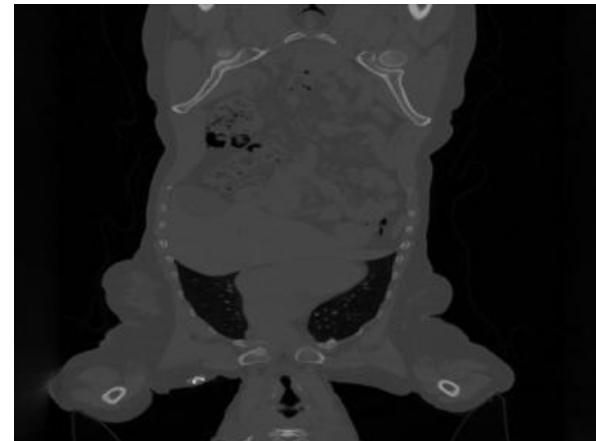
0.9996	0.0288	0.0036
-0.0287	0.9632	0.2671
0.0043	-0.2671	0.9637

Image Origin: 0mm | 0mm | 2mm

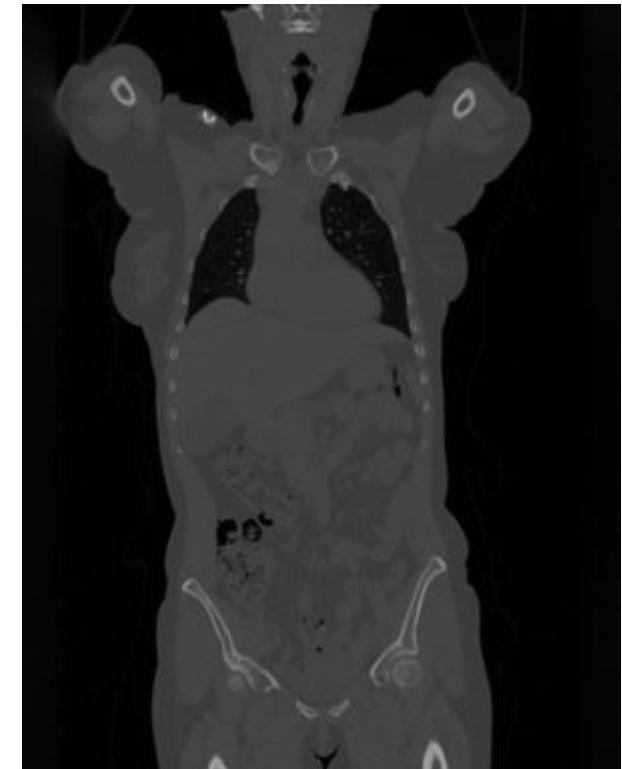
IJK to RAS Direction Matrix:

-1.0000	0.0000	0.0000
0.0000	-1.0000	0.0000
0.0000	0.0000	1.0000

Different **origins** and **direction matrices**



Wrong **spacing** and **direction matrix**



corrected

DICOM (Digital Imaging and Communications in Medicine)

- Globally adopted standard for the **digital storage and transmission** of medical images and other clinical information.
- Stores **metadata** – like **patient information** (name, sex, weight, etc.) but also **image acquisition parameters**:

How? Each information field is attributed a **hexadecimal tag** (e.g. (0010,0010) for patient name) – which is used by **all manufacturers**

The screenshot shows the DICOM Library website with a sidebar containing links like Study Share Service, DICOM Knowledge, Modality, DICOM Tags (which is the active page), Transfer Syntaxes, SOPs, Space storage, Calculator, About DICOM Viewer, About DICOM Library, and Contacts. The main content area has a header "DICOM Tags" with sub-sections "POWERED BY: medDream" and "FUNDDED BY: EU". It includes a table of DICOM tags and their meanings, a search bar, and a note about the Data Dictionary from DICOM PS3.6 version 2013c.

Tag	VR	Name
(0002,0000)	UL	File Meta Information Group Length
(0002,0001)	OB	File Meta Information Version
(0002,0002)	UI	Media Storage SOP Class UID
(0002,0003)	UI	Media Storage SOP Instance UID
(0002,0004)	UI	Transfer Syntax UID
(0002,0012)	UI	Implementation Class UID
(0002,0013)	SH	Implementation Version Name
(0002,0016)	AE	Source Application Entity Title
(0002,0017)	AE	Sending Application Entity Title
(0002,0018)	AE	Receiving Application Entity Title
(0002,0100)	UI	Private Information Creator UID
(0002,0102)	OB	Private Information

(0010,0020)	PatientID
(0010,0040)	PatientSex
(0018,0000)	GenericGroupLength
(0018,0050)	SliceThickness
(0018,1020)	SoftwareVersions
(0018,1210)	ConvolutionKernel
(0018,1242)	ActualFrameDuration
(0020,0000)	GenericGroupLength
(0020,000d)	StudyInstanceUID
(0020,000e)	SeriesInstanceUID
(0020,0010)	StudyID
(0020,0011)	SeriesNumber
(0020,0013)	InstanceNumber
(0020,0032)	ImagePositionPatient
(0020,0037)	ImageOrientationPatient
(0020,0052)	FrameOfReferenceUID
(0020,1040)	PositionReferenceIndicator
(0028,0000)	GenericGroupLength
(0028,0002)	SamplesPerPixel
(0028,0004)	PhotometricInterpretation
(0028,0010)	Rows
(0028,0011)	Columns
(0028,0030)	PixelSpacing
(0028,0100)	BitsAllocated
(0028,0101)	BitsStored

005_S_0221
M
54
2.42500
72
Ramp
1800000
252
1.3.6.1.4.1.13856.242000.1.2.5057.2.624698184470.2
1.3.6.1.4.1.13856.242000.1.2.5057.3.624698184493.2

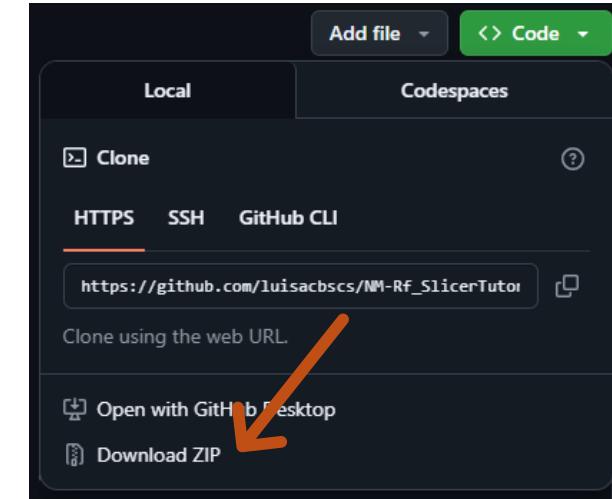
1
[3] 0.0, 0.0, 2.42490
[6] 1, 0, 0, 1, 0
1.3.6.1.4.1.13856.242000.1.2.5057.4.624698184494.2

146
1
MONOCHROME2
128
128
[2] 2.05941, 2.05941
16
16

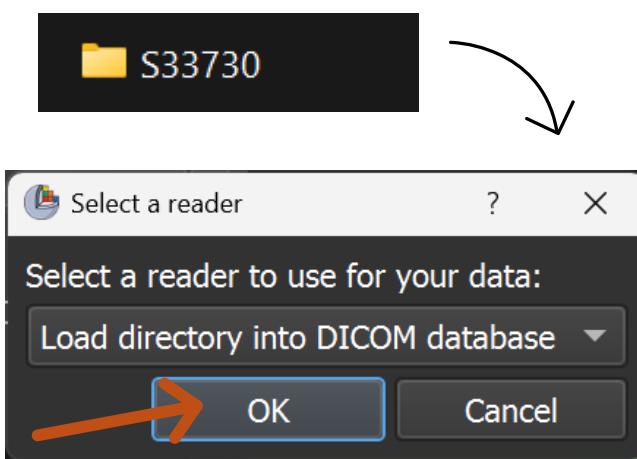
Hands-on tutorial: Whole-body Imaging

1. Open 3D Slicer
2. Download the images (DICOM series) from GitHub

You can **download the entire folder** for the tutorial:
https://github.com/luisacbscs/NM-Rf_SlicerTutorial



3. Drag the **DICOM series (S33730) folder** into 3D Slicer

A screenshot of the 3D Slicer DICOM database interface. It shows three tables: 'Patient', 'Study', and 'Series'.

Patient name	Patient ID	Birth date	Sex	Studies	Last study date	Date added
DOE, JANE	ID123456		F	1	2025-05-01 01:969	

Study date	Study ID	Study description	Series	Date added
3373		PET-CT_FDG	2	2025-05-01 01:974

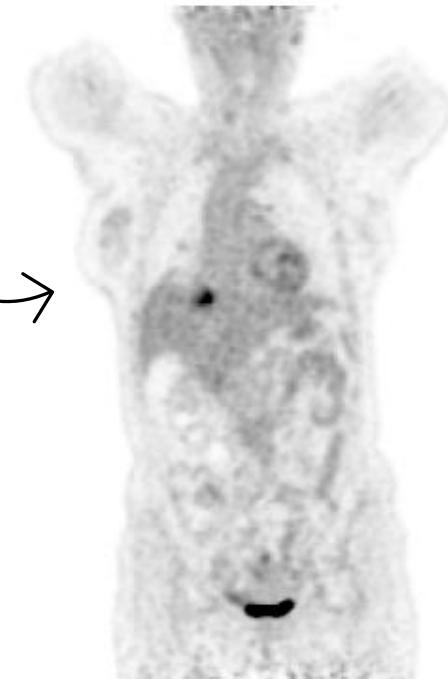
Series #	Series description	Modality	Size	Count	Date added
202	CT	CT	512x512	382	2025-05-01 01:977
4628	FDG_PET	PT	144x144	191	2025-05-02 02:785

[¹⁸F]FDG PET/CT

1. Hands-on tutorial: Whole-body Imaging 1.1. Whole-body [¹⁸F]FDG PET/CT

In **Positron Emission Tomography (PET)** Imaging, a **target molecule** labelled with a **radioisotope** is administered to the patient – this allows us to see the **biodistribution of that molecule in the body**.

- [¹⁸F]FDG – analog of glucose labelled with fluorine-18: we can see the **metabolic activity in the body!**
- **Cancer cells** are characterized by **uncontrolled growth/proliferation**, requiring **more energy (glucose!)** than normal healthy cells → tumor lesions with glucose avidity can be observed in [¹⁸F]FDG PET.

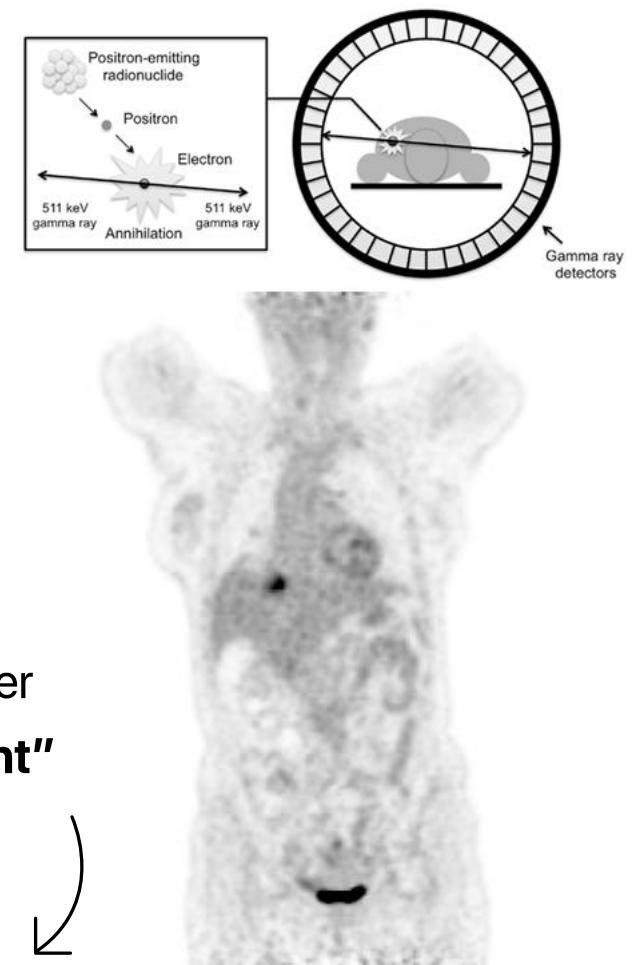


[¹⁸F]FDG PET/CT

1. Hands-on tutorial: Whole-body Imaging 1.0. Whole-body [¹⁸F]FDG PET/CT

In **Positron Emission Tomography (PET)** Imaging, a **target molecule** labelled with a **radioisotope** is administered to the patient – this allows us to see the **biodistribution of that molecule in the body**.

- The PET scanner's detectors count **how many radioactive decays occur** in a given volume in space (voxel).
- The image is, thus, provided in **activity concentration**, i.e. radioactive decays per unit of volume (Bq/mL) – this highly depends on **patient weight** and the “**amount injected**...



Converting PET image to **SUV** (standardized uptake value): normalizing images with respect to weight and administered activity

1. Hands-on tutorial: Whole-body Imaging

1.1. Accessing DICOM metadata

Converting PET image to **SUV** (standardized uptake value): normalizing images with respect to weight and administered activity

$$\text{SUV conversion factor} = \frac{\text{administered activity [Bq]}}{\text{weight [g]}}$$

The screenshot shows the 3D Slicer 5.6.1 interface. Step 1 highlights the 'DCM' icon in the toolbar. Step 2 highlights the 'FDG_PET' series in the 'Series' table and points to the context menu option 'View DICOM metadata'. Step 3 shows the expanded DICOM metadata table with the 'RadionuclideTotalDose' field highlighted.

Tag	Description	Value
(0054,0016)	RadiopharmaceuticalInformationSequence	
(ffe,e000)	Item	
(0018,0031)	Radiopharmaceutical	FDG
(0018,1070)	RadiopharmaceuticalRoute	Intravenous route
(0018,1072)	RadiopharmaceuticalStartTime	155700
(0018,1074)	RadionuclideTotalDose	216450000
(0018,1075)	RadionuclideHalfLife	6586.199707
(0018,1076)	RadionuclidePositronFraction	0.9673
(0018,1078)	RadiopharmaceuticalStartTimeDateTime	20190228155700

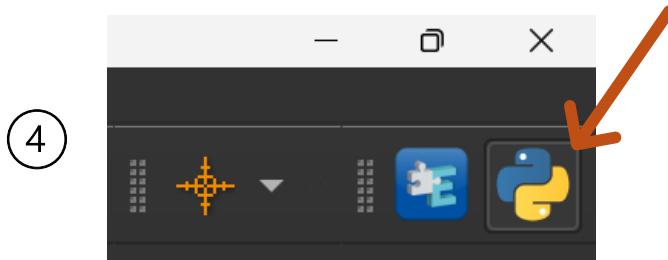
③

$$\text{SUV conversion factor} = \frac{216450000 \text{ [Bq]}}{???? \text{ [g]}}$$

1. Hands-on tutorial: Whole-body Imaging
1.2. Array manipulation using Python Console

Converting PET image to **SUV** (standardized uptake value): normalizing images with respect to weight and administered activity

$$\text{SUV conversion factor} = \frac{\text{administered activity [Bq]}}{\text{weight [g]}}$$
$$= \frac{216450000 \text{ [Bq]}}{63000 \text{ [g]}} \approx 3435.7 \text{ [Bq/g]}$$



⑤

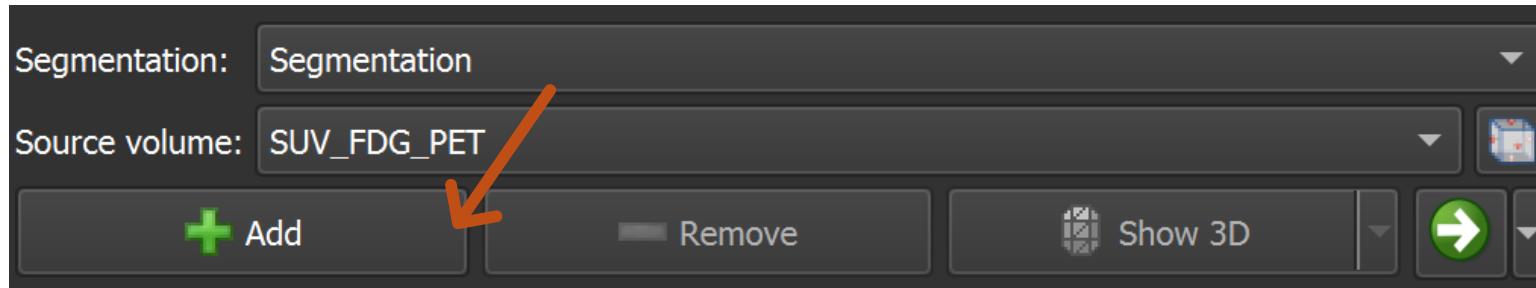
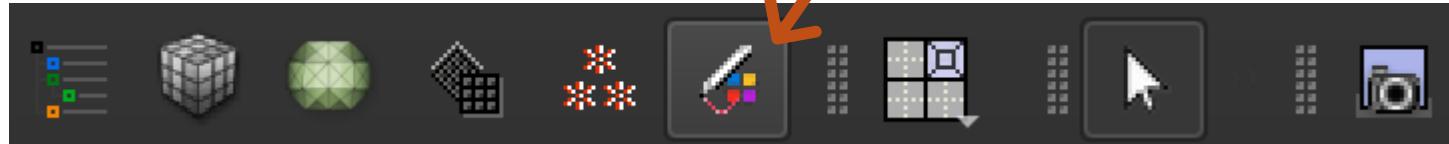
Python Console

```
Python 3.9.10 (main, Dec 12 2023, 02:25:18) [MSC v. 1935 64 bit (AMD64)] on win32
>>> petNode = slicer.util.getNode("4628: FDG_PET")
>>> arr = slicer.util.array(petNode.GetID())
>>> suv_factor=3435.7
>>> arr = arr/suv_factor
>>>
suvNode=slicer.modules.volumes.logic().CloneVolume(
slicer.mrmlScene,petNode,"SUV_FDG_PET")
>>> slicer.util.updateVolumeFromArray(suvNode, arr)
>>> slicer.app.processEvents()
>>>
```

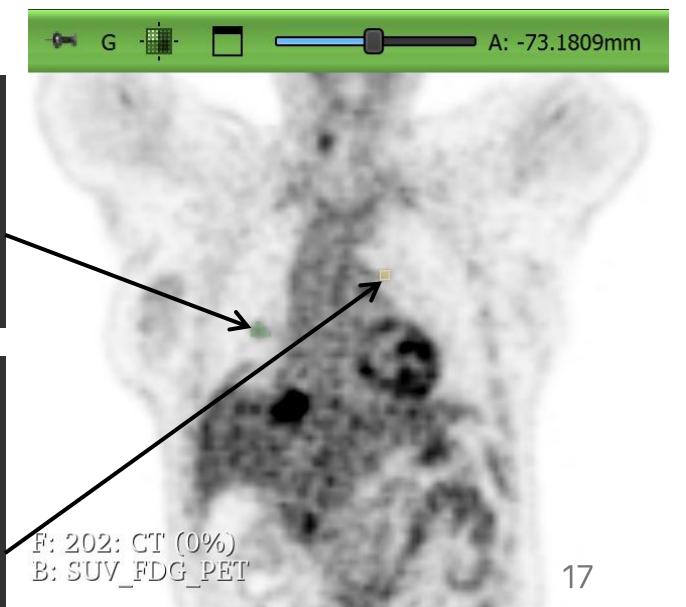
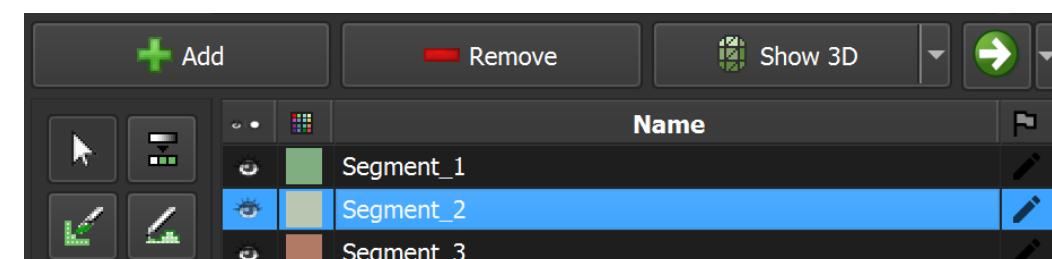
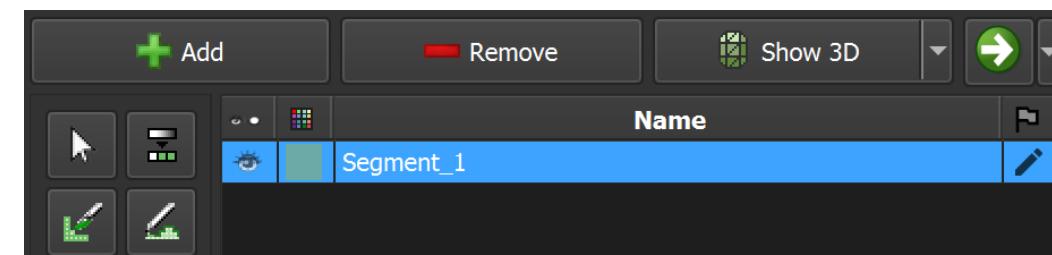
Or copy+paste from the .txt file on GitHub

1. Hands-on tutorial: Whole-body Imaging

1.3. Segmentation

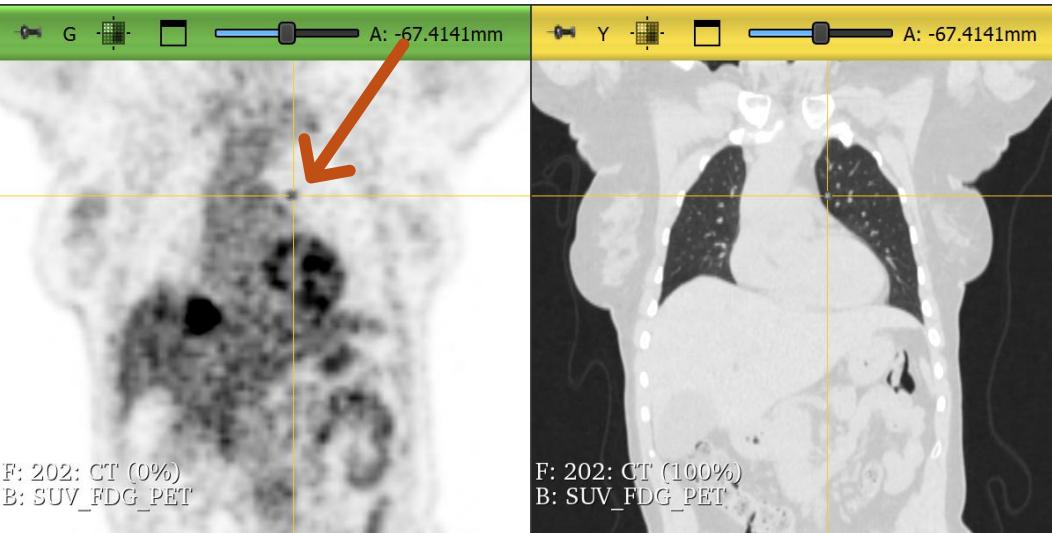
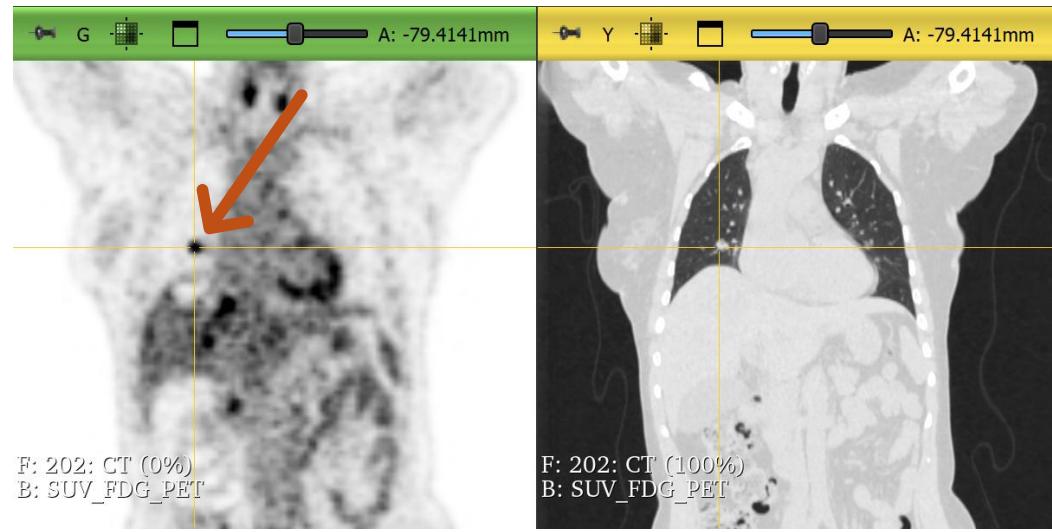


Add a new segment every time you change labels – i.e. every time you start a new lesion segmentation!

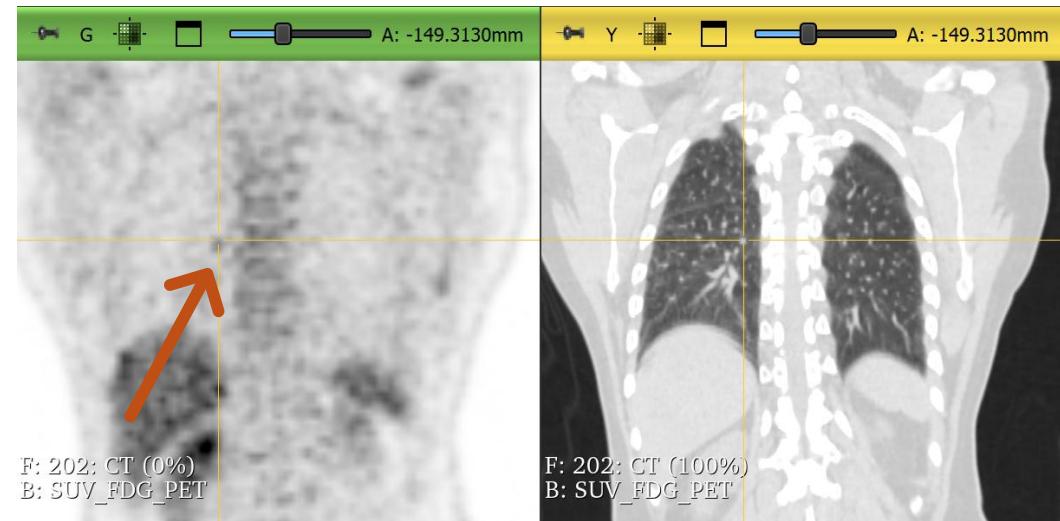


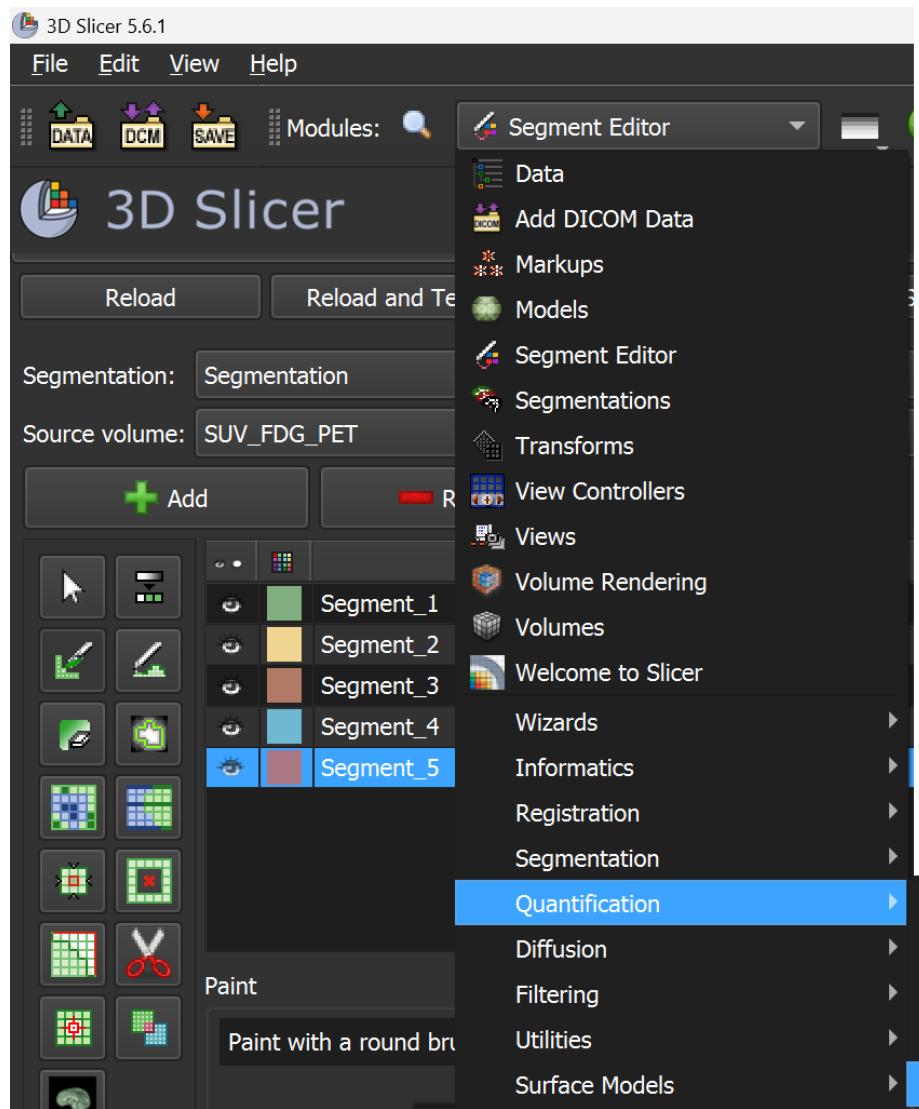
1. Hands-on tutorial: Whole-body Imaging

1.3. Segmentation



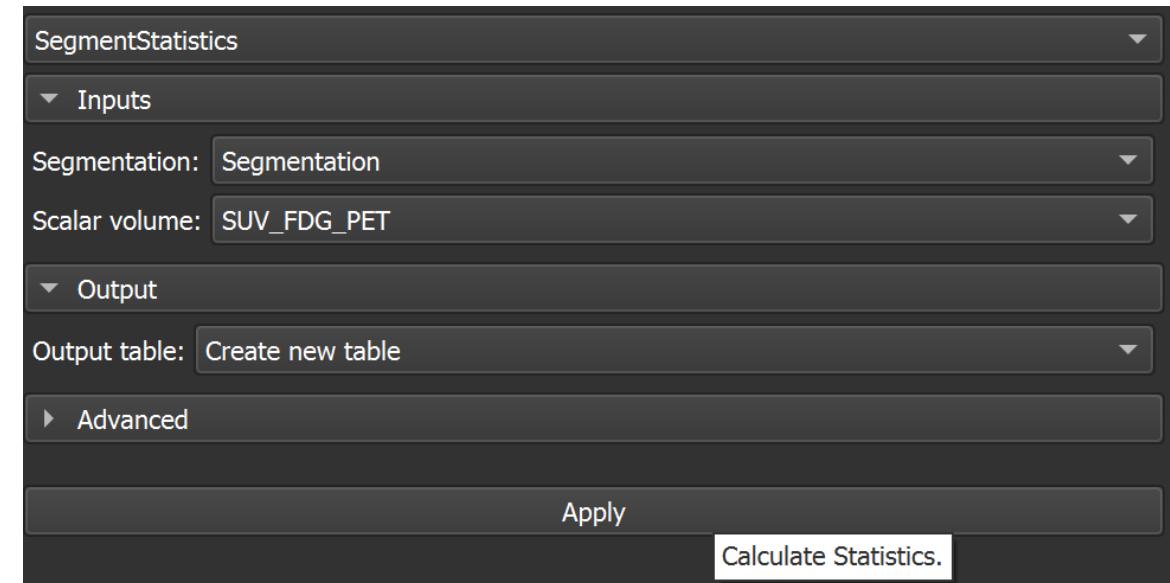
Add a new segment every time you change labels –
i.e. every time you start a new lesion segmentation!





1. Hands-on tutorial: Whole-body Imaging

1.4. Quantification

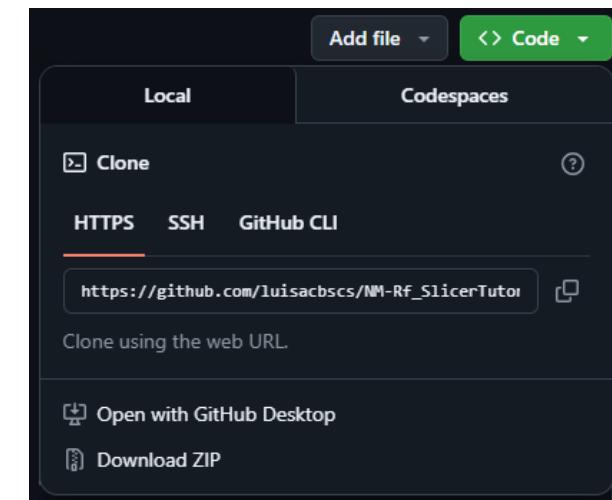


Which is the **most metabolically active** lesion?

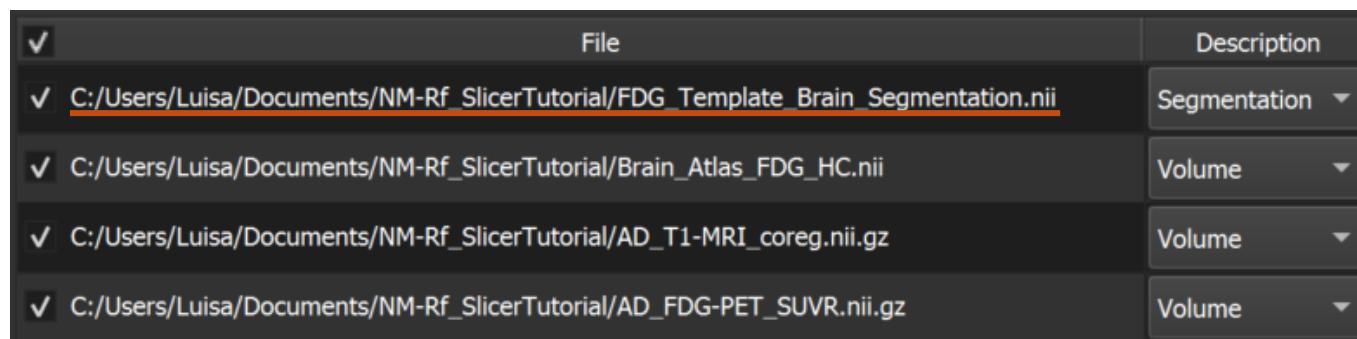
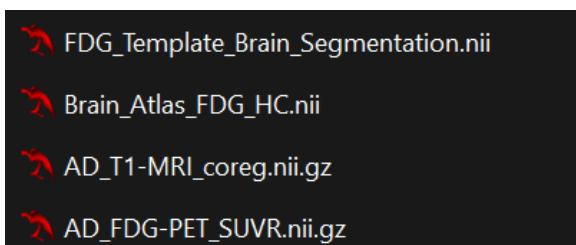
Hands-on tutorial: Brain Imaging

1. Open 3D Slicer
2. Download the images from GitHub

You can **download the entire folder** for the tutorial:
https://github.com/luisacbscs/NM-Rf_SlicerTutorial



3. Drag the images (and mask) into 3D Slicer

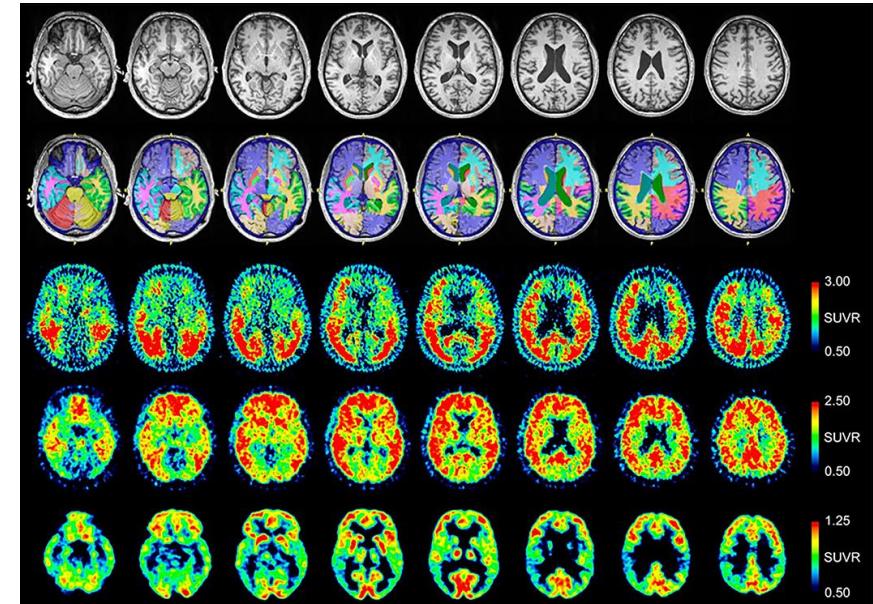


Brain PET

2. Hands-on tutorial: Brain Imaging 2.0. Brain PET

Brain PET is a non-invasive imaging technique that uses a radioactive tracer to assess **brain function and metabolism**. Different radiopharmaceuticals are used to assess different functions/biodistributions:

- **[¹⁸F]FDG** – Specific patterns of **hypometabolism** (decreased activity) and **hypermetabolism** (increased activity) are used to distinguish different types of dementia.
- **Amyloid PET** (e.g. **[¹⁸F]FBB**, **[¹⁸F]FBP**, **[¹¹C]PiB**) – Amyloid **deposits**, particularly those of **amyloid beta (Aβ) protein**, are a key characteristic of Alzheimer's disease (AD) and other dementias.
- **Tau PET** (e.g. **[¹⁸F]FTP**) – Similar to amyloid PET but for the **Tau protein**, another biomarker of AD and other **tauopathies**.



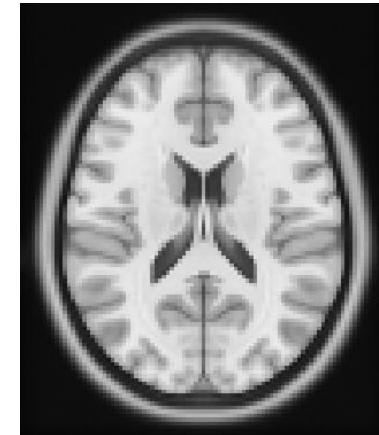
Brain PET

Brain PET is a non-invasive imaging technique that uses a radioactive tracer to assess **brain function and metabolism**. Different radiopharmaceuticals are used to assess different functions/biodistributions.

- To assess **if the biodistribution in different brain regions is altered**, it should be **compared with a healthy brain**.
- **Brain atlases** correspond to the **average of the brain across multiple subjects** (in this case, healthy controls) and are used as a benchmark for comparison.

The **brain PET study of the patient** must be **deformed into the corresponding atlas**, so we can assess regional differences in radiopharmaceutical uptake.

2. Hands-on tutorial: Brain Imaging 2.0. Brain PET



MRI brain atlas:
average of multiple
brain MRIs of healthy
subjects



FDG PET brain atlas:
average of multiple
brain [18F]FDG PET of
healthy subjects

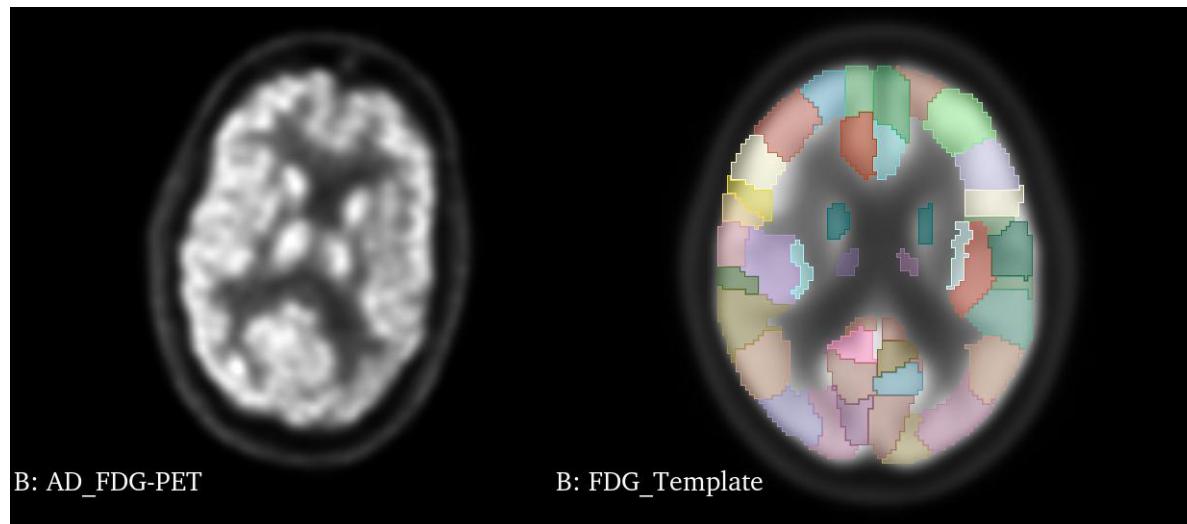
2. Hands-on tutorial: Brain Imaging

2.1. Registration

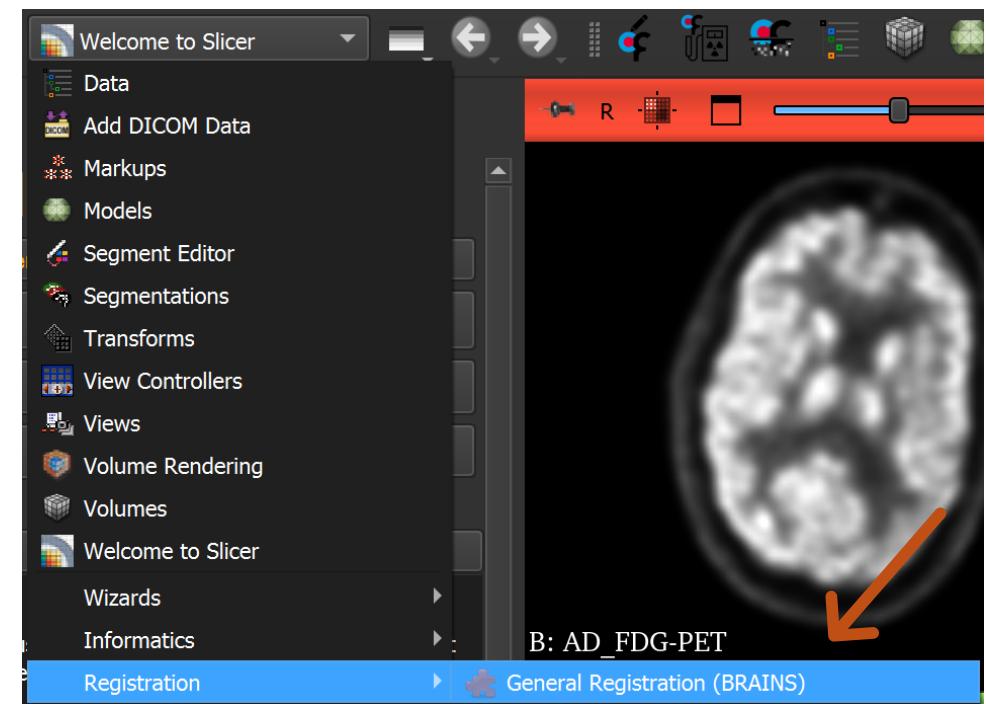
The brain PET study of the patient must be **deformed** into the corresponding **atlas**, so we can assess regional differences in radiopharmaceutical uptake.

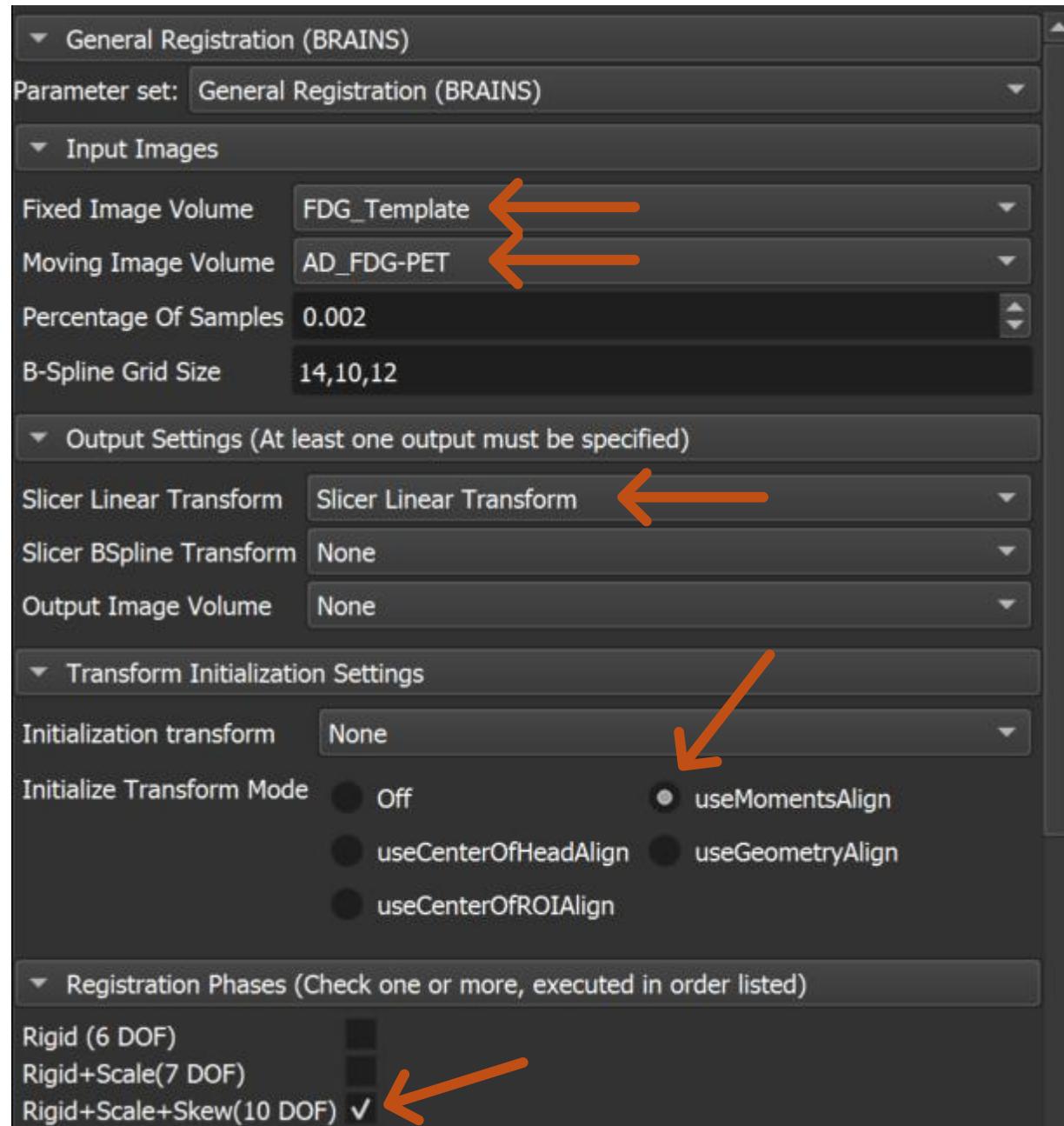


This is called **registration**.



We need to make these two brains – the patient's (left) and the atlas (right) – **overlap**, so the **anatomical regions coincide**.

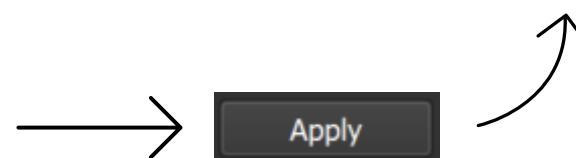




2. Hands-on tutorial: Brain Imaging

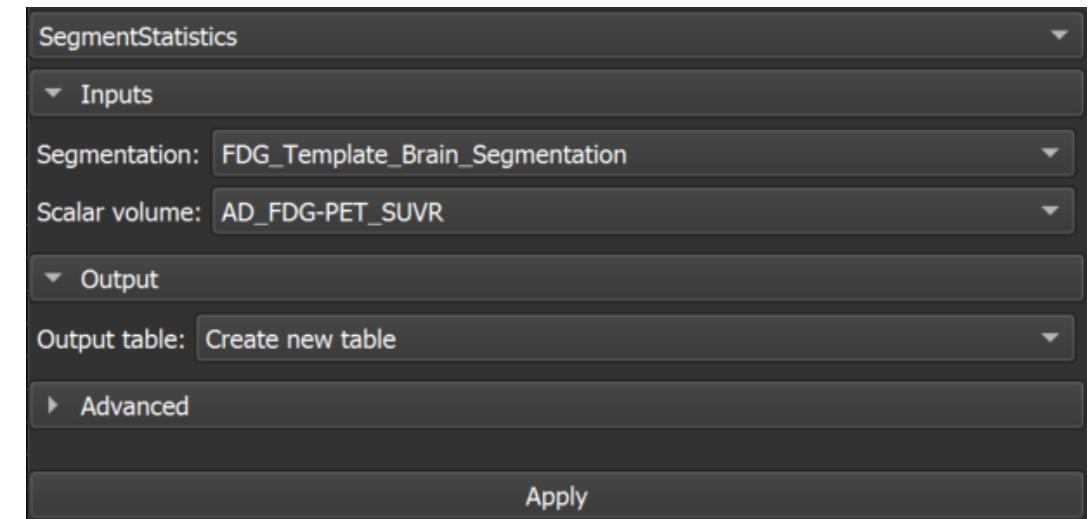
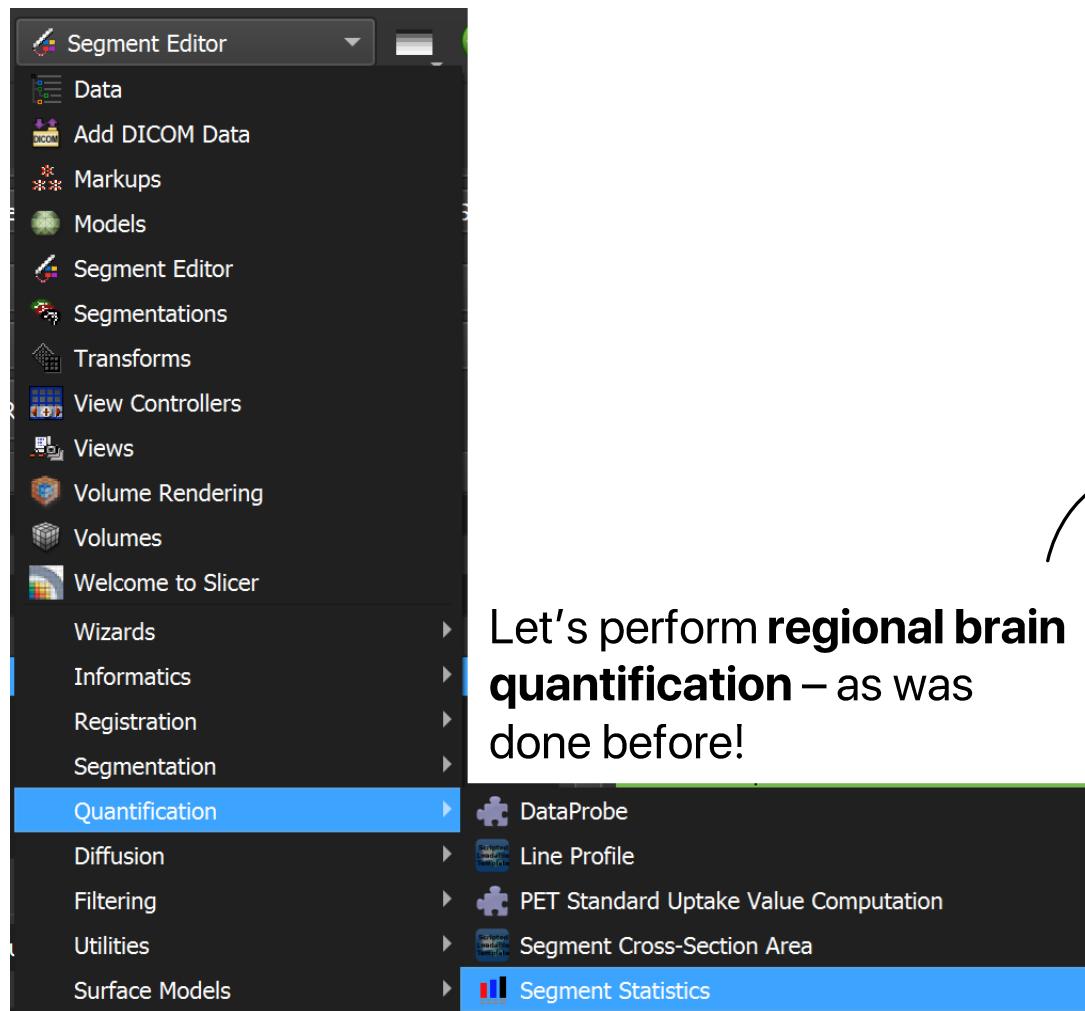
2.1. Registration

After **registration** is done, you'll see that the patient's brain (AD_FDG-PET) now overlaps with the FDG PET brain atlas!



2. Hands-on tutorial: Brain Imaging

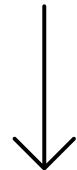
2.2. Quantification



In patients with **Alzheimer's Disease**, FDG PET scans typically reveal a characteristic pattern of **hypometabolism (decreased glucose uptake)** in specific brain regions, particularly in the parietotemporal cortex - **inferior parietal lobule** and **middle temporal gyrus**.



Labels **61** and **62** (left and right, respectively)



Labels **85** and **86** (left and right, respectively)

FDG uptake in the **brain atlas – healthy** controls

Label	Region	Mean Uptake
61	Parietal_Inf_L	1.31715
62	Parietal_Inf_R	1.22215
85	Temporal_Mid_L	1.35607
86	Temporal_Mid_R	1.38914

Given the **healthy uptake values** in the regions of interest for Alzheimer's disease (AD), is the **metabolic activity in the patient's brain FDG PET in agreement with a diagnosis of AD?**



Thank you!

Luísa CastelBranco Silva
Biomedical engineer, researcher @ MN-Rf



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