JACMP Pub 2009

JOURNAL OF APPLIED CLINICAL MEDICAL PHYSICS, VOLUME 10, NUMBER 1, WINTER 2009

Automated Quality Assurance for Image-Guided Radiation Therapy

Eduard Schreibmann,[a] Eric Elder, Tim Fox
Department of Radiation Oncology, Emory University School of Medicine, Atlanta, GA, U.S.A.
edi@radonc.emory.org

Received 2 April 2008; accepted 18 August 2008

The use of image-guided patient positioning requires fast and reliable Quality Assurance (QA) methods to ensure the megavoltage (MV) treatment beam coincides with the integrated kilovoltage (kV) or volumetric cone-beam CT (CBCT) imaging and guidance systems. Current QA protocol is based on visually observing deviations of certain features in acquired kV in-room treatment images such as markers, distances, or HU values from phantom specifications. This is a time-consuming and subjective task because these features are identified by human operators. The method implemented in this study automated an IGRT QA protocol by using specific image processing algorithms that rigorously detected phantom features and performed all measurements involved in a classical QA protocol. The algorithm was tested on four different IGRT QA phantoms. Image analysis algorithms were able to detect QA features with the same accuracy as the manual approach but significantly faster. All described tests were performed in a single procedure, with acquisition of the images taking approximately 5 minutes, and the automated software analysis taking less than 1 minute. The study showed that the automated image analysis based procedure may be used as a daily QA procedure because it is completely automated and uses a single phantom setup.

Any phantom?

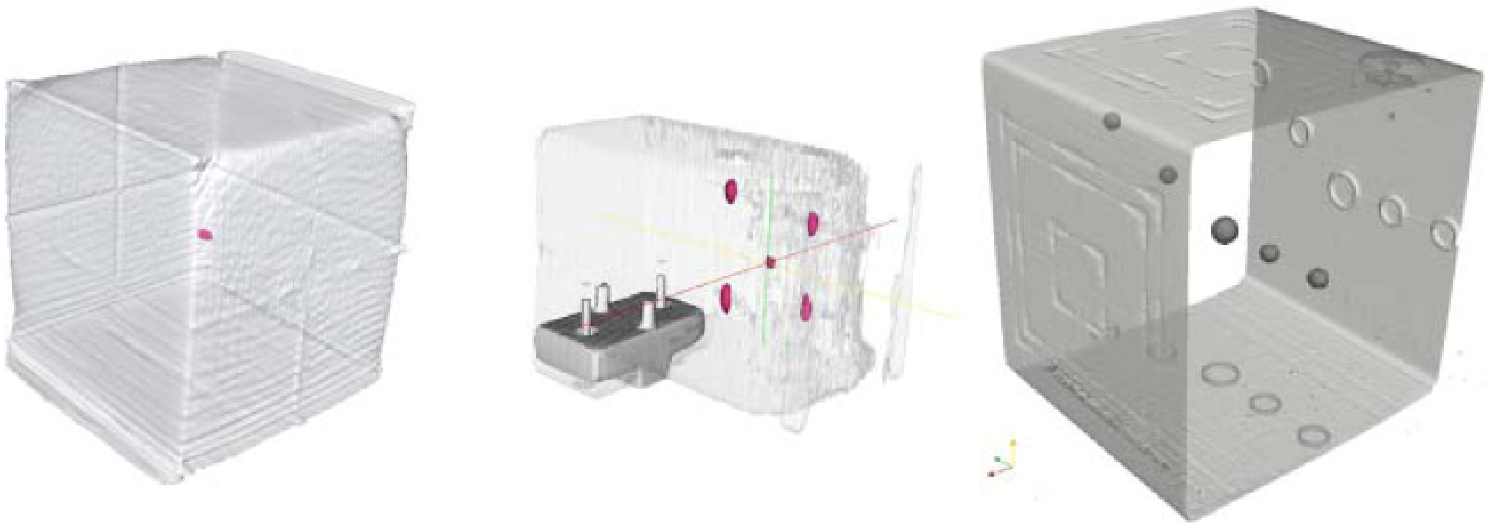
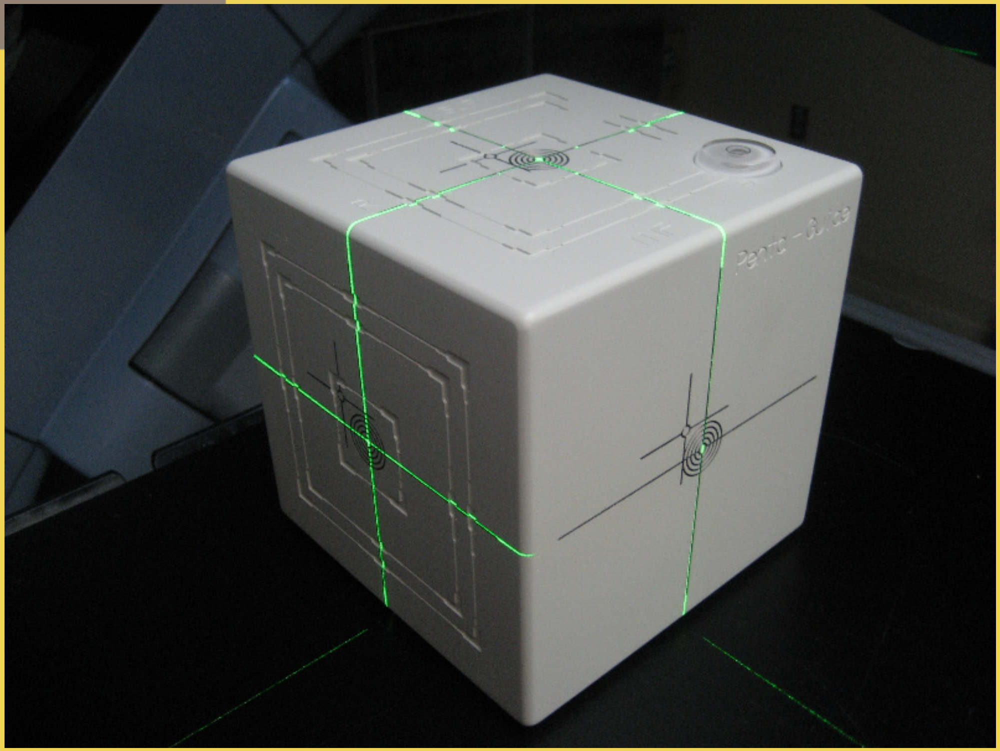


FIG. 2. Example of our automated feature extraction tool applied on four different phantoms. (a) The Varian cube phantom consists of a central 2 mm marker embedded in a cube. (b) The Exact Track phantom consist of five radioopaque markers arranged in a star pattern. (c) The Modus phantom consists of five spheres of different sizes embedded in a acrylic cube.

Test Setup



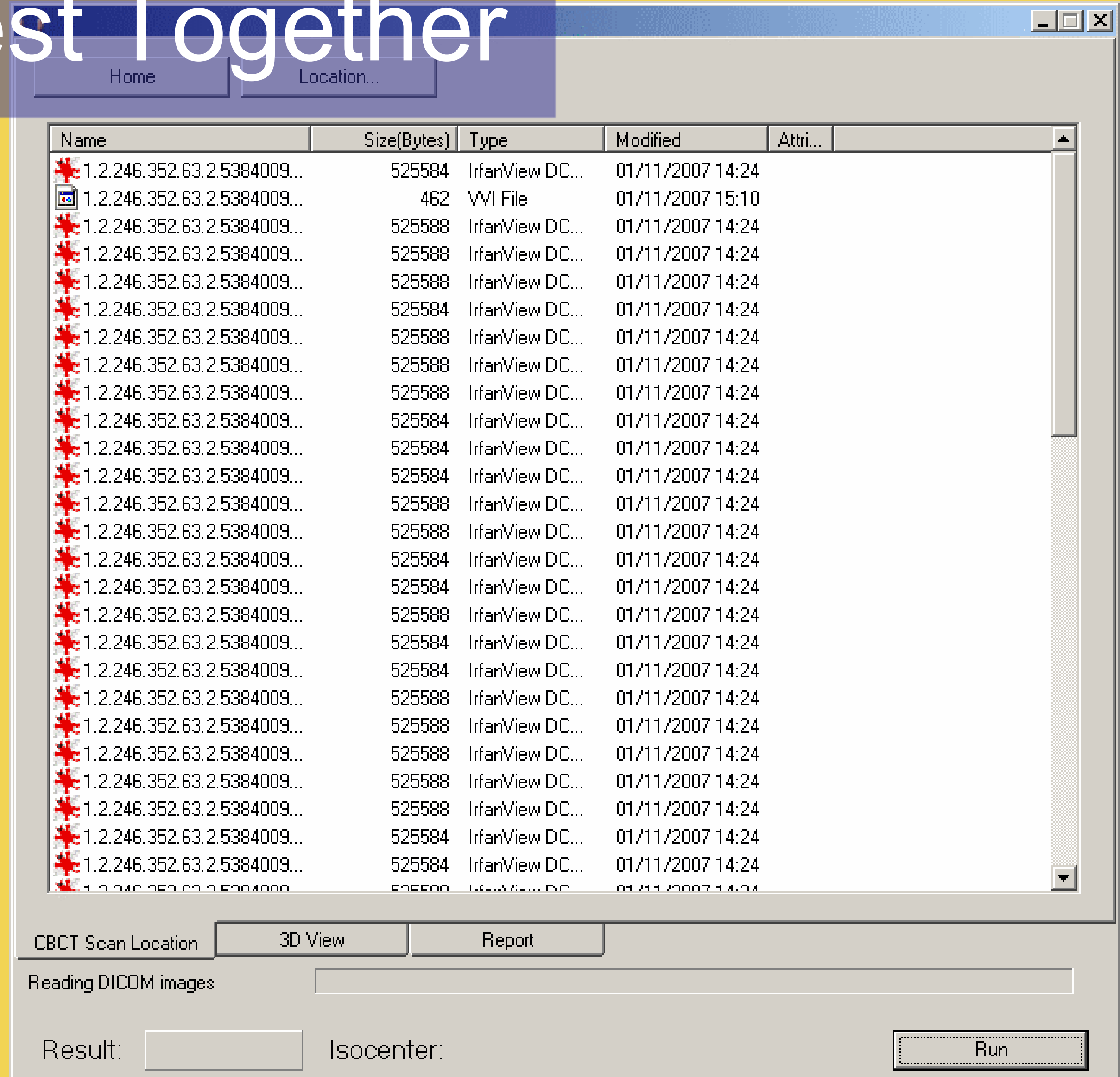
Therapist Process (5 min):
1. Aligns phantom on table with isocenter.
2. Acquires kV, MV, and CBCT.

Physicist Process (1.5 min):
1. Runs the software on the saved images

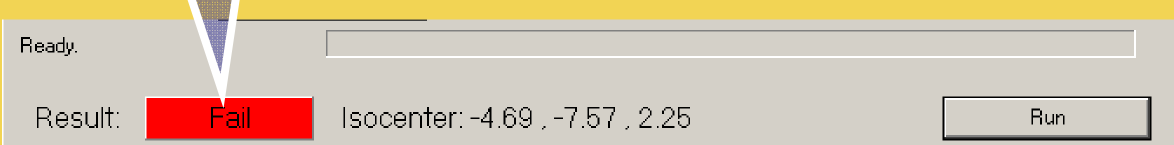
<u>Software Processing Times</u>

CBCT Position Test: < 1 minute
KV-MV Test: < 30 sec

Let’s Do a Test Together



Pass or fail clearly visible



Winston-Lutz Test

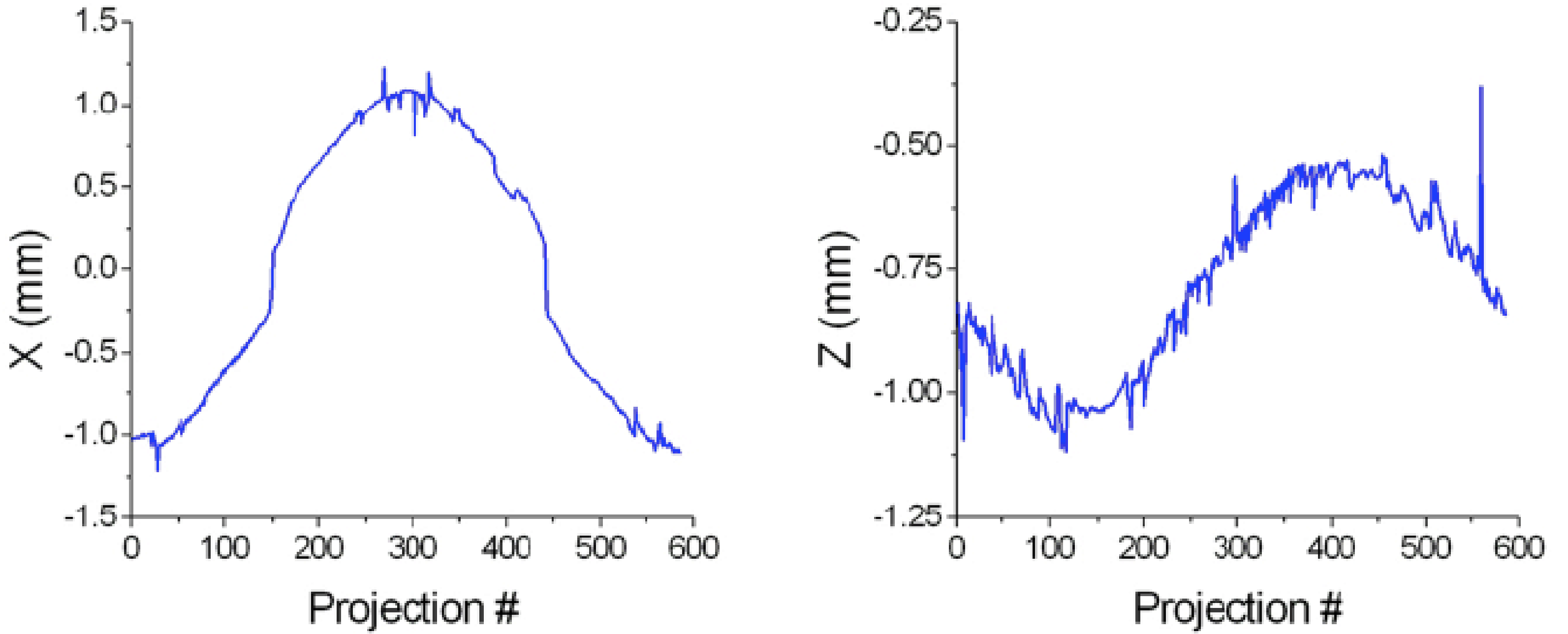
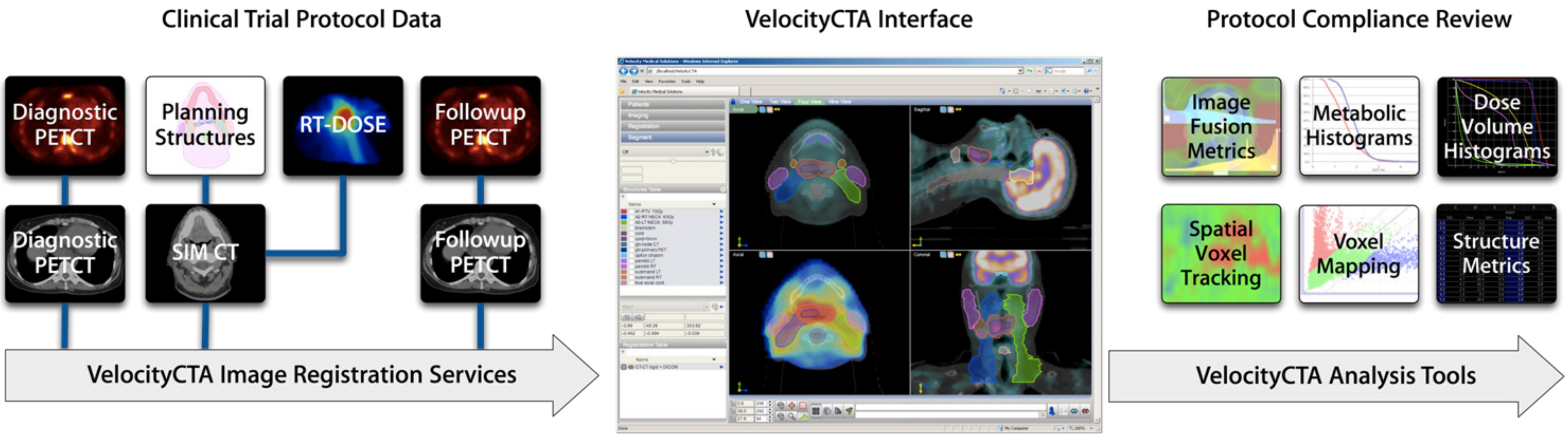


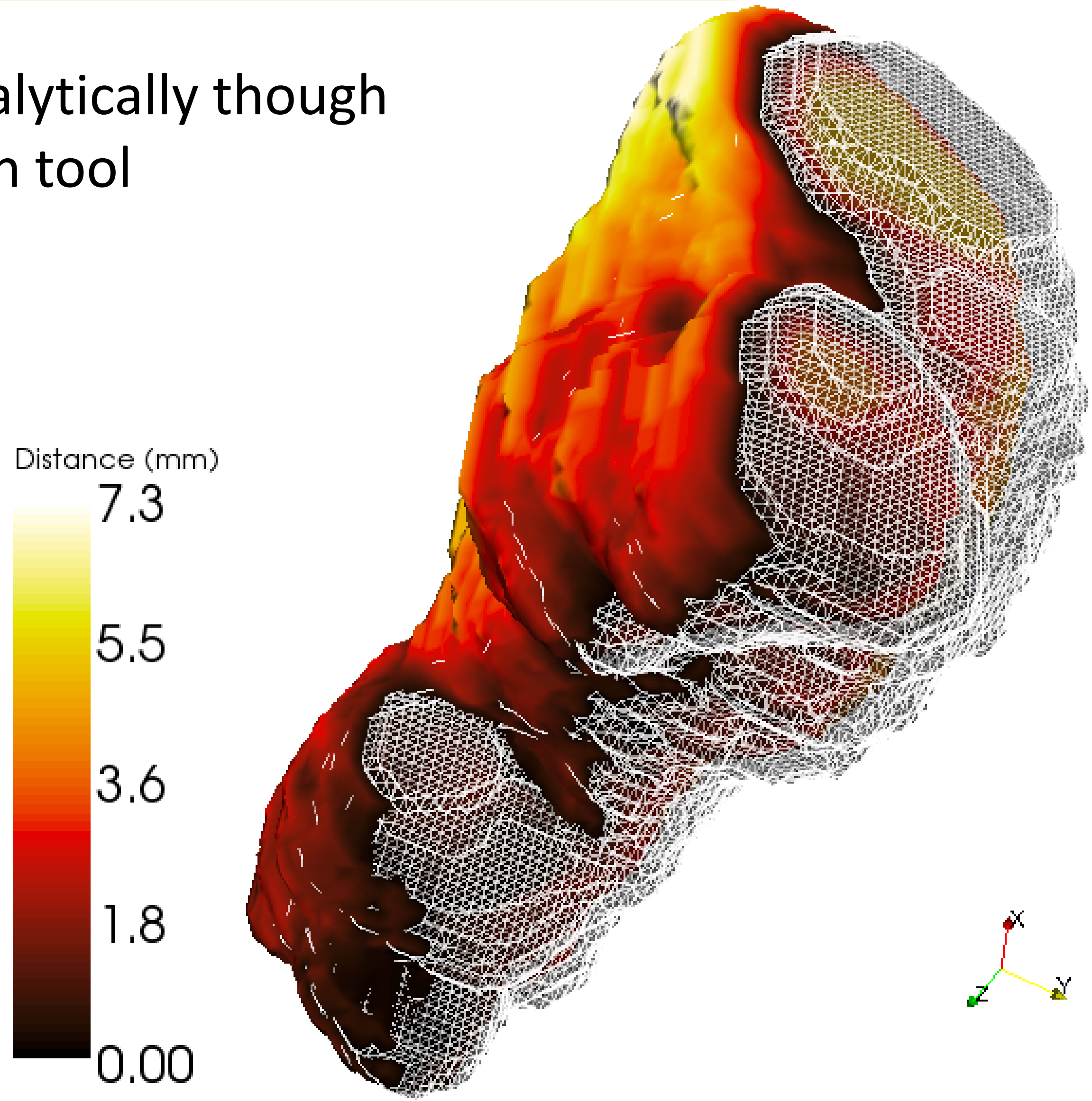
FIG. 6. Winston-Lutz tests are performed directly on the OBI-acquired projections of a CBCT scan. The gantry sag with rotation on the X and Y directions is plotted in these graphs.

ATC Interface for Clinical Trials Analysis



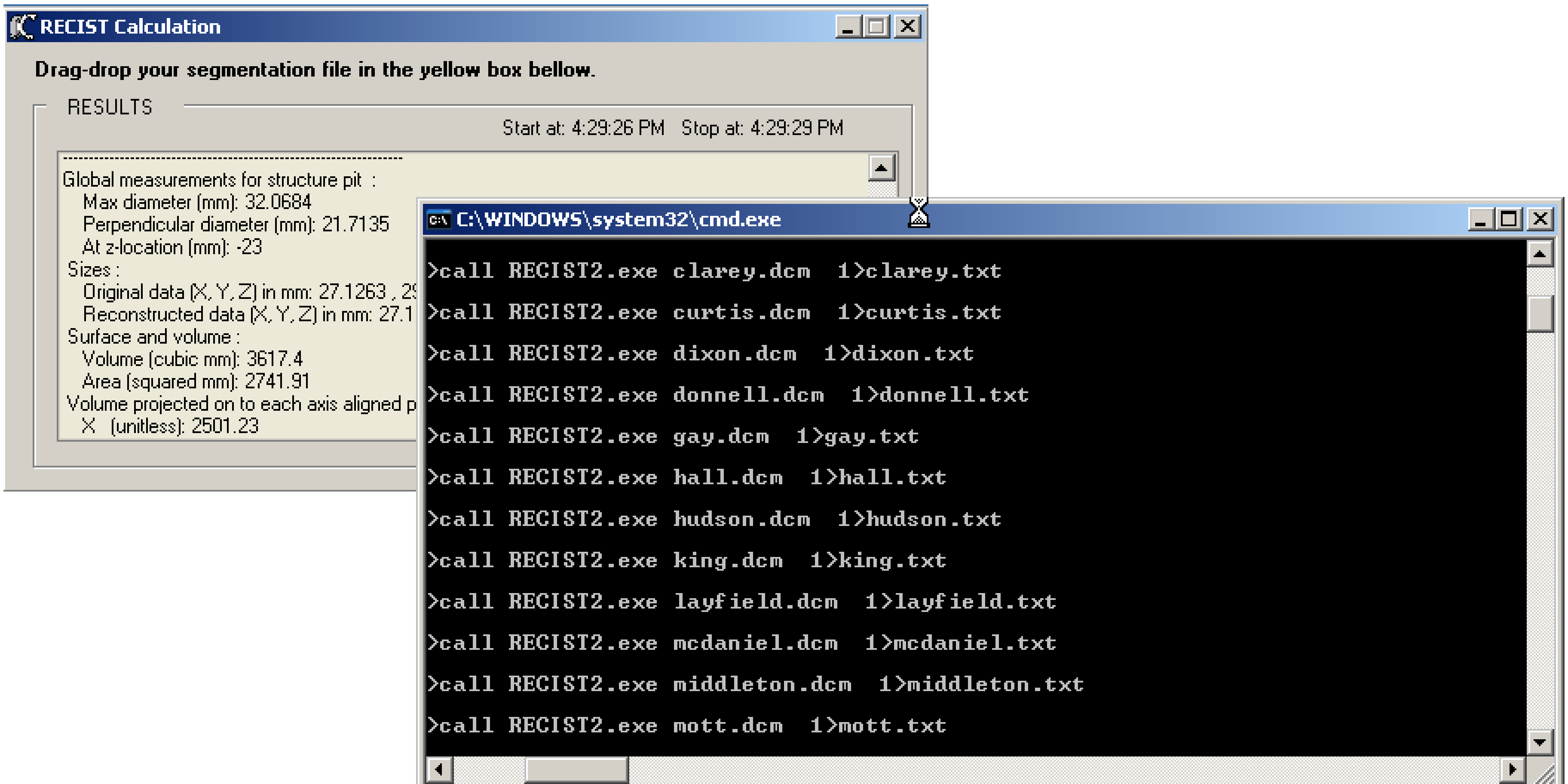
Shape Measurements

- Changes measured analytically though the surface comparison tool



RECIST Measurements

- Takes as input structures in DICOM files, outputs table of measurements for easy integration into research analyses



RECIST-Style Statistics By Regions

Bellow are some RECIST-style measurements for the area of treatment response.

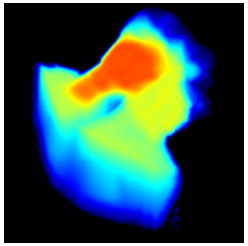
- *Centroid* is the position of the center of the shape in physical coordinates. It is not constrained to be in the object, and thus can be outside if the object is not convex. Its type is *itk::Point¡ double, ImageDimension ¿*.
- *Region* is the bounding box of the object given in the pixel coordinates. The physical coordinate can easily be computed from it. Its type is *itk::ImageRegion¡ ImageDimension ¿*.
- *RegionElongation* is the ratio of the longest physical size of the region on one dimension and its smallest physical size. This descriptor is not robust, and in particular is sensitive to rotation. Its type is *double*.
- *SizeRegionRatio* is the ratio of the size of the object region (the bounding box) and the real size of the object. Its type is *double*.
- *SizeOnBorder* is the number of pixels in the objects which are on the border of the image. A pixel on several borders (a pixel in a corner) is counted only one time, so the size on border can't be greater than the size of the object. This attribute is particulary useful to remove the objects which are touching too much the border. Its type is *unsigned long*.
- *PhysicalSizeOnBorder* is the physical size of the objects which are on the border of the image. In 2D, it is a distance, in 3D, a surface, etc. Contrary to the *PhysicalSize* attribute which is directly linked to the *Size*, this attribute is not directly linked to the *SizeOnBorder* attribute. This attribute is particulary useful to remove the objects which are touching too much the border. Its type is *double*.
- *FeretDiameter* is the diameter in physical units of the sphere which include all the object. The feret diameter is not computed by default, because of its high computation. Its type is *double*.
- *BinaryPrincipalMoments* contains the principal moments. Its type is *itk::Vector¡ double, ImageDimension ¿*.
- *BinaryPrincipalAxes* contains the principal axes of the object. Its type is *itk::Matrix¡ double, ImageDimension, ImageDimension ¿*.

Tumor response region characteristics:

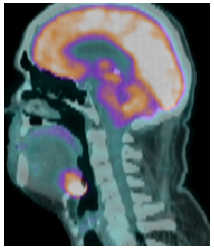
Physical Size: 63861.1
Centroid: [7.95188, -30.8319, 2.50007]
Region Elongation: 1.18052
Size Region Ratio: 0.290998
Size On Border: 0
Physical Size On Border: 0
Feret Diameter: 0
Principal Moments: [80.8521, 161.733, 204.239]
Principal Axes: -0.553485 -0.20586 -0.807017
-0.111143 -0.942048 0.316531
-0.82541 0.26489 0.498529
Elongation: 1.12375
Perimeter: 9876.21
Roundness: 0.782321
Equivalent Radius: 24.7961
Equivalent Perimeter: 7726.36
Equivalent Ellipsoid Size: [37.8576, 53.5436, 60.1696]
Binary Flatness: 1.41434

Multi-Modality Imaging and RT Integration

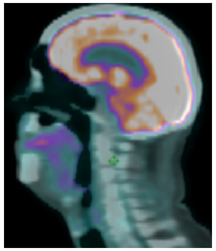
CT Sim



RT Dose



Pre-Tx

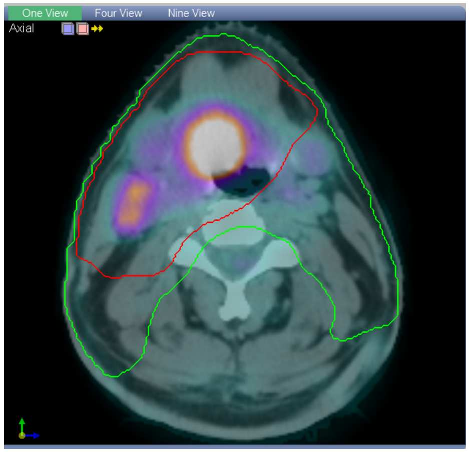


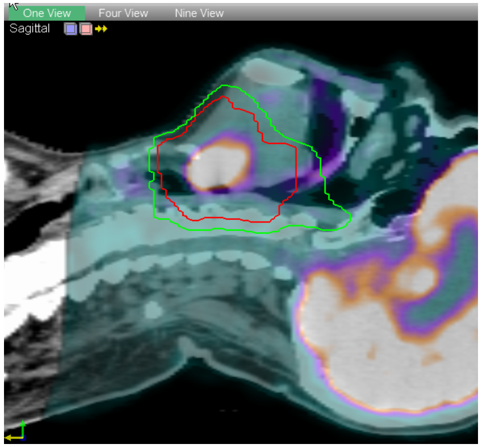
Post-Tx

RT Tx Plan

RT & Image Integration

Biological



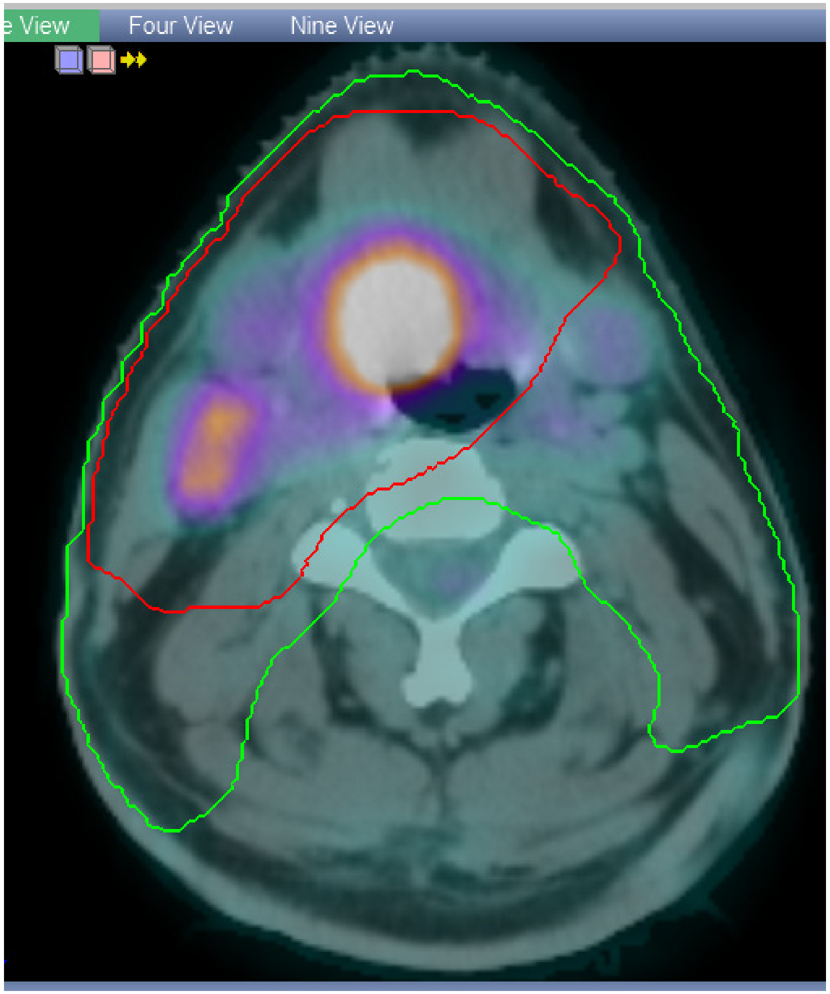


RTOG 0522 Data Integrity: 13 Acceptable Cases

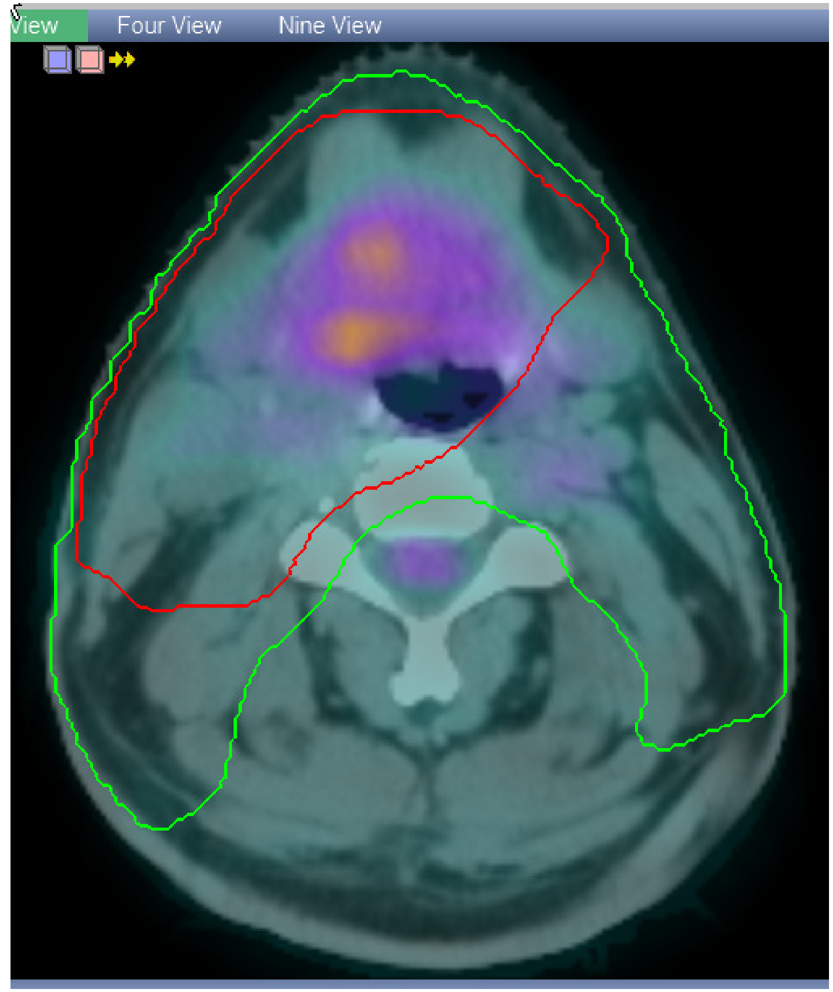
Patient #	CTSim	Struct	Dose	Pre-Tx PET/CT	Post-Tx PET/CT
002	Yes	Yes	Yes	No CT	No CT
009	Yes	Yes	Yes	No CT	No CT
013	Yes	Yes	Yes	No CT	No CT
027	Yes	Yes	Yes	None	Yes
072	Yes,	Yes	Yes	None	Yes
117	Yes	Yes	Yes	Yes	Yes (No SUV)
133	Yes	Yes	Yes	Bad CTs	Bad CTs
139	Yes,	Yes	Yes	No CT	None
142	Yes	Yes	Yes	Yes	Yes (No SUV)
147	Yes	Yes	Yes	No CT	None

Acceptable Cases:
015, 017, 029, 057, 077, 079, 081, 125, 132, 133, 139, 149, 159

DICOM Object Registration



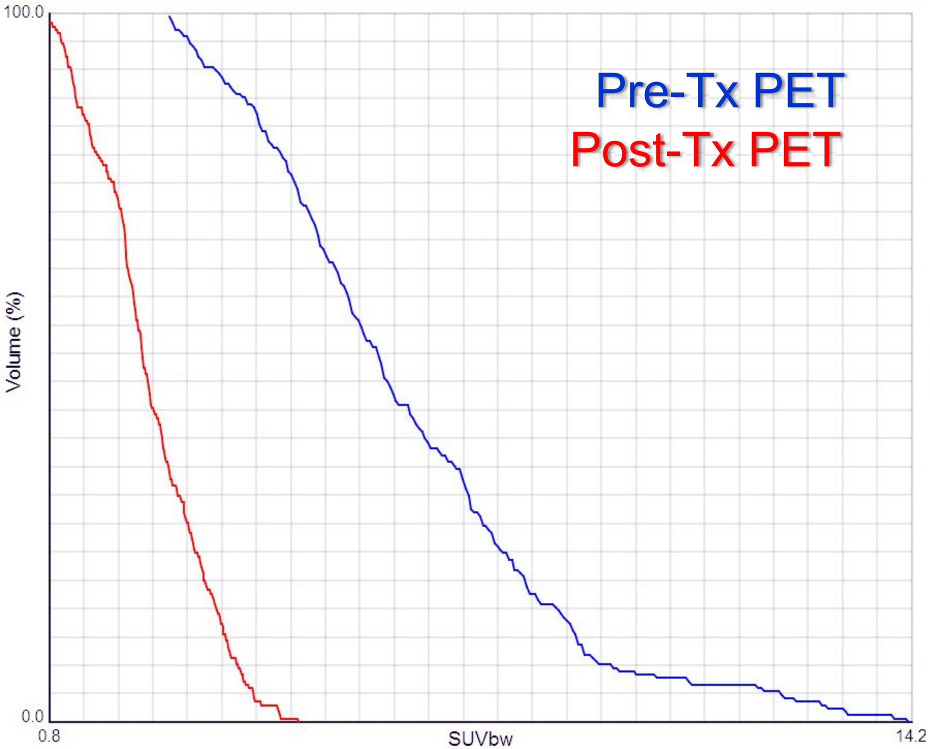
Pre-Tx PET fused w/ Planning CT and Dose



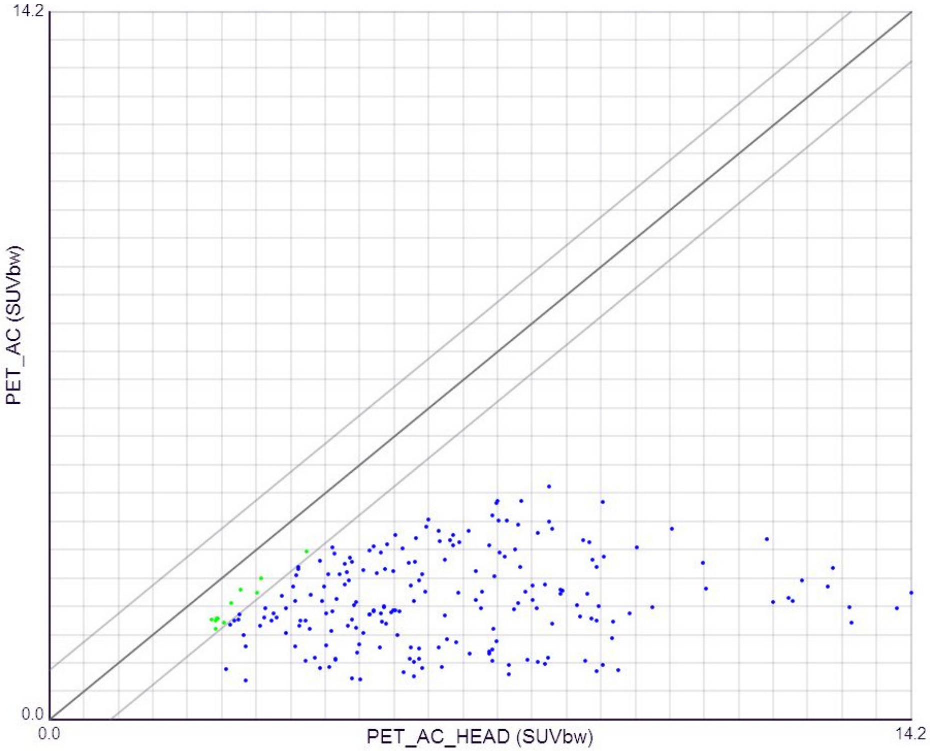
Post-Tx PET fused w/ Planning CT and Dose

Velocity Response for RTOG 0522

Compute volumetric and voxel response maps for quantitative assessment.

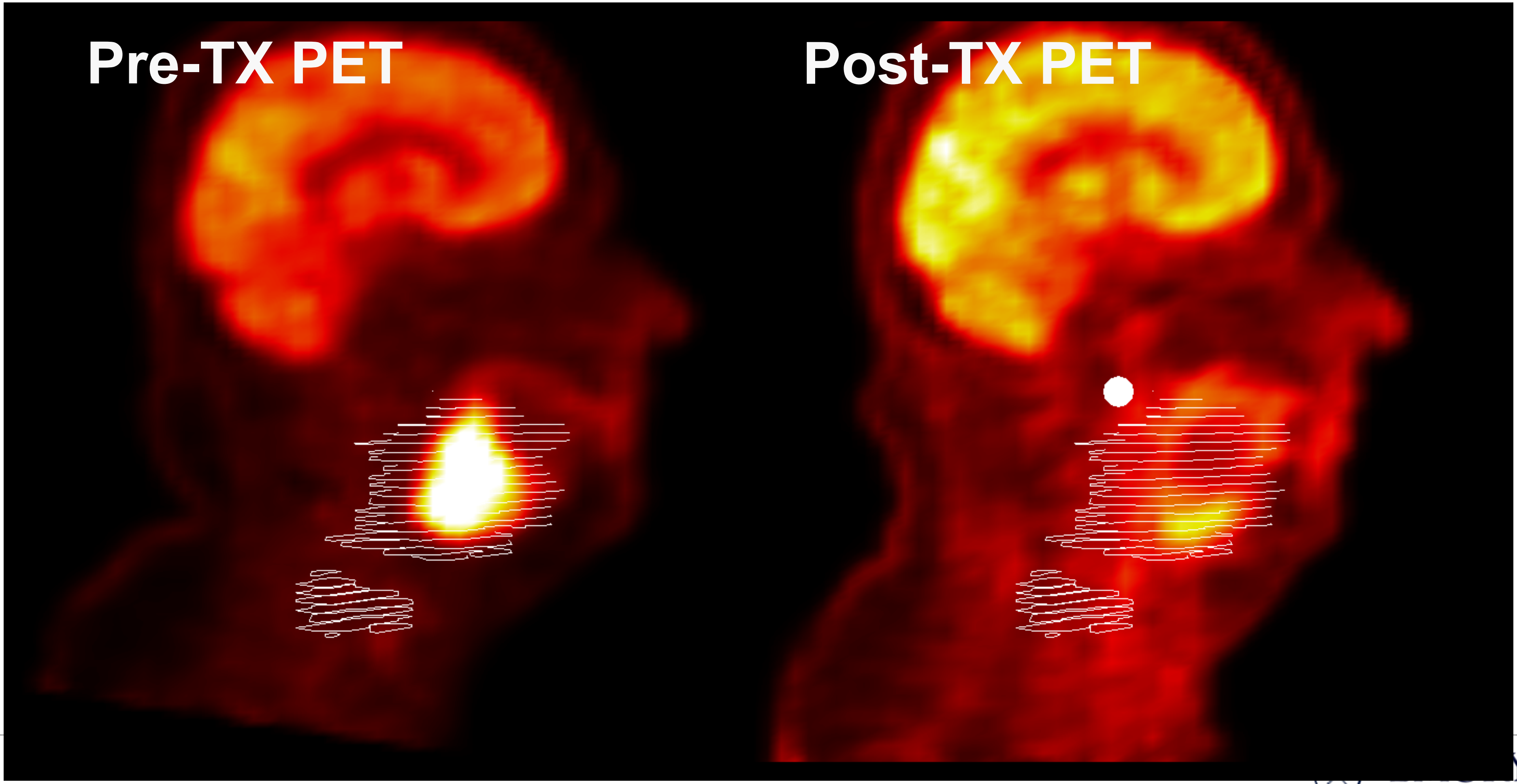


Metabolic Volume Histogram (MVH)



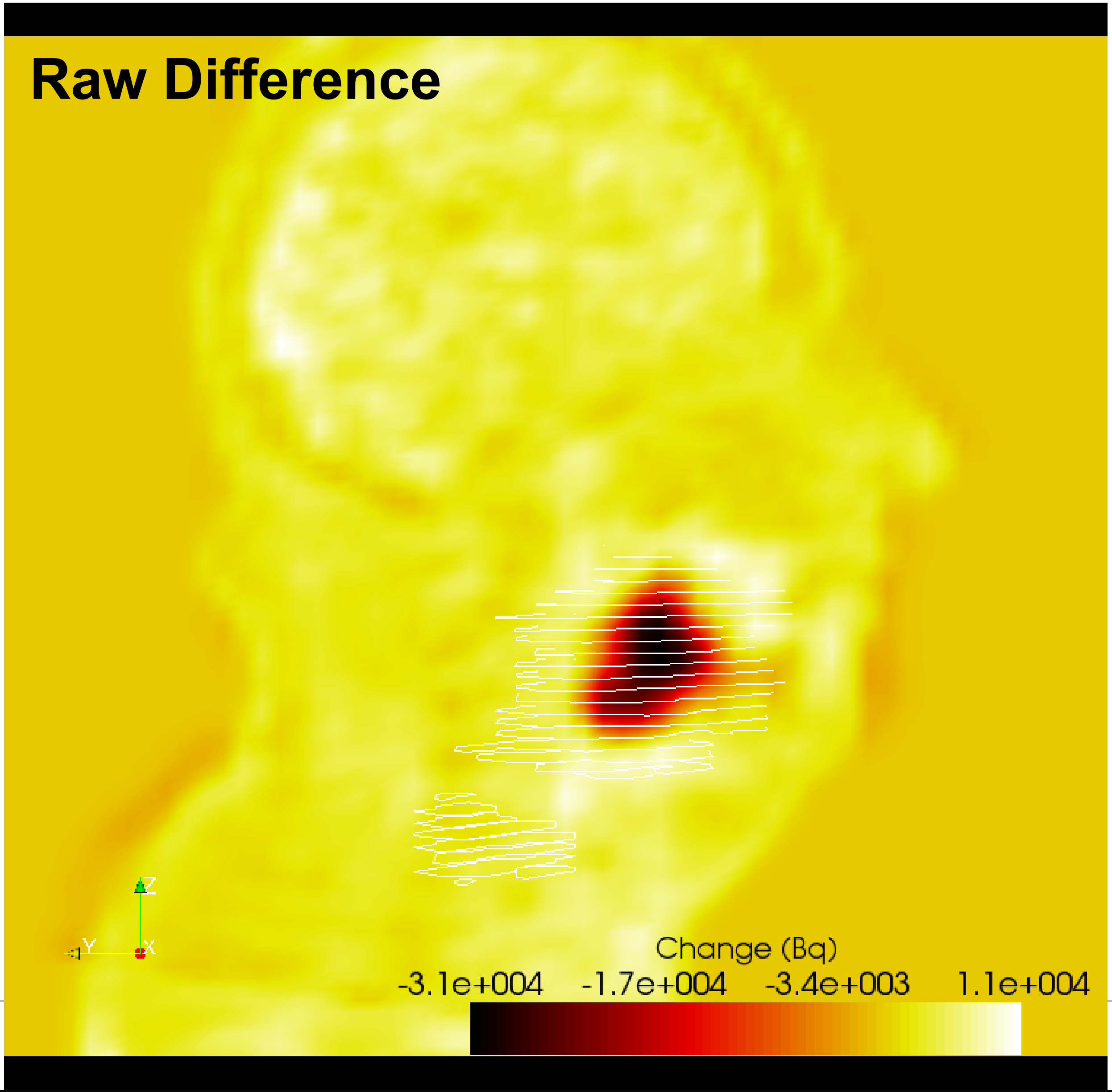
Voxel Map Response (VMR)

RTOG 0522: Pre and Post PET



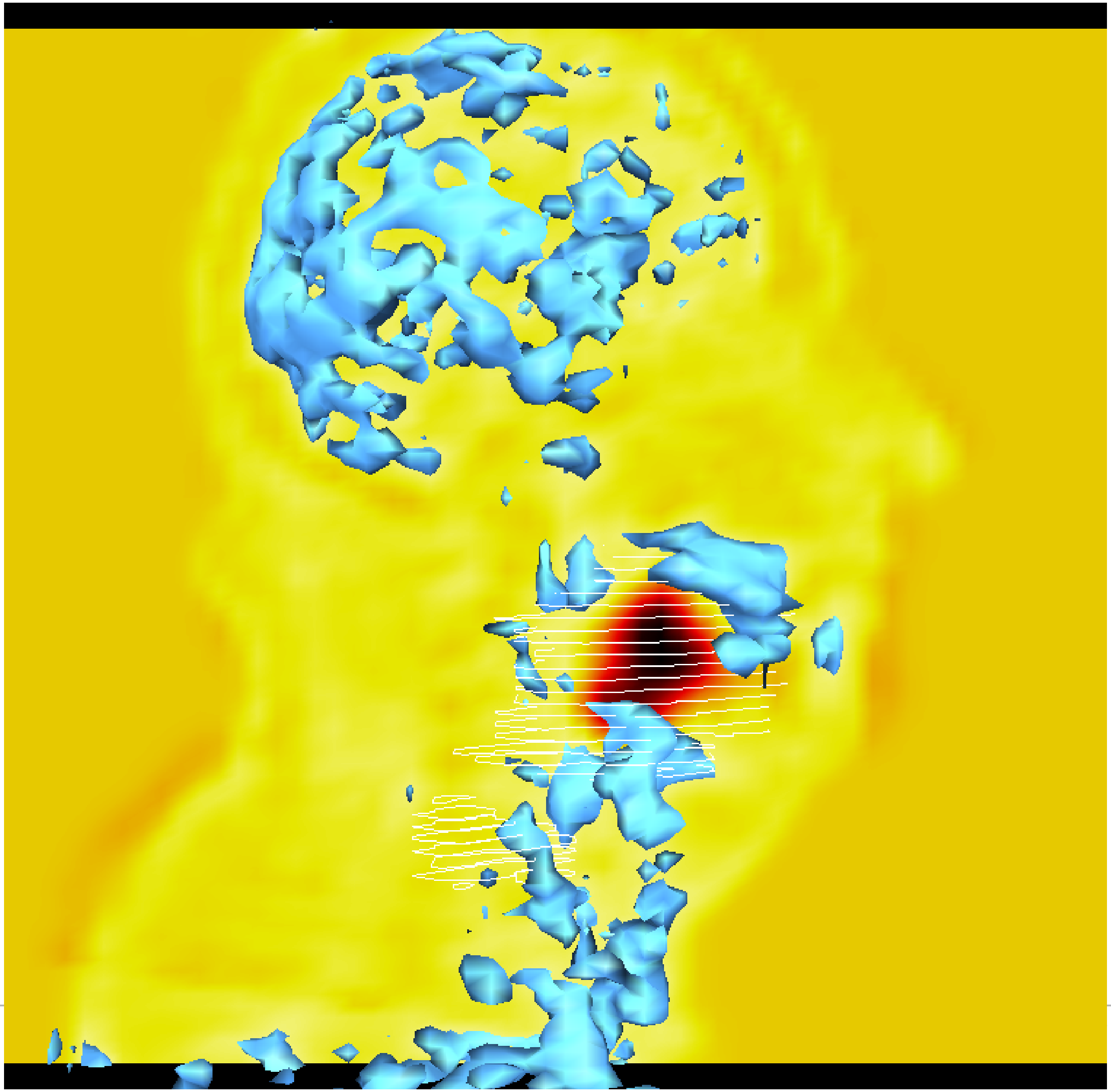
Raw Difference

- Regions of tumor response (black to red) are easy to identify.
- Regions of tumor progression appear as spots, hardly identifiable from noise



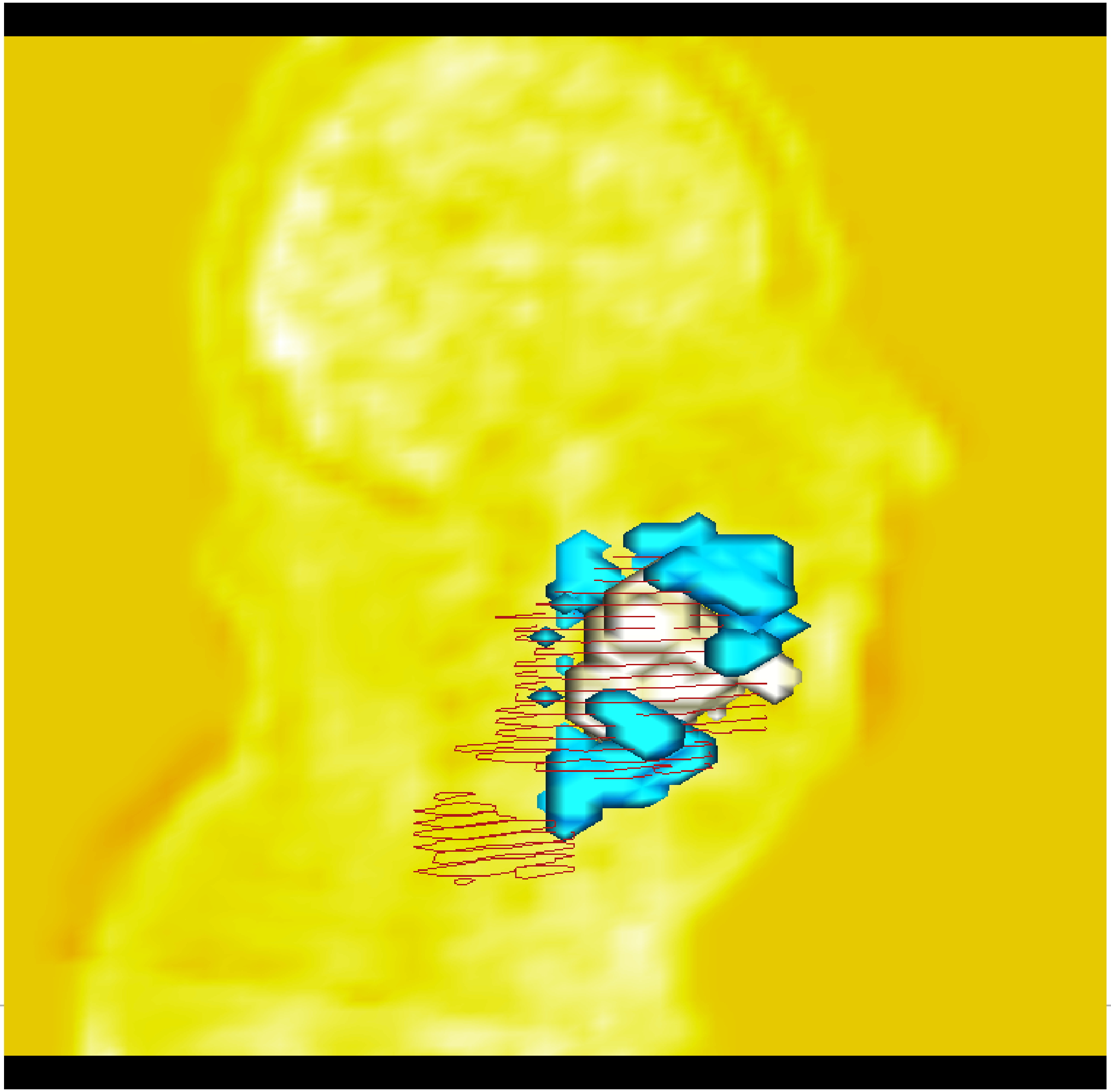
Simple Analysis

- Here we use a simple analysis tool to detect regions of tumor growth.
- Just thresholding would be affected by noise in the PET dataset

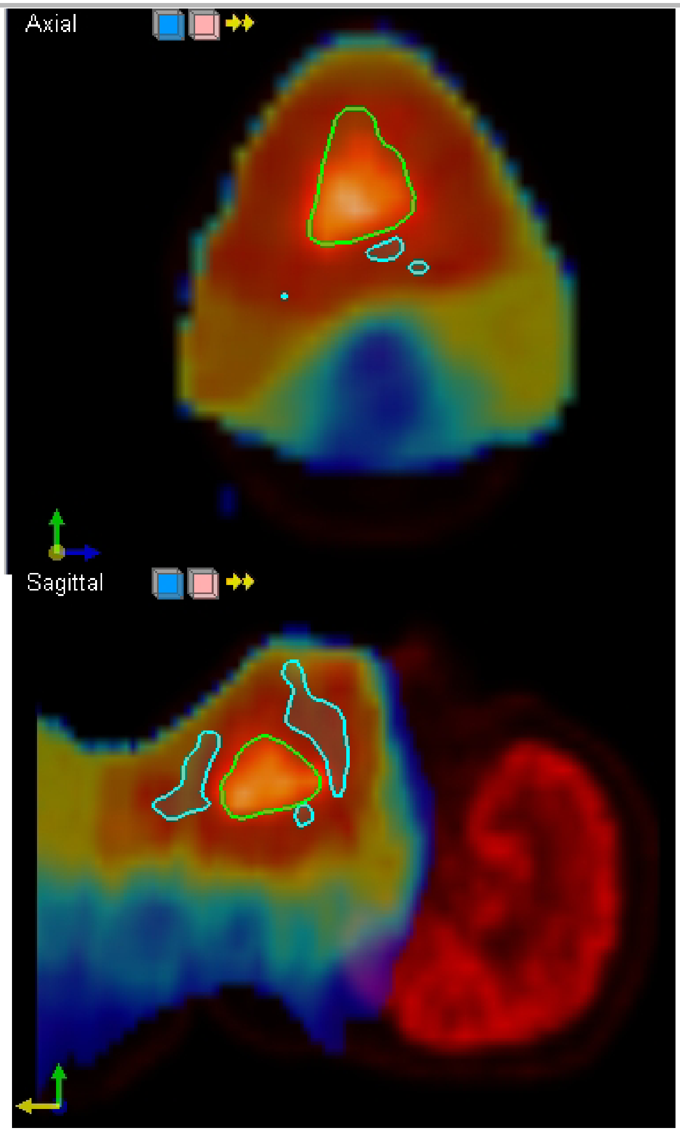


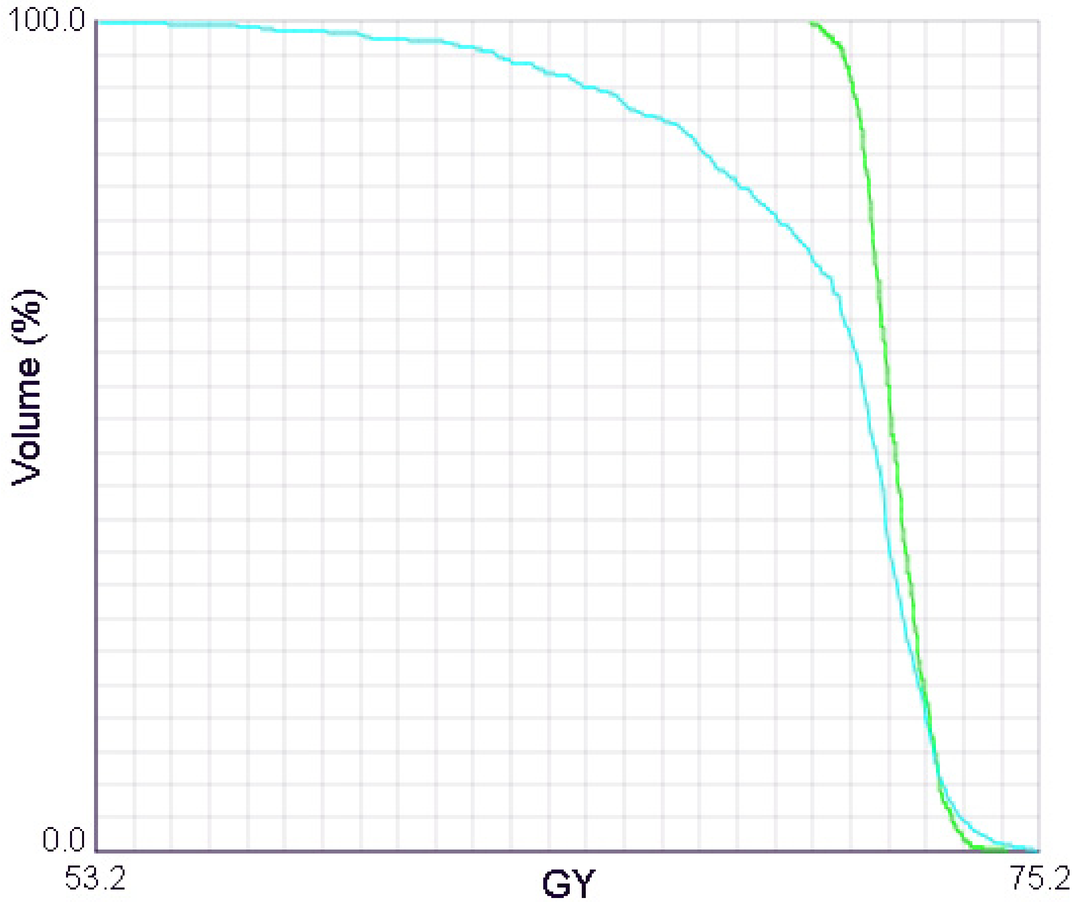
Level Set Based Clustering

Clustering algorithm to identify regions of tumor response (white) and tumor progression (blue)



PET Changes and RT Dose



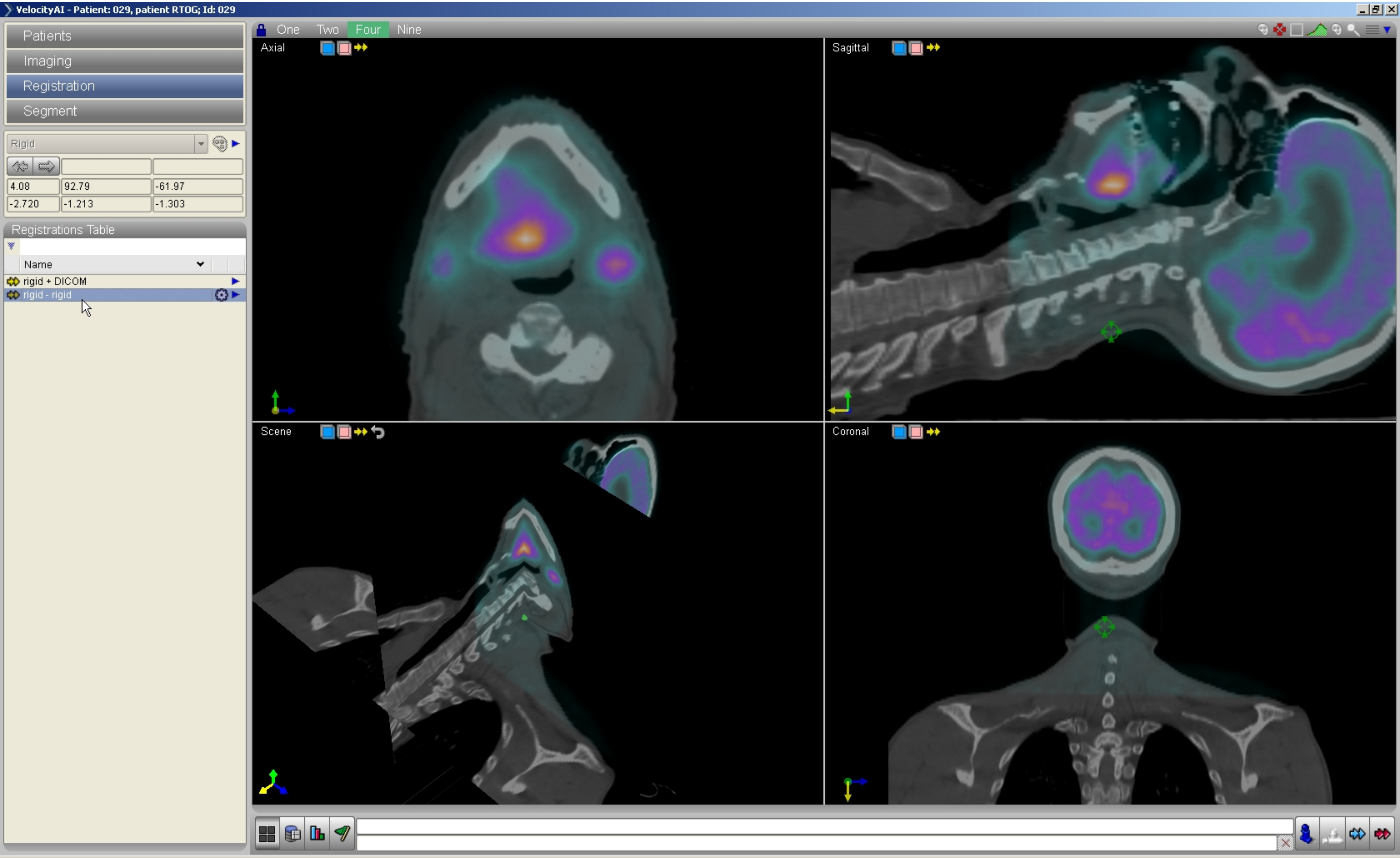


Preliminary Analysis: Case Examples

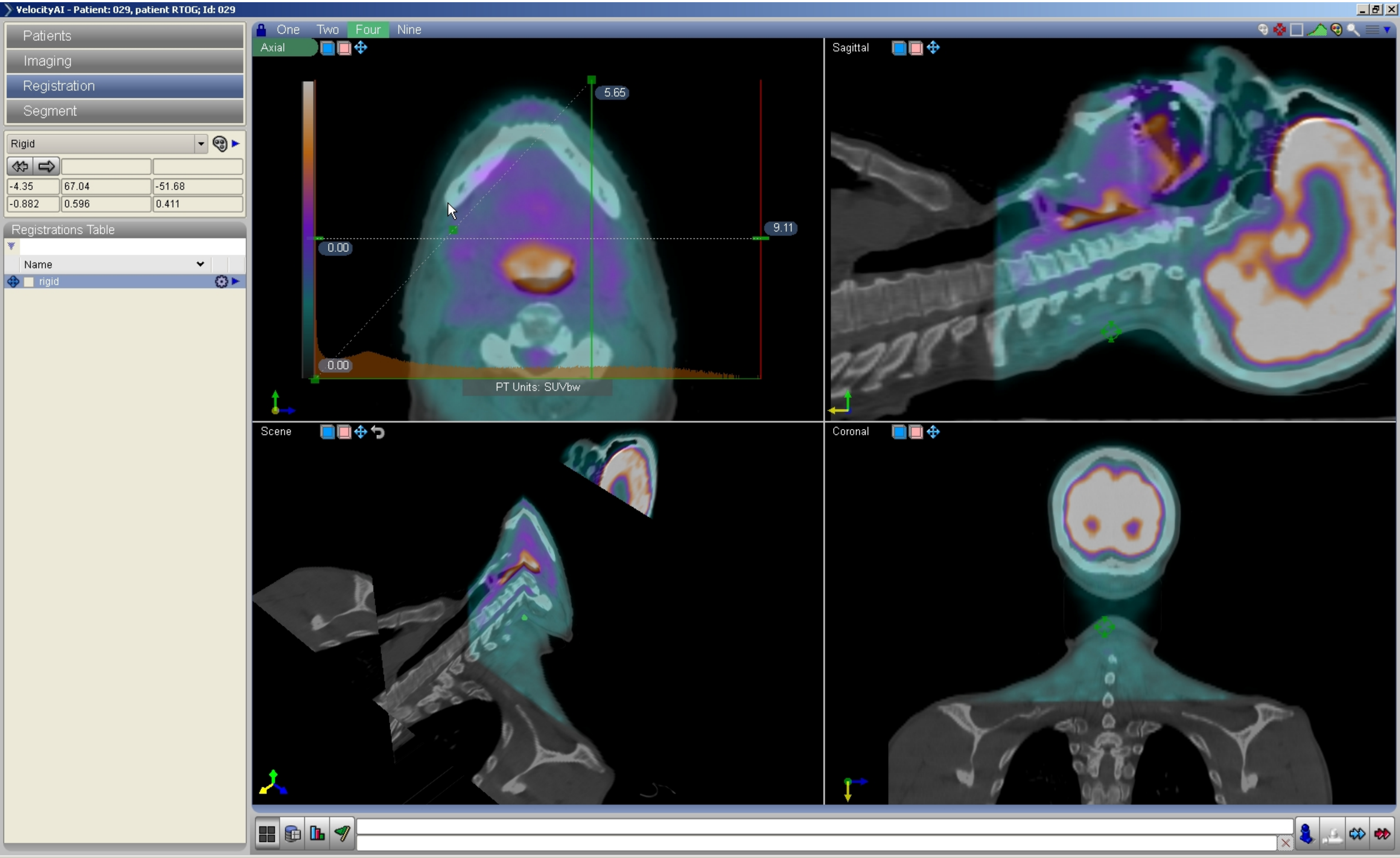
- **Case 013**: Possible geometrical miss, since there is activity at a peak 5 SUV growing out of the primary target.
- **Case 015** Not sure how to classify. There is some activity lightening up in the neck, that may or may not be normal. If it is normal, than this case is ok. If that activity in the post-TX scan is not normal, than this is due to some activity at % SUV in the pre-TX PET not included in the PTV.
- **Case 017:** There is some activity left in the lower region near the field. However, the plan looks good, geometrically. For this patient, there was a large tumor in the neck, that disappeared in the post-TX PET. In other words, tumor mass replaced with air. Would it be possible that changes in beam absorption would alter the dose distribution near the field edges, lowering the given dose ?
- **Case 029** – This seems to be another geometric miss because the head posture was different between the pre-tx Pet and sim CT.

Case 29

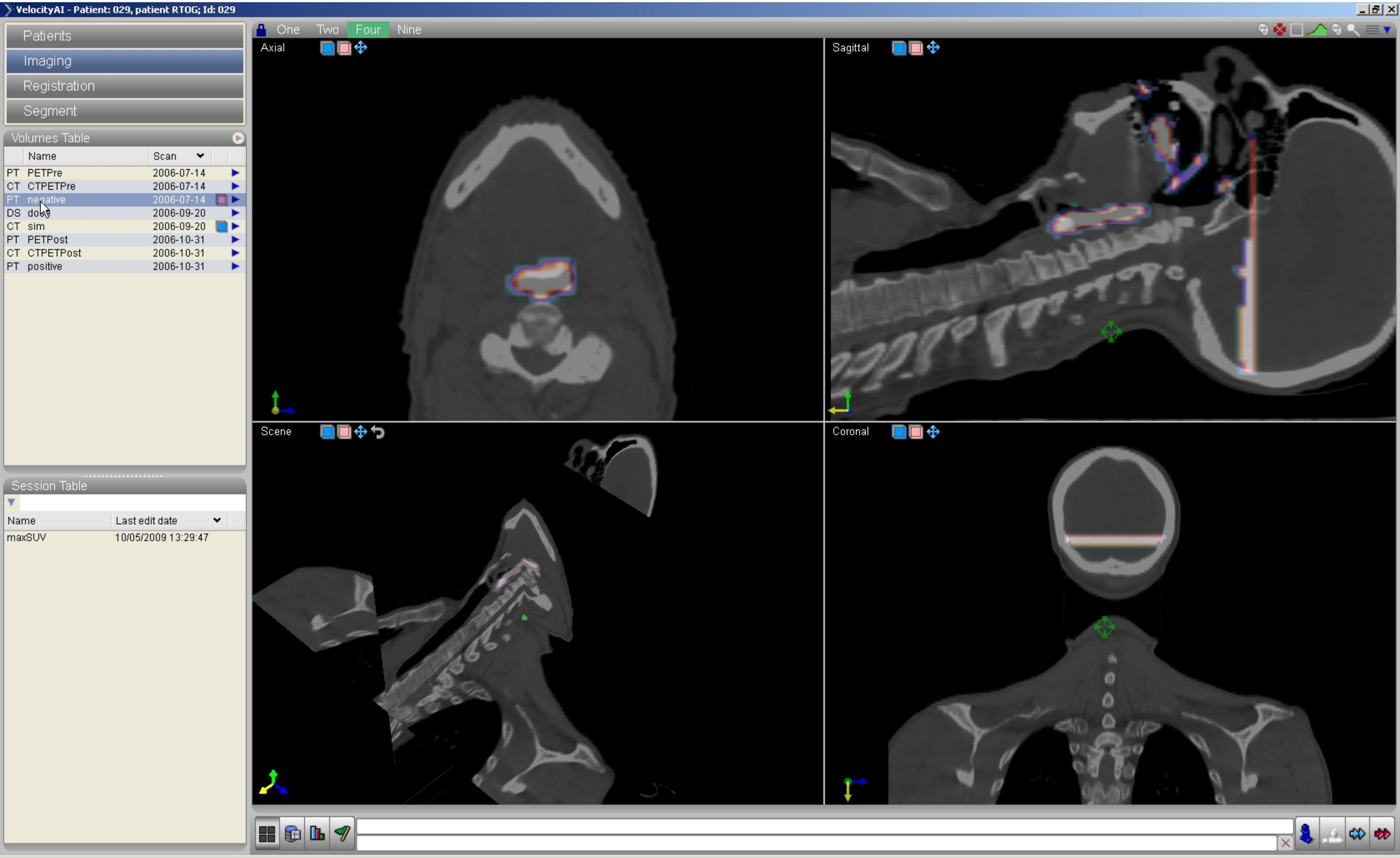
Pre-Tx PET & PlanCT: Rigid Registration



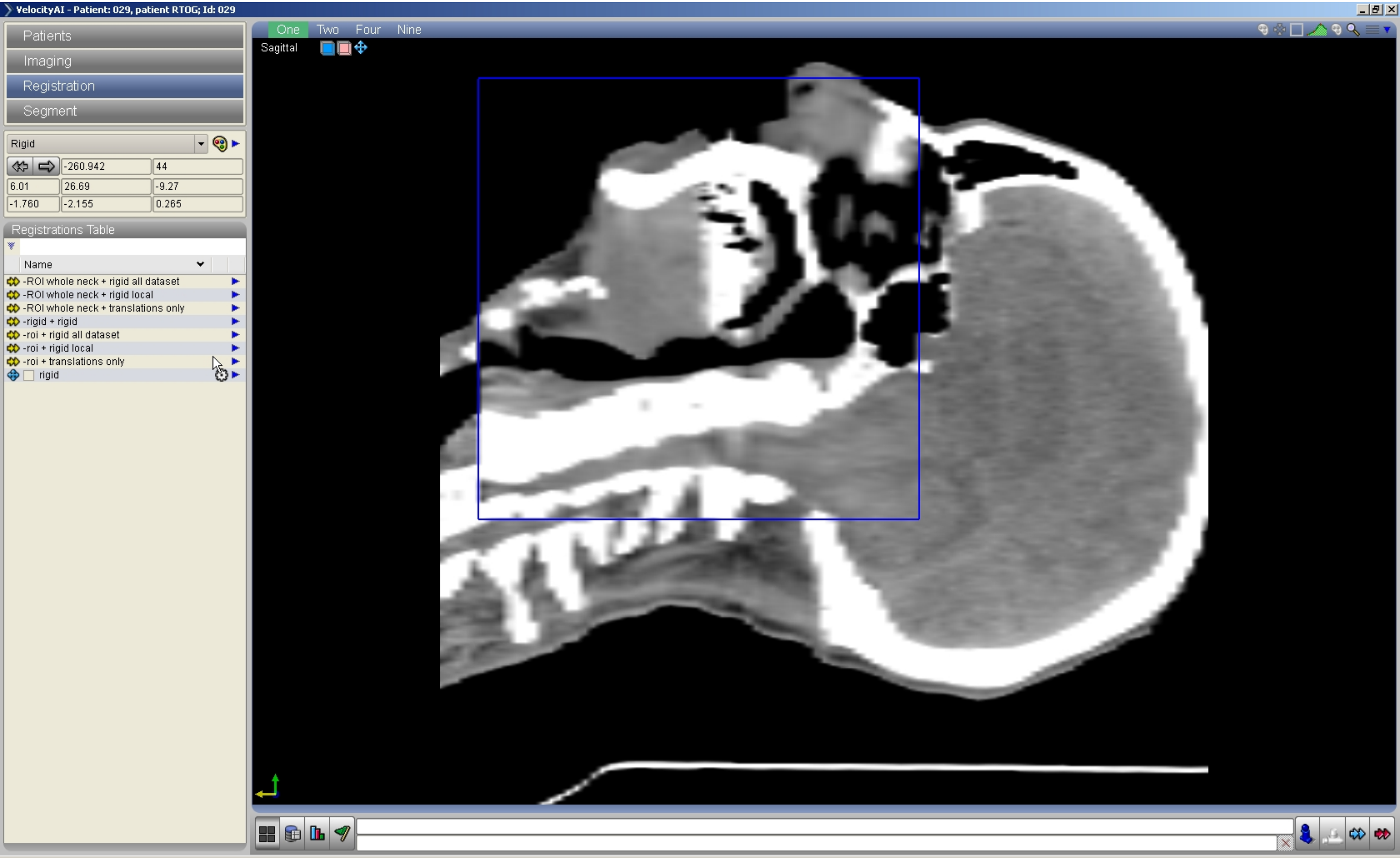
Post-Tx PET & PlanCT: Rigid Registration



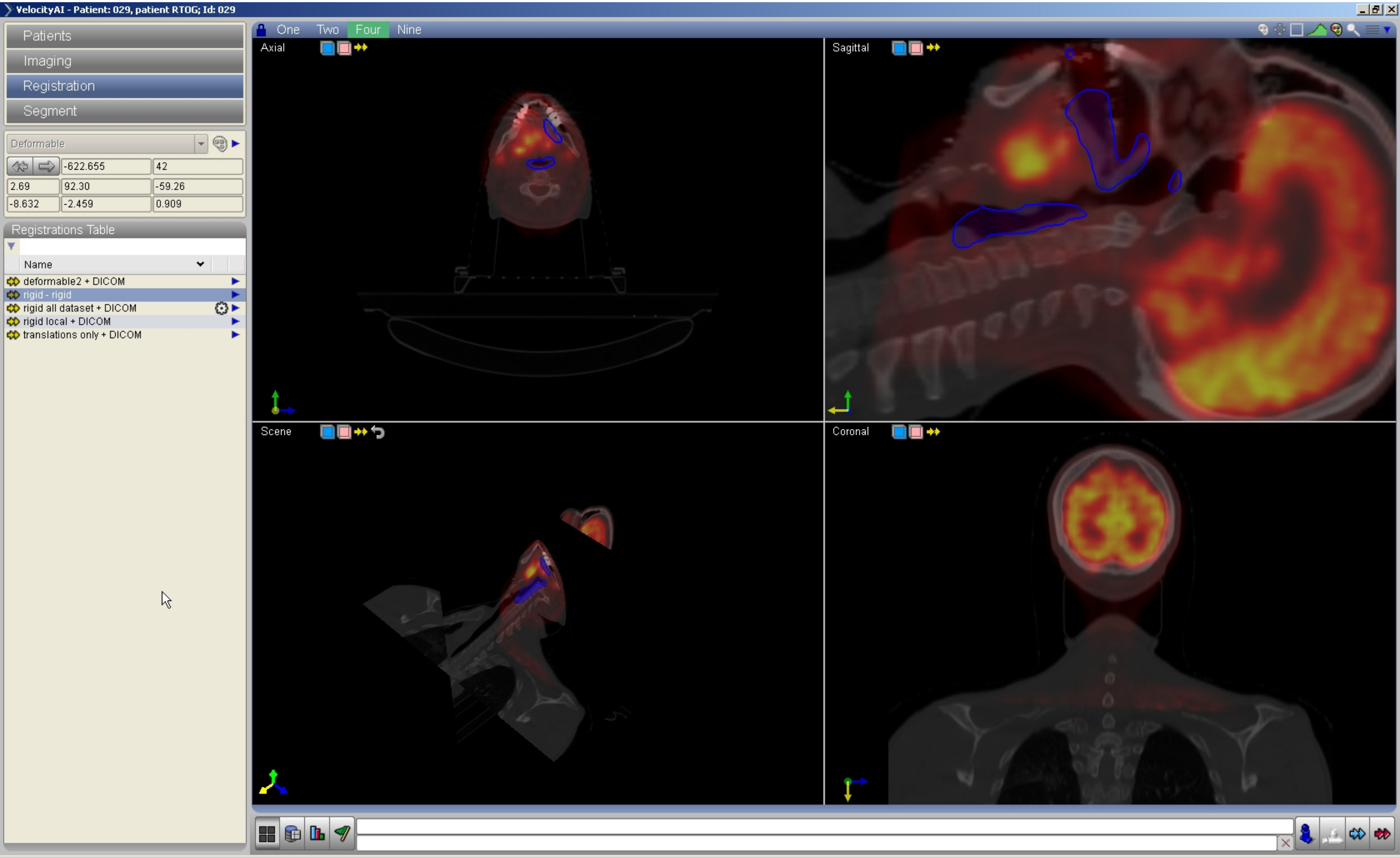
Clustering analysis of increased SUV on Post-Tx PET



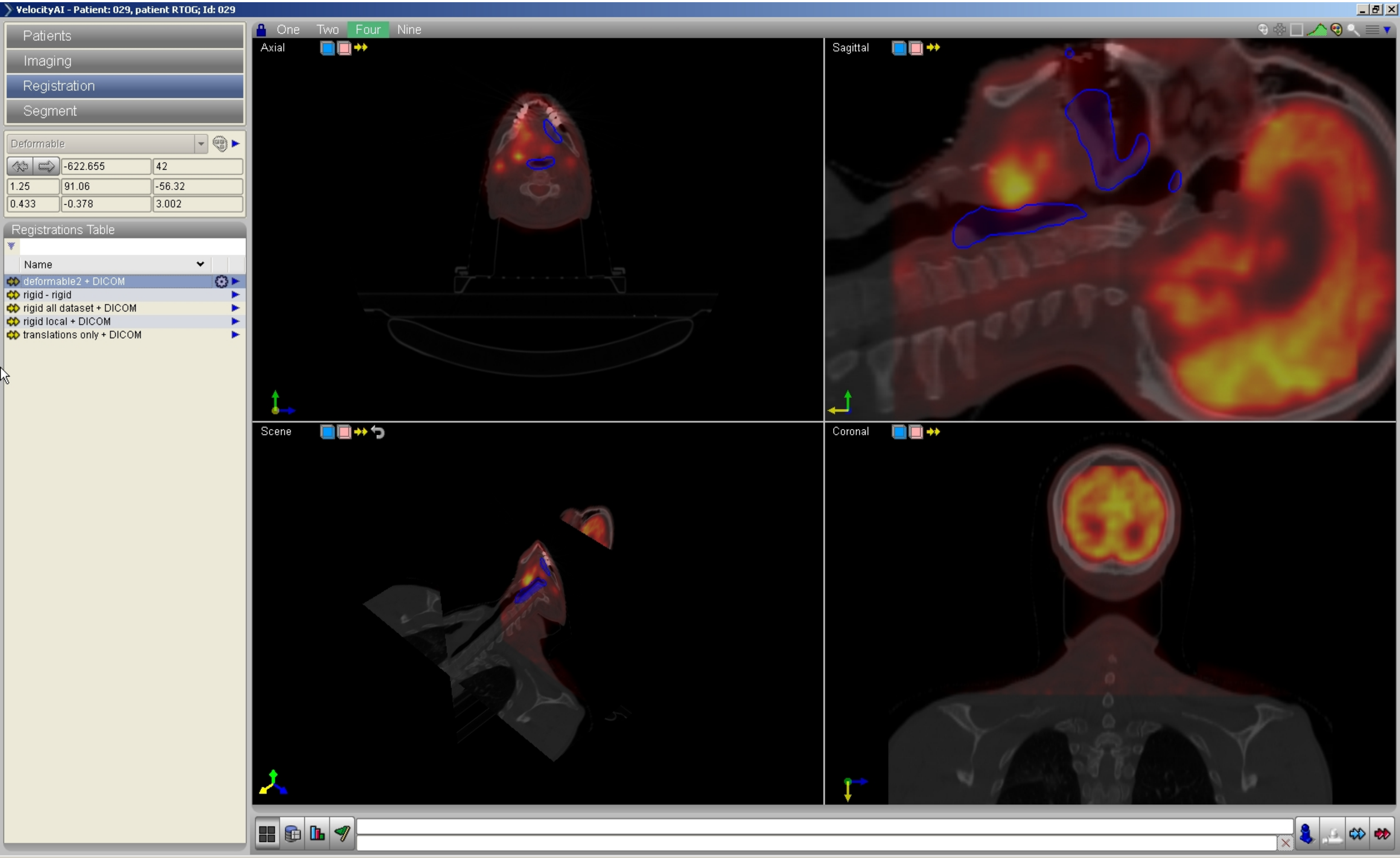
CT of Pre-Tx and Post-Tx PET: Chin position?



Rigid Registration: Pre-Tx PET to PlanCT



Deformable Registration: Pre-Tx PET to PlanCT

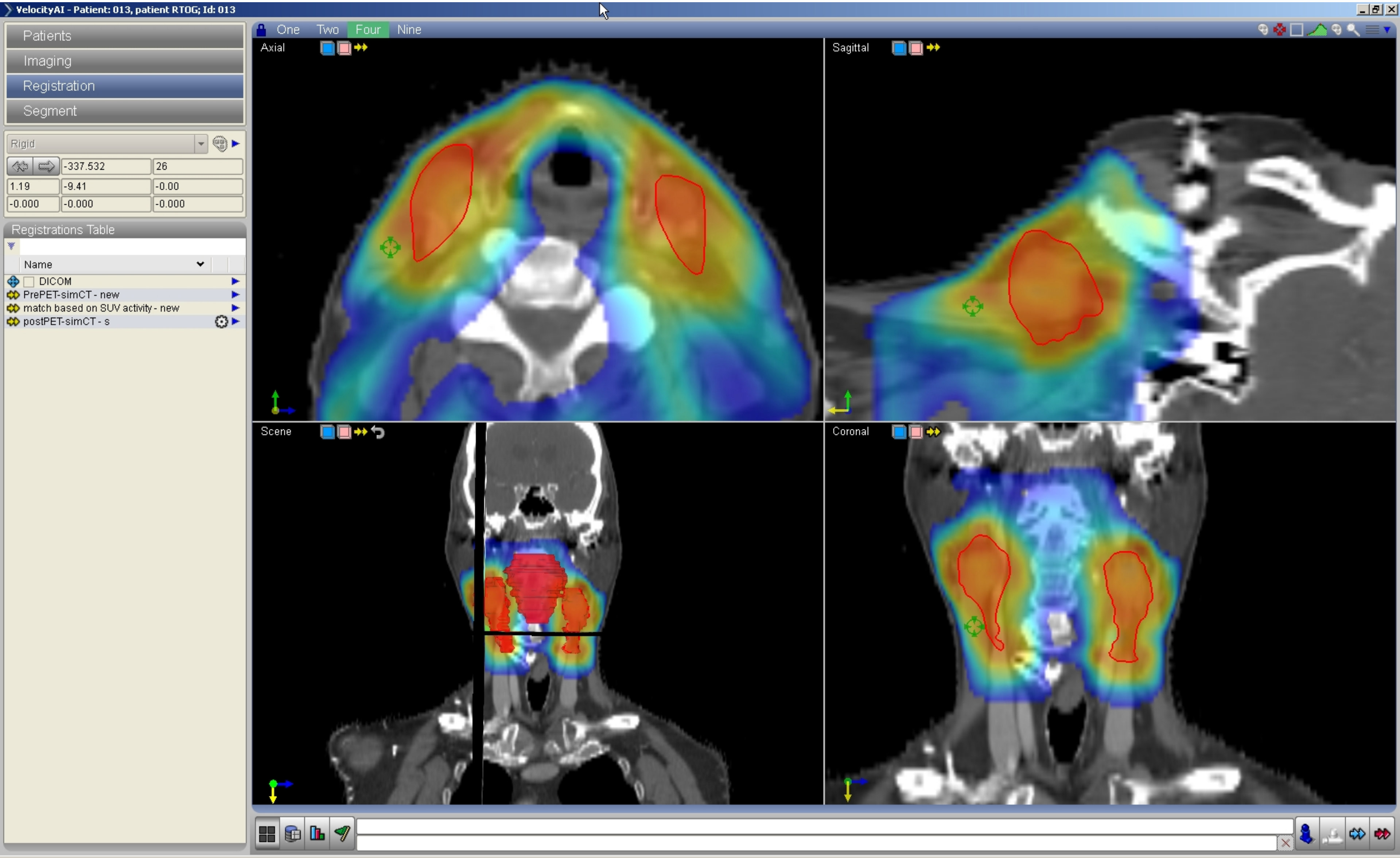


ASTRO 2009 Poster: PET-CT Tumor Delineation & Dosimetric Consequences from Image Registration Methods

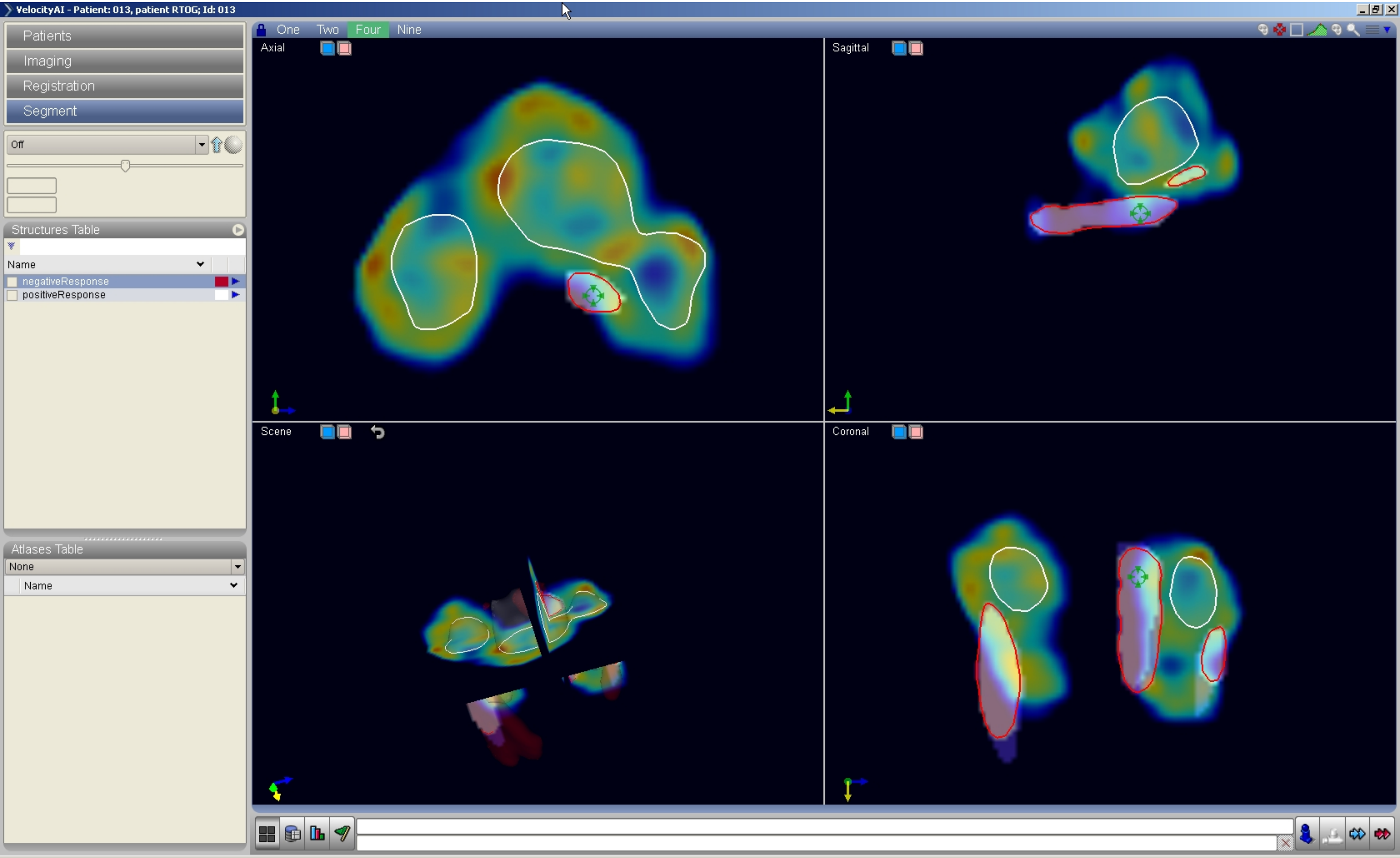
- **Methods to incorporate previously obtained PET/CT data include rigid registration techniques (RRT) and deformable registration techniques (DRT).**
- The DRT uses a constrained intensity-based free-form deformable CT-CT registration algorithm allowing for the diagnostic CT scan to be deformed in order to match the neck position of the planning CT scan.
- Retrospectively evaluated 10 head-and-neck cancer patients that were planned and treated without PET fusion.
- The GTV and PTVs were defined as the actual GTV and PTV used for radiotherapy contoured from nonfused PET scans and clinical data.
- These clinical contours were compared to PET-derived GTVs obtained via RRT or DRT techniques.
- **The DRT for PET fusion is <u>superior</u> to RRT in terms of accurately defining tumor location.**
- **We have also shown that this has dosimetric consequences in that the variation from RRT-defined GTVs would result in significant changes in PTV coverage.**

Kubicek et al. "PET Registration Methods and Dosimetric Consequences,"
Thomas Jefferson University Hospital, Philadelphia, PA
Department of Computer Science, Wake Forest University, Winston-Salem, NC

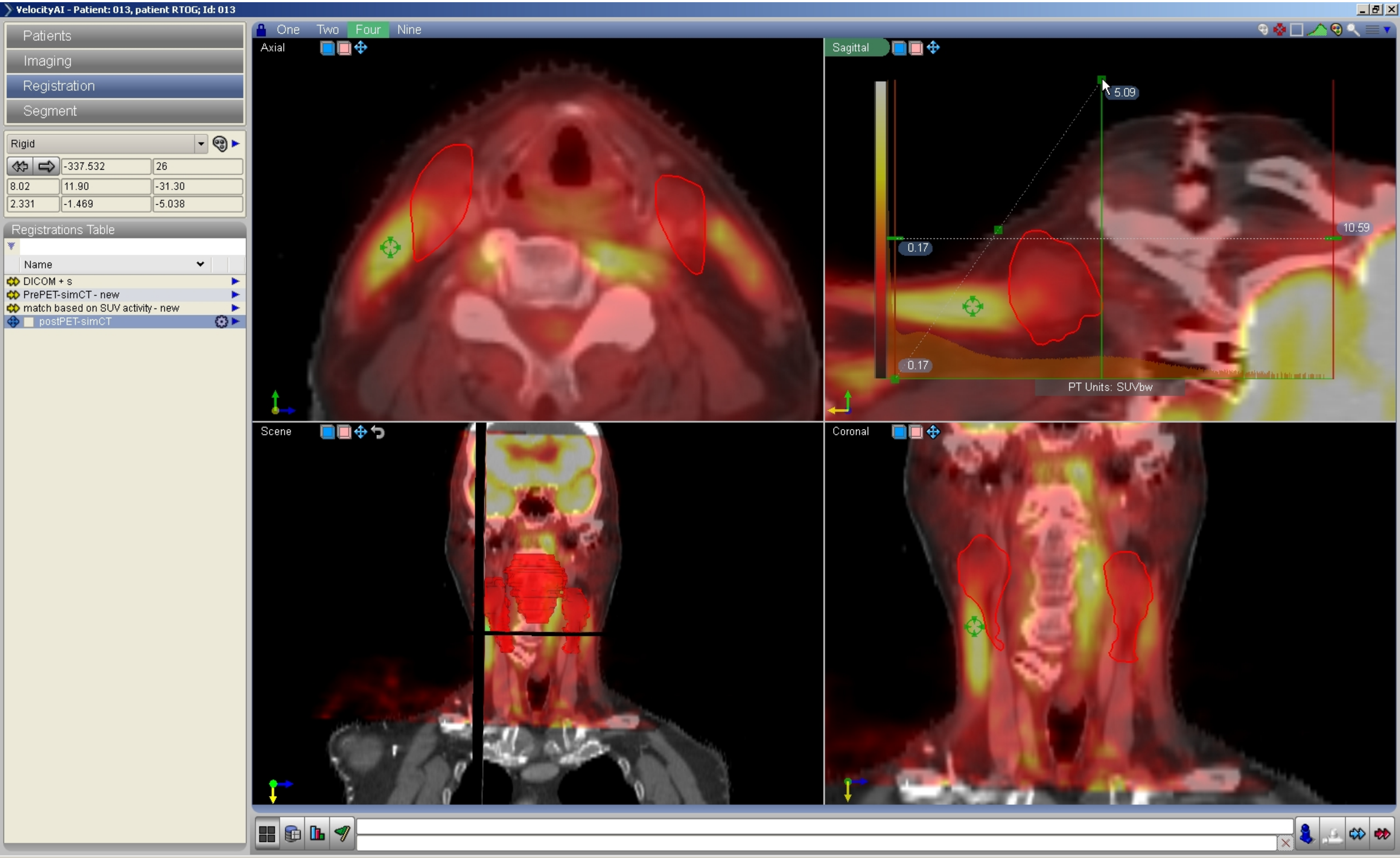
Case 13: Dose and PTV



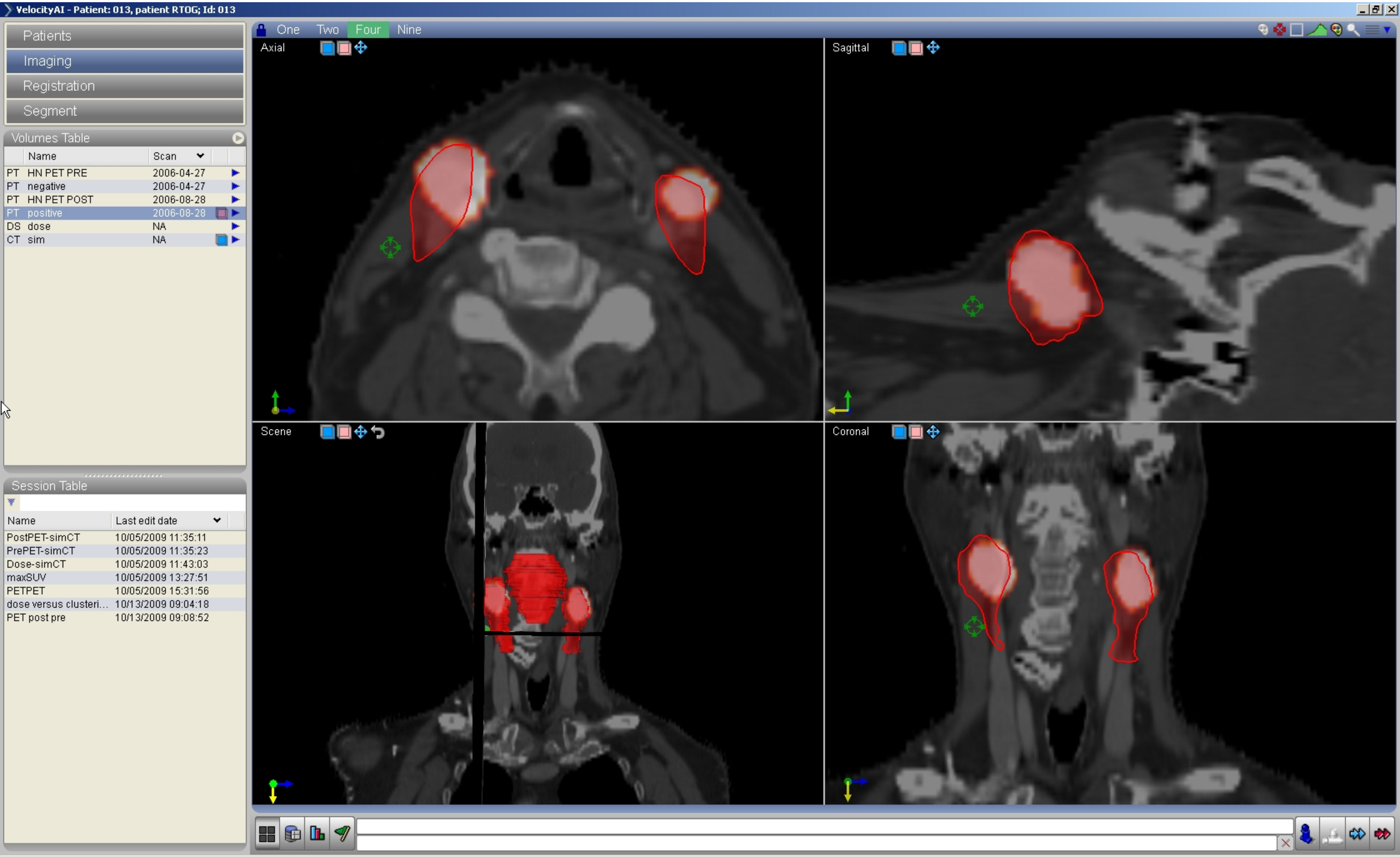
Dose vs Clustering



Post-Tx PET & PTV: Areas of Increased SUV



PTV & Clustering: Good response overlaps with PTV



PTV & Clustering: Poor response outside of PTV and RT field