

# A methodology for assessing and improving the total geometric accuracy in gamma knife radiosurgery

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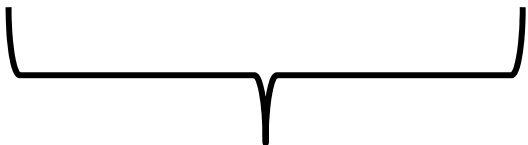
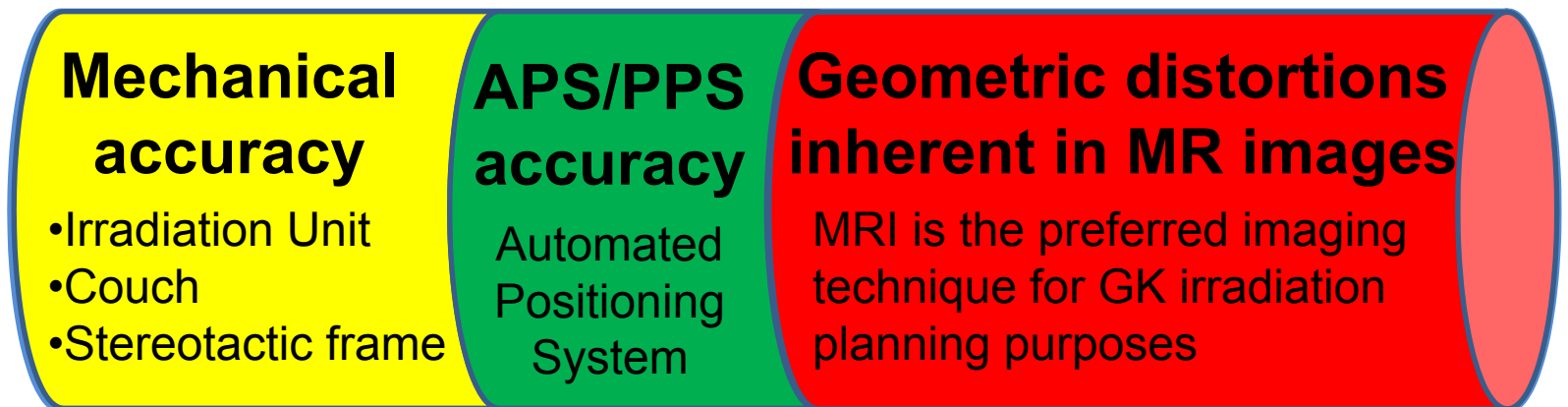
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MANAGING AUTHORITY

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**< 0.5 mm**



**Machine and Patient related**

# Study Background

The total geometric accuracy of GK treatment delivery may be impaired due to the spatial distortions inherent in the MR images used for target volume definition in 3D space.

These distortions vary

- from system to system
  - ✓ gradient coil design
  - ✓ magnetic field strength and its homogeneity
  - ✓ imaging protocol parameters
- from patient to patient
  - ✓ Susceptibility and chemical shift artifacts

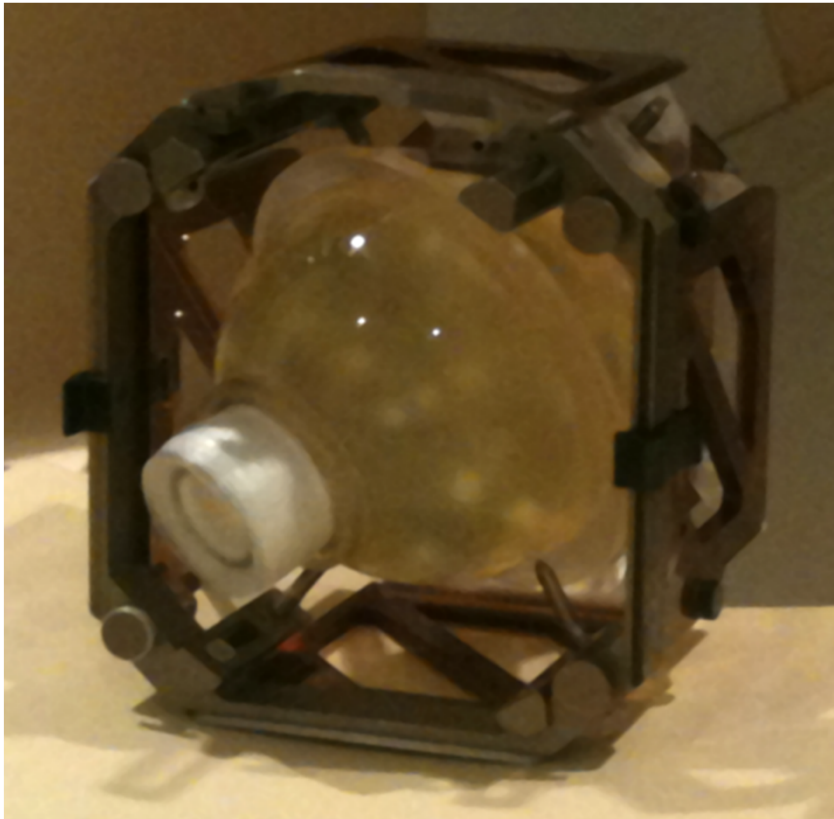


# Purpose

- ❑ To present an end-to-end experimental procedure, based on a polymer gel phantom, capable of assessing the total geometric uncertainty in GK radiosurgery applications, in which MR images are solely used for both target delineation and registration of patient image coordinates to the Leksell space.<sup>1</sup>
- ❑ to propose a time-efficient method, based on corresponding polymer gel results, which considerably improves the geometric accuracy in GK treatment delivery.

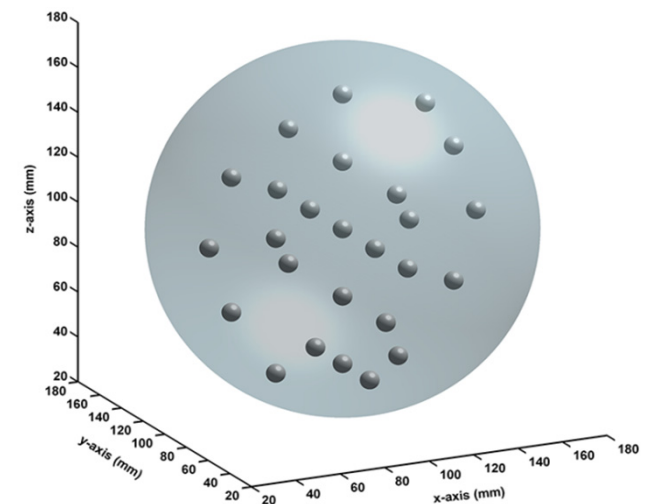
<sup>1</sup>Moutsatsos *et al.*, Med. Phys., **40**(3), 031704-1 031704-14 (2013)

# Methods

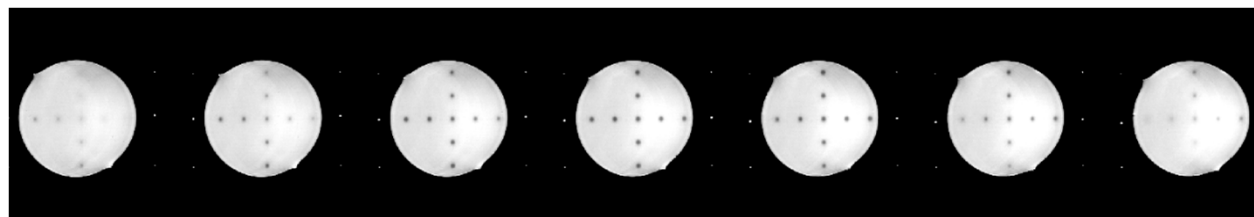


- Custom-made PMMA spherical phantom
- VIP normoxic gel formulation
  - ✓ Tissue-like MRI properties
- Accurate representation of every link in the GK treatment chain; from patient imaging and treatment planning to patient positioning and dose delivery using the patient positioning system (PPS) of a PERFEXION GK model

- 26, 4-mm single shots (25 Gy maximum dose) were planned and delivered to the gel substance covering a region spanning from 40 to 160 mm in each direction of the Leksell stereotactic space. Planning was performed on pre-irradiation CT images of the phantom.



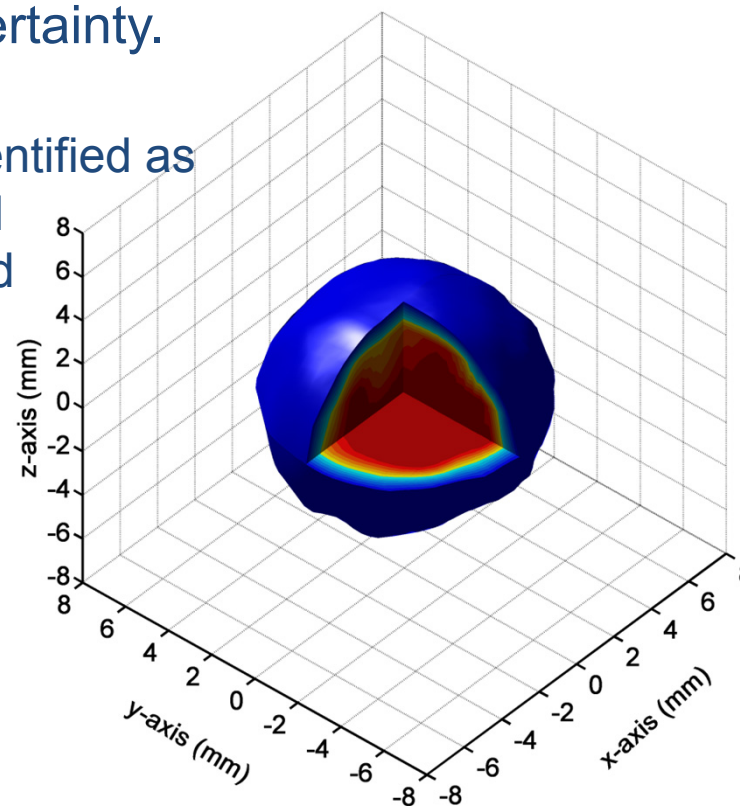
The irradiated phantom was imaged at 1.5 T employing a T2-weighted pulse sequence commonly applied for clinical target delineation.



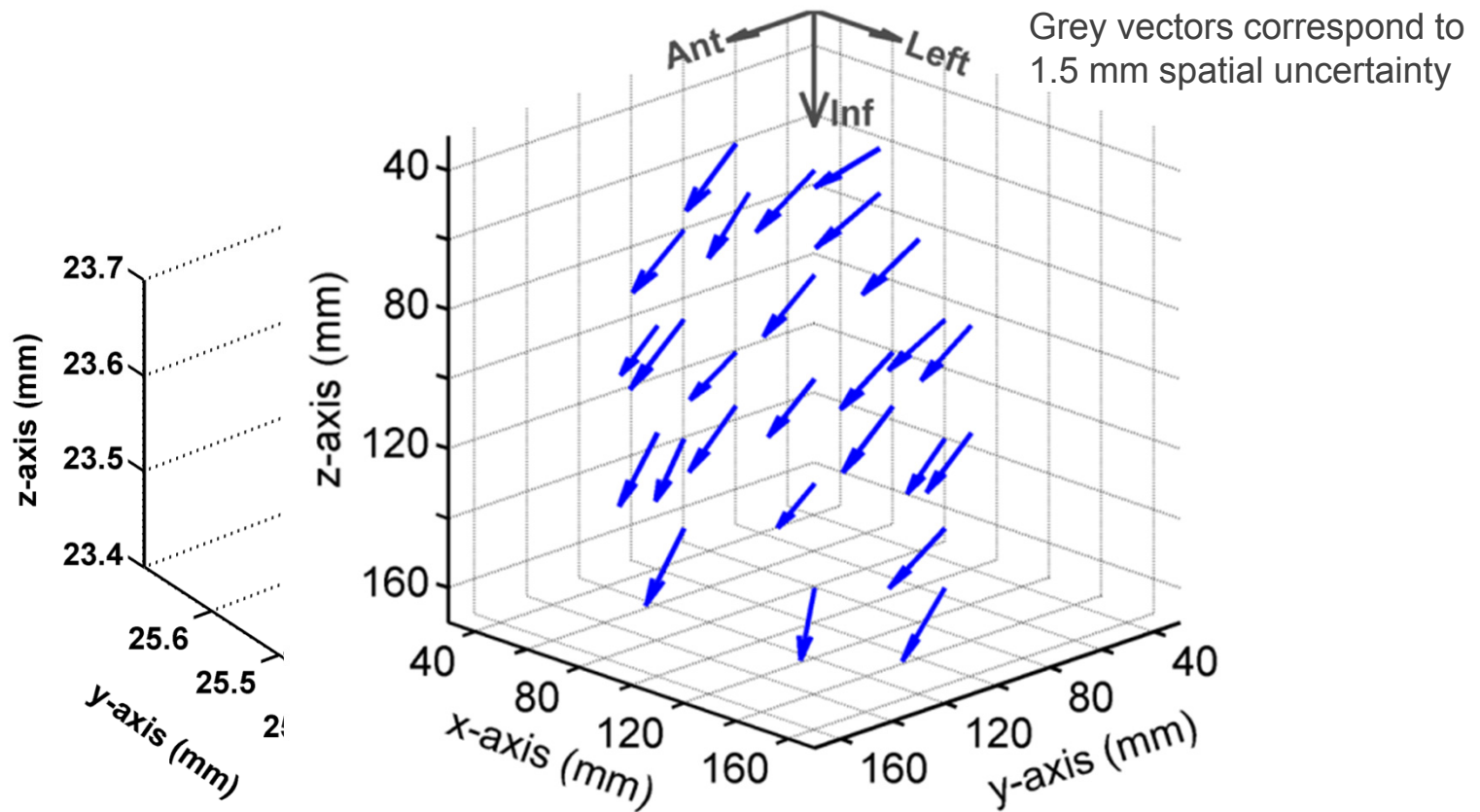
The center of each GK shot served as a “control point” in the assessment of the GK total geometric uncertainty.

In the obtained MR series, these points were identified as the centre of mass (CM) of the radiation induced polymerization area corresponding to a delivered GK shot.

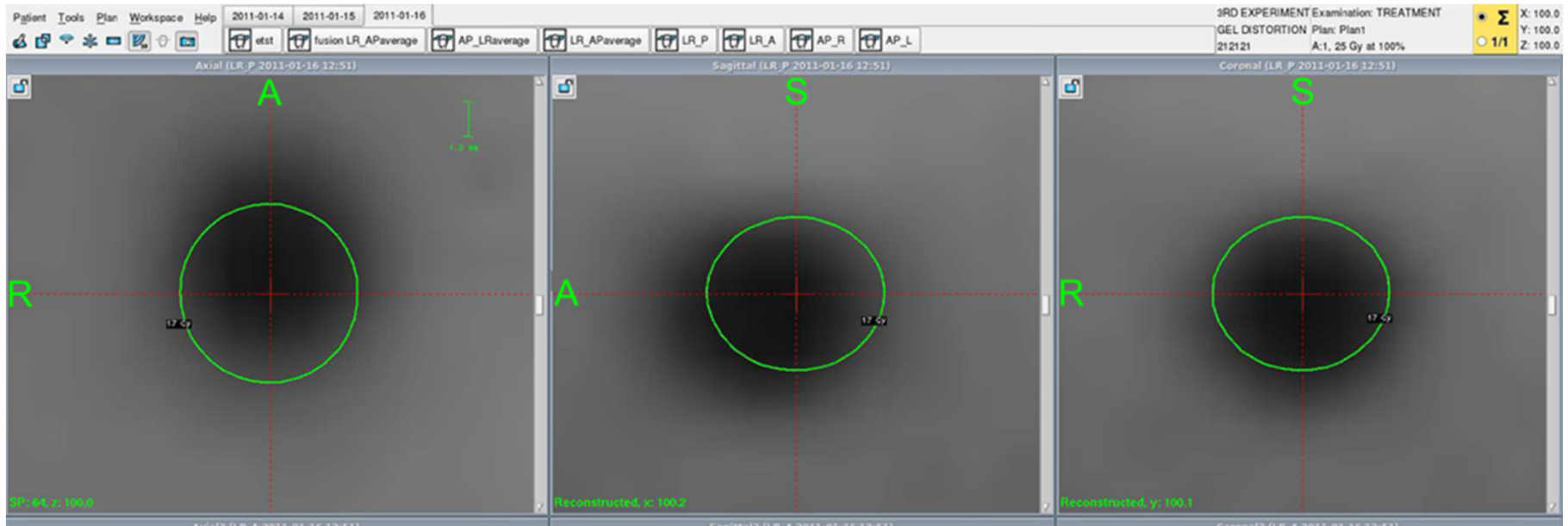
CM coordinates were determined with sub-millimeter accuracy, using an in-house written algorithm which exploits the symmetry that the MR signal intensity distributions are expected to exhibit in space with regard to their CM, in view of the corresponding symmetry characterizing GK single shot dose distributions.



For each control point, the total geometric uncertainty ( $u_{tot}$ ) was determined by comparing the CM coordinates of the corresponding polymerization area in the acquired MR images to its “reference” location which corresponds to the shot’s planned coordinates (determined also in the MR coordinate system through DICOM-RT dose export).



## But, also...

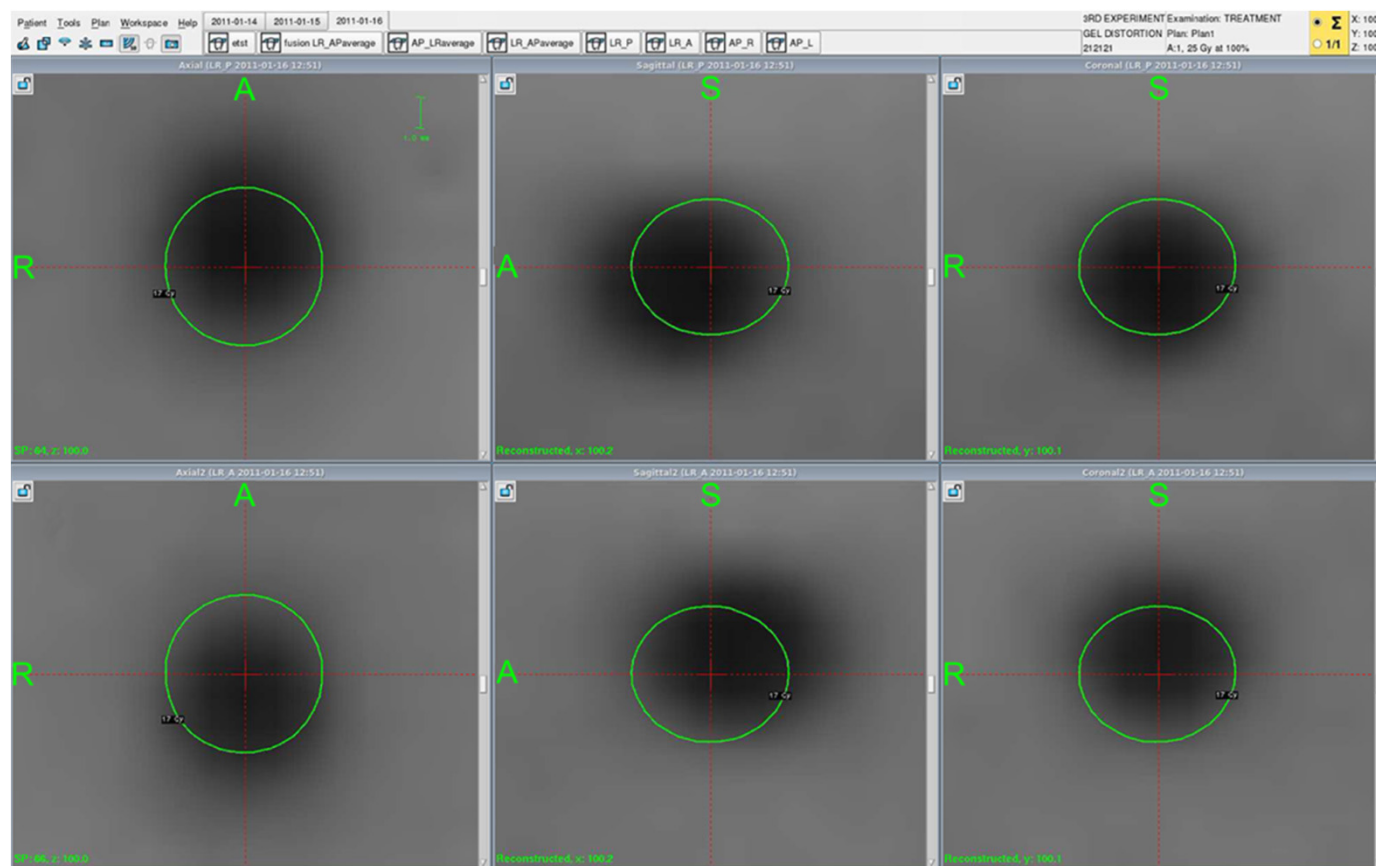


The proposed method allows for the semi-quantitative assessment of the total spatial uncertainty by the user directly in the TPS environment!

# A key-observation towards the improvement of GK total geometric accuracy...

The vector of the total geometric uncertainty,  $u_{\text{tot}}$ , exhibits a directional dependence with respect to the frequency encoding axis and **read gradient polarity** (direction) selected during MRI acquisition.<sup>1</sup>

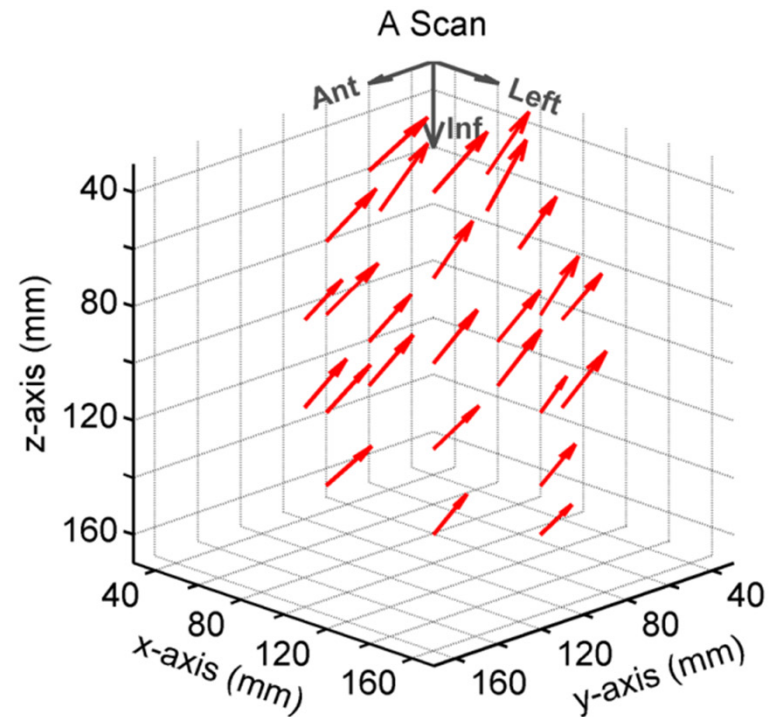
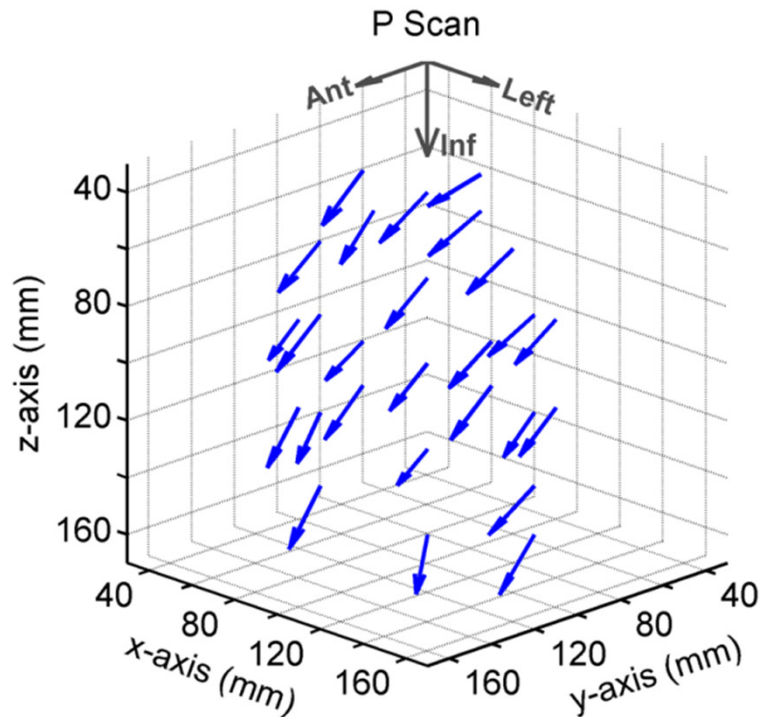
Read gradient polarity



<sup>1</sup>Moutsatsos *et al.*, *Med. Phys.*, **40**(3), 031704-1 031704-14 (2013)



# Polymer gel phantom $u_{tot}$ results



Mean: P-scan (clinically used) :  $1.02 \pm 0.09$  mm  
A- scan (reversed gradient polarity):  $1.15 \pm 0.24$  mm

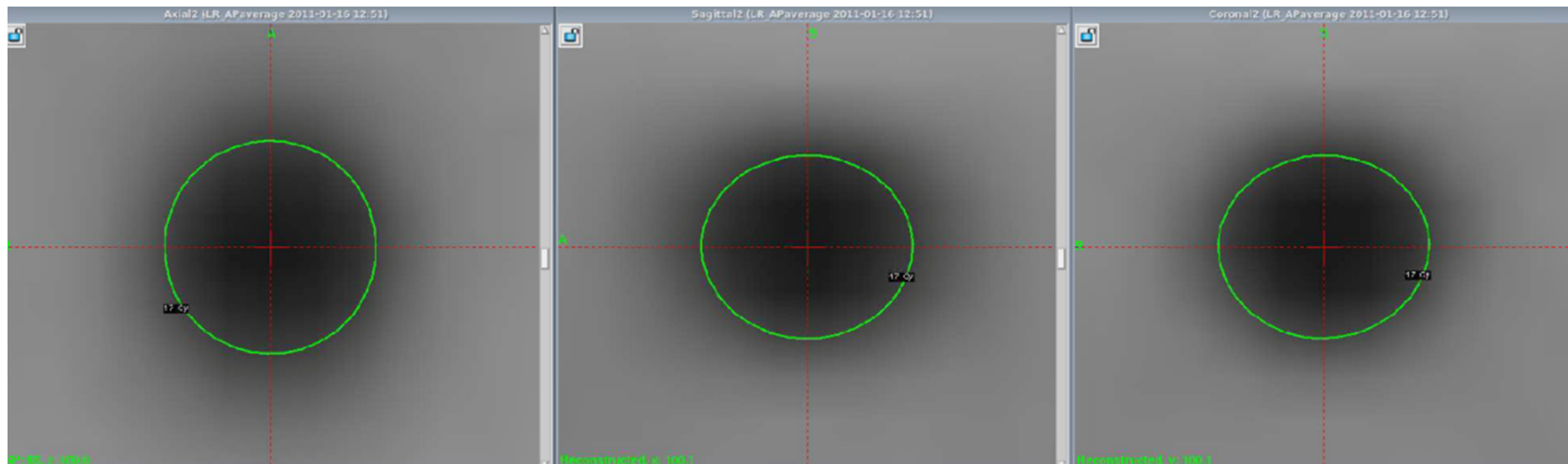
Range: 0.72 mm (minimum in A-scan) -1.65 mm (maximum in A-scan)

# “Average” image series

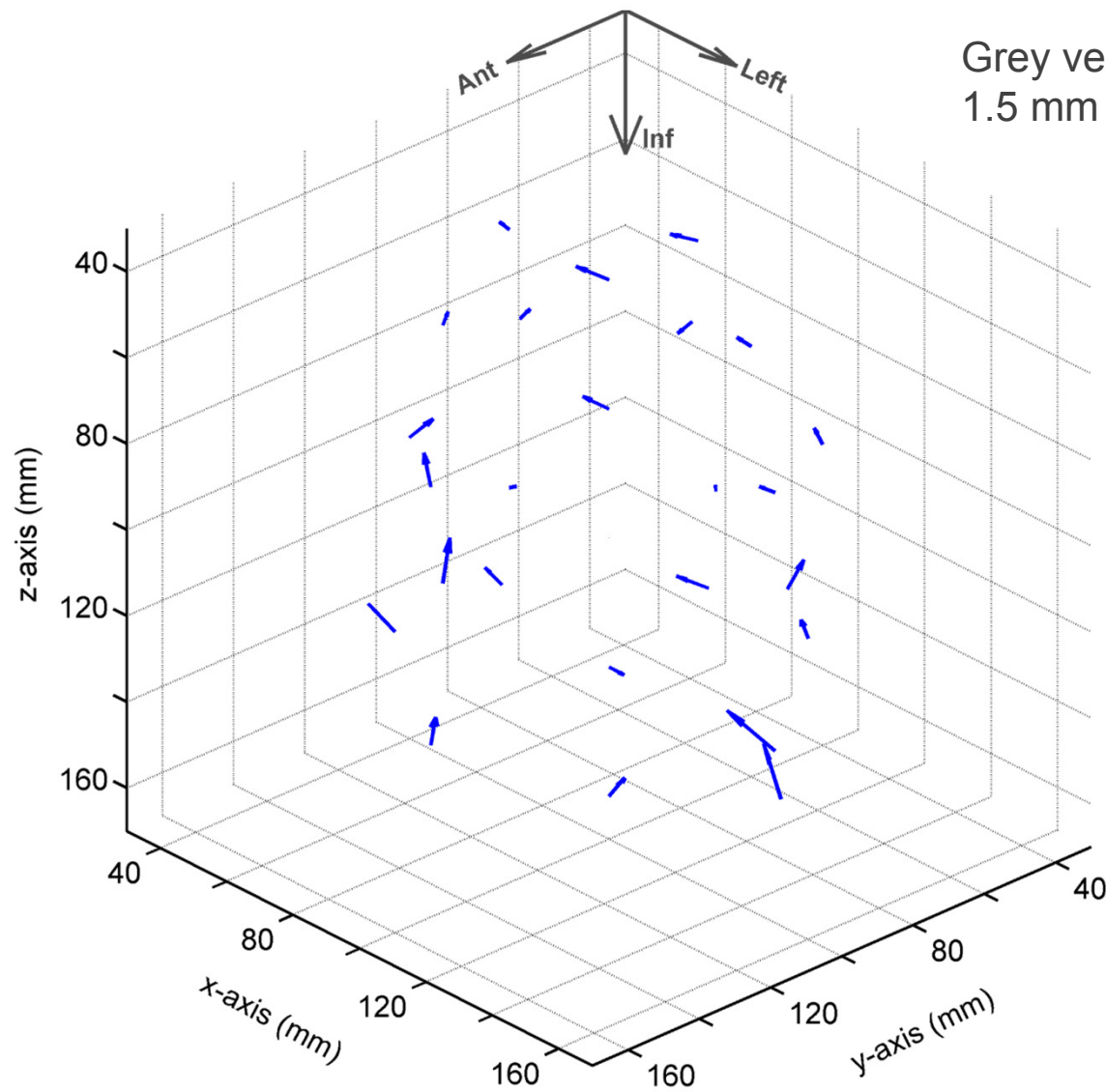
In order to improve the total geometric accuracy, an “average” MR series was created on a pixel-by-pixel basis from corresponding forward and reversed read gradient polarity images employing an in-house developed algorithm.

This “average” MR series concept was applied to the phantom images and pertinent  $u_{\text{tot}}$  measurements were obtained.

## Central shot (100, 100, 100), 17Gy isodose line







Grey vectors correspond to 1.5 mm spatial uncertainty

26 shots: Geometric uncertainty of less than 0.4 mm (0.04 – 0.4 mm)

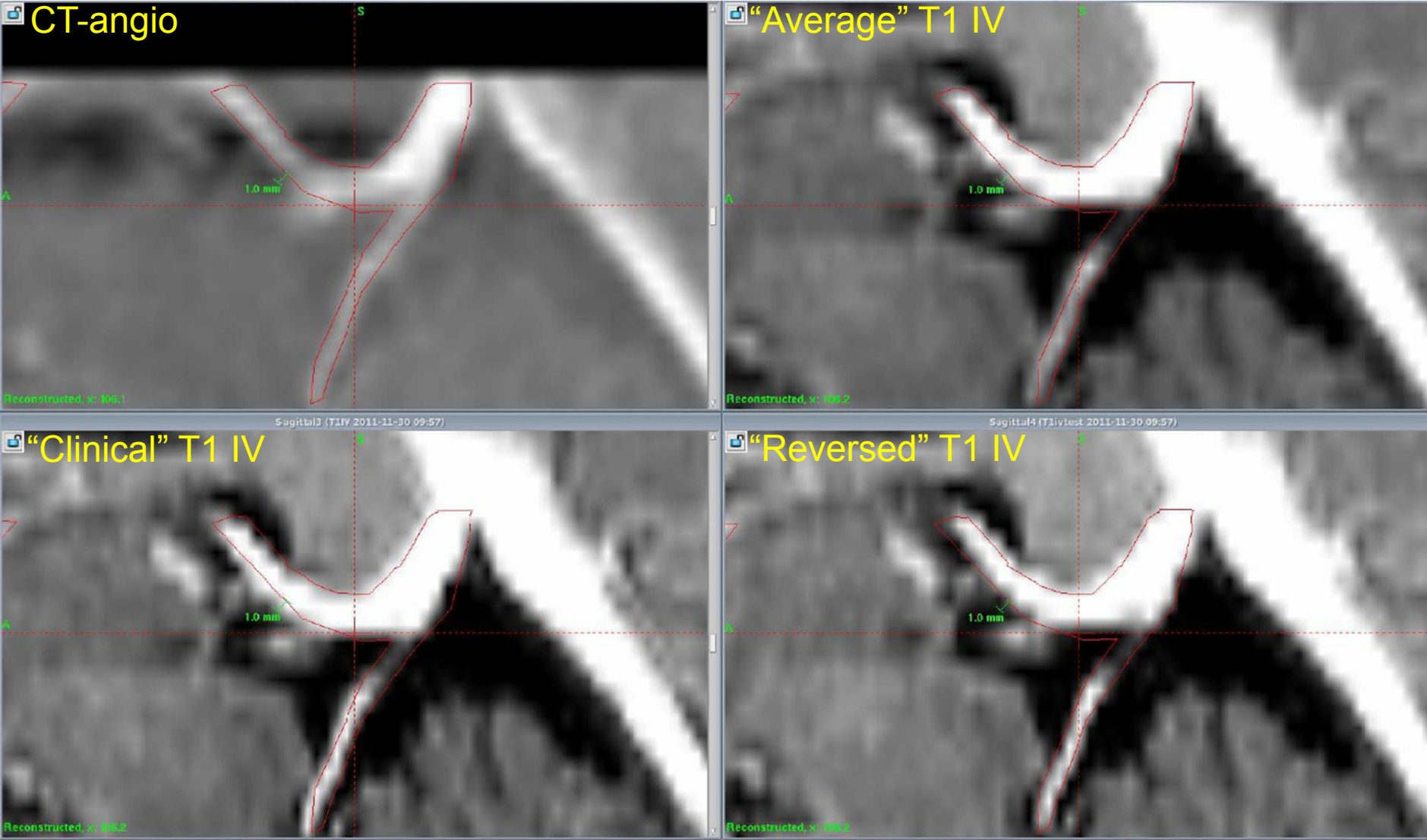
# Patients

The method was used in patients with different lesions (e.g. AVMs, multiple metastasis, acoustic schwannomas and pituitary adenomas)

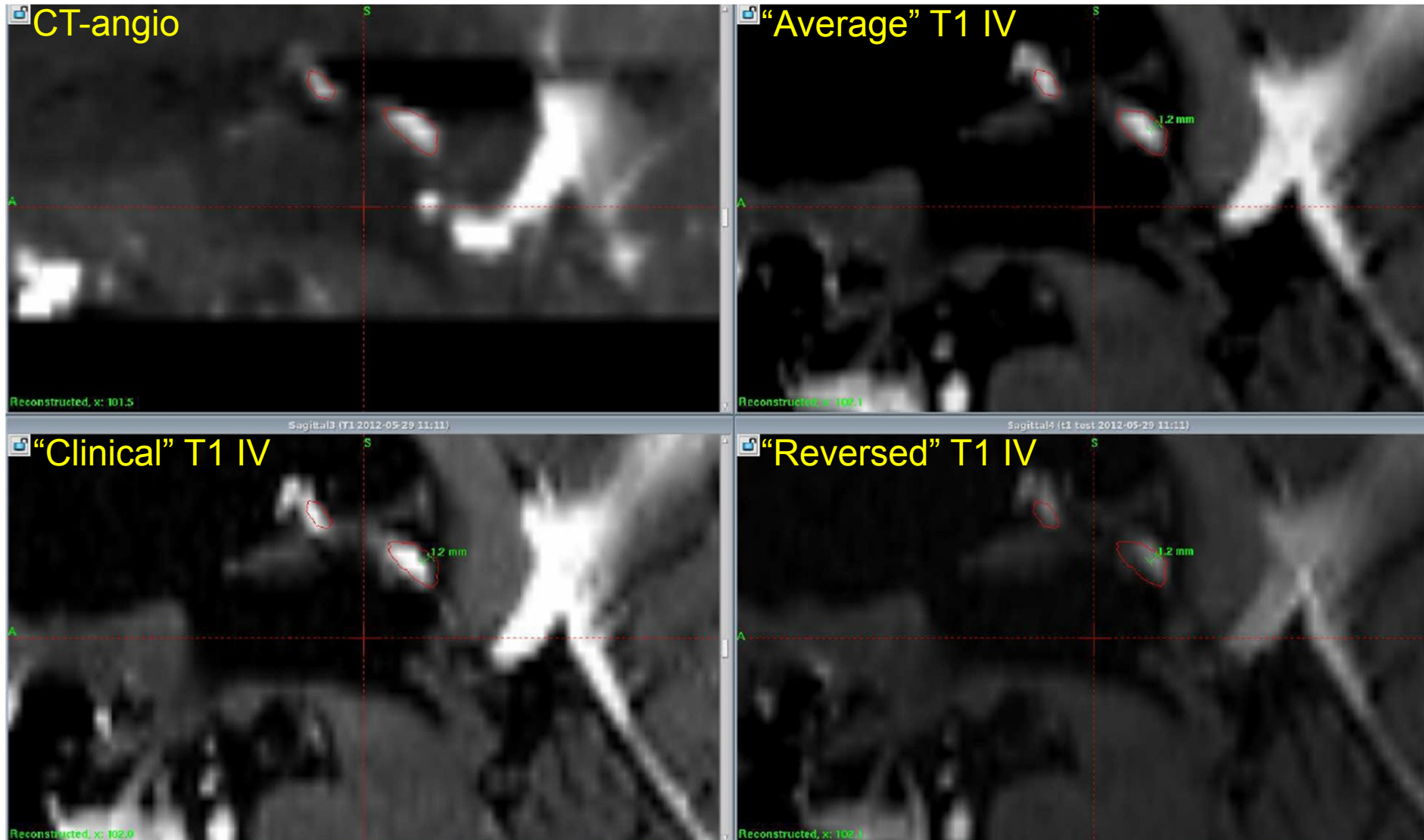
The patients were scanned using:

- ✓ A Gd-enhanced 3D T1-weighted **or** a 3D T2-weighted MR sequence routinely used for target delineation (read gradient direction: P and R, respectively)
  - ✓ An extra MR sequence with the same imaging parameters with the clinical series aside from a reversal in the read gradient polarity
  - ✓ CT with slice thickness 1 – 1.5 mm
- 
- An “averaged” MR series was produced for every patient

# Patient 1 : AVM

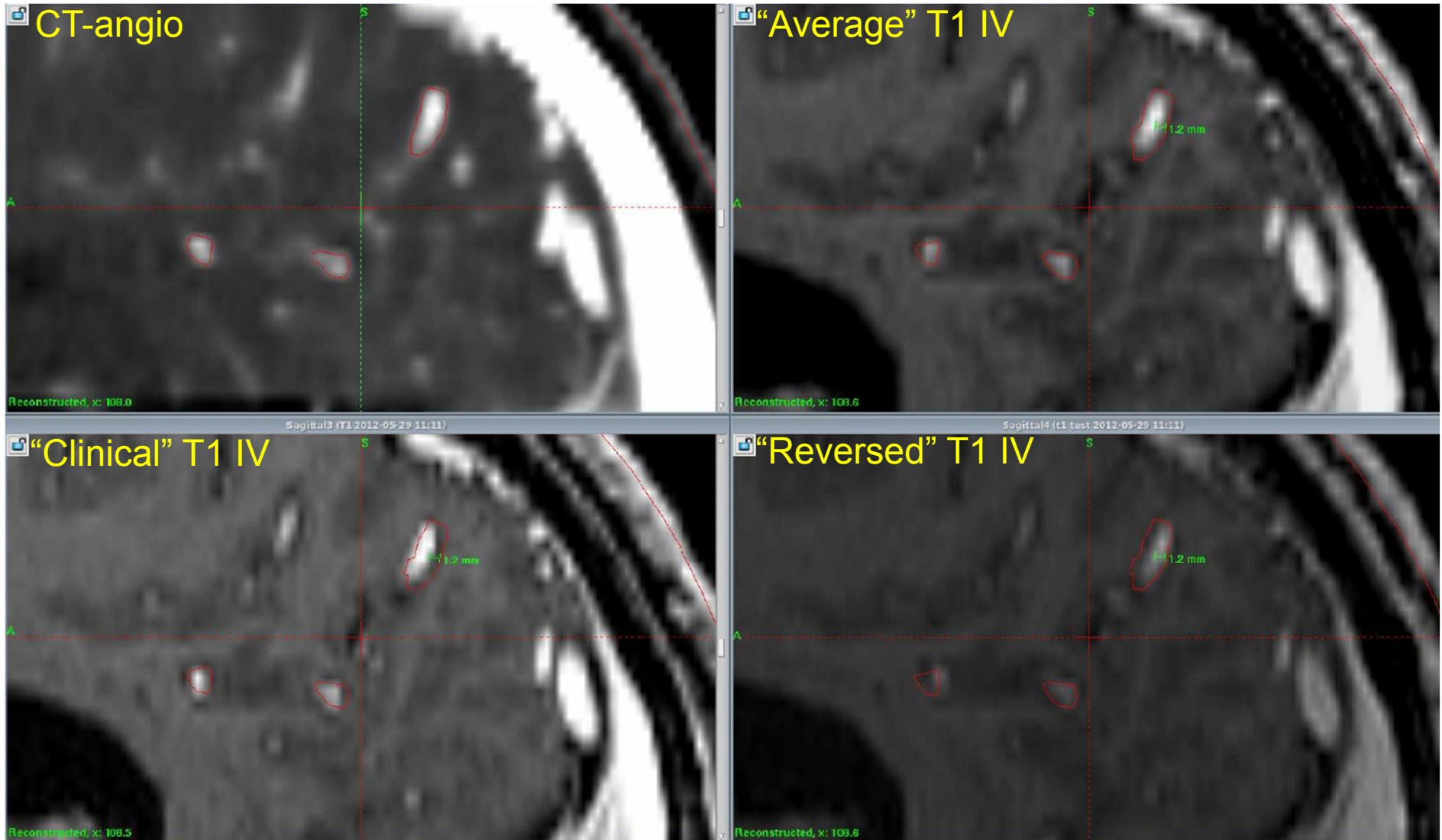


# Patient 2 : AVM

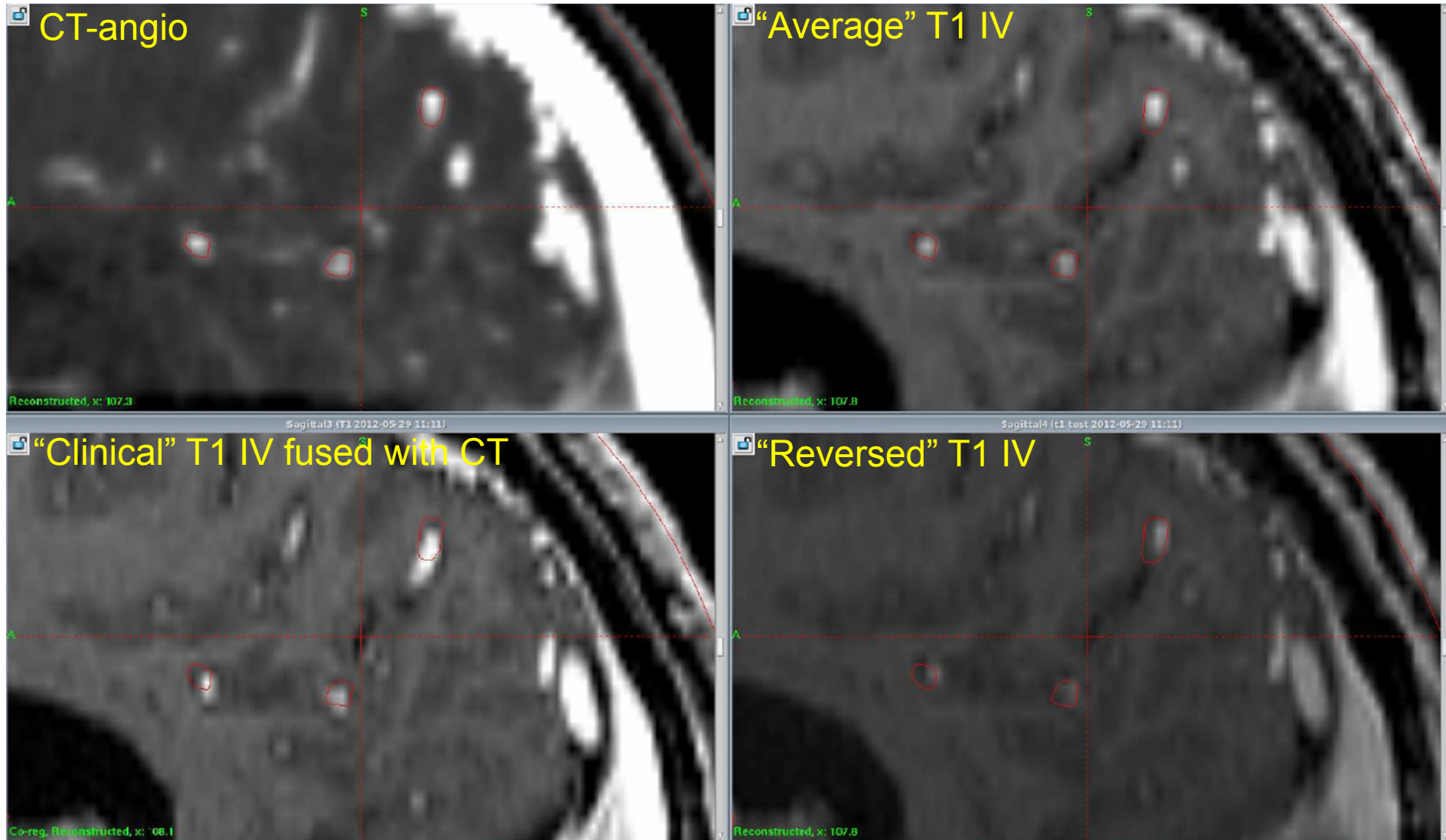




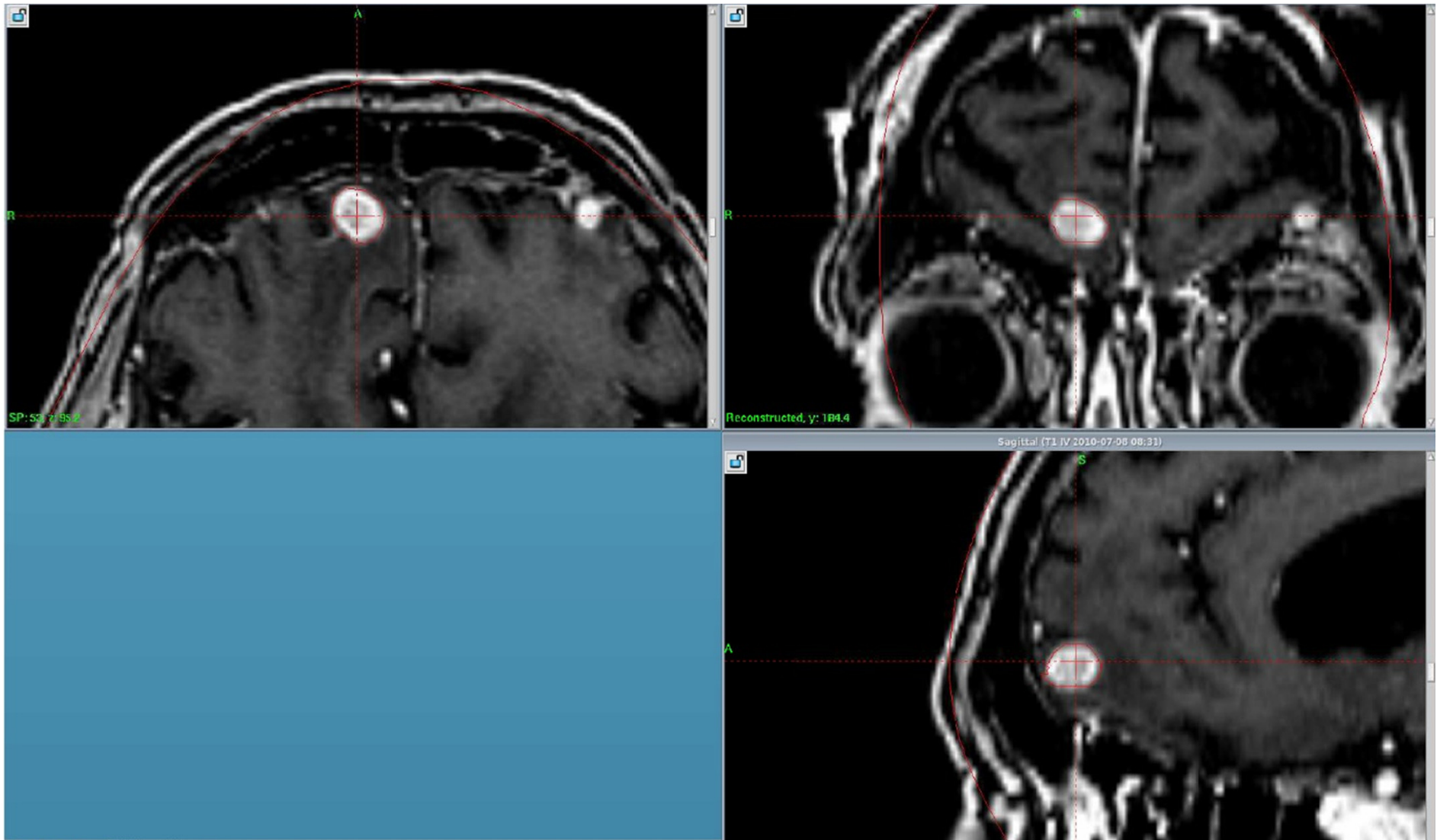
# Patient 2 : AVM



## Patient 2 : AVM

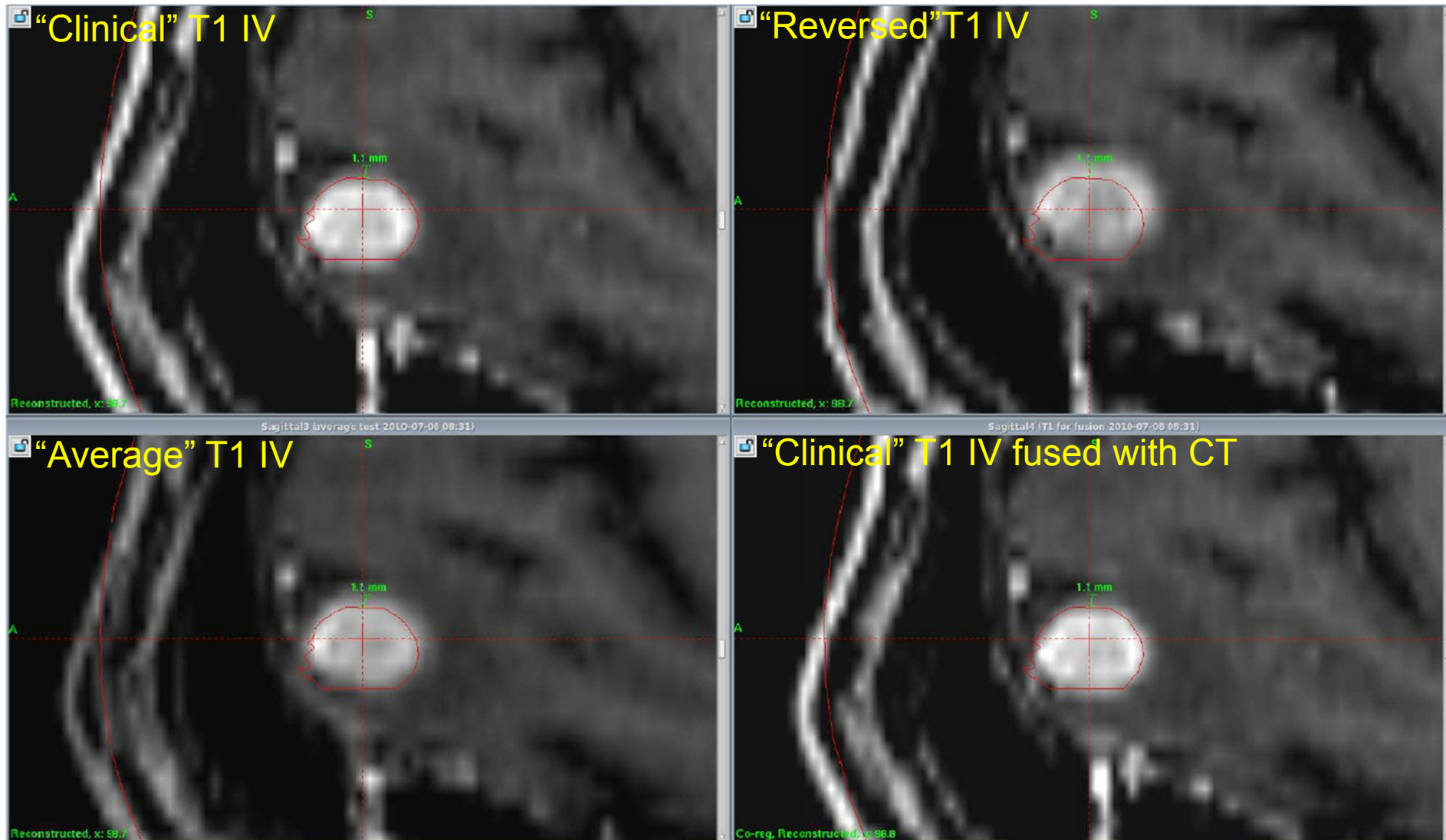


# Patient 3 : multiple metastases (target-1: 1 cm diameter)





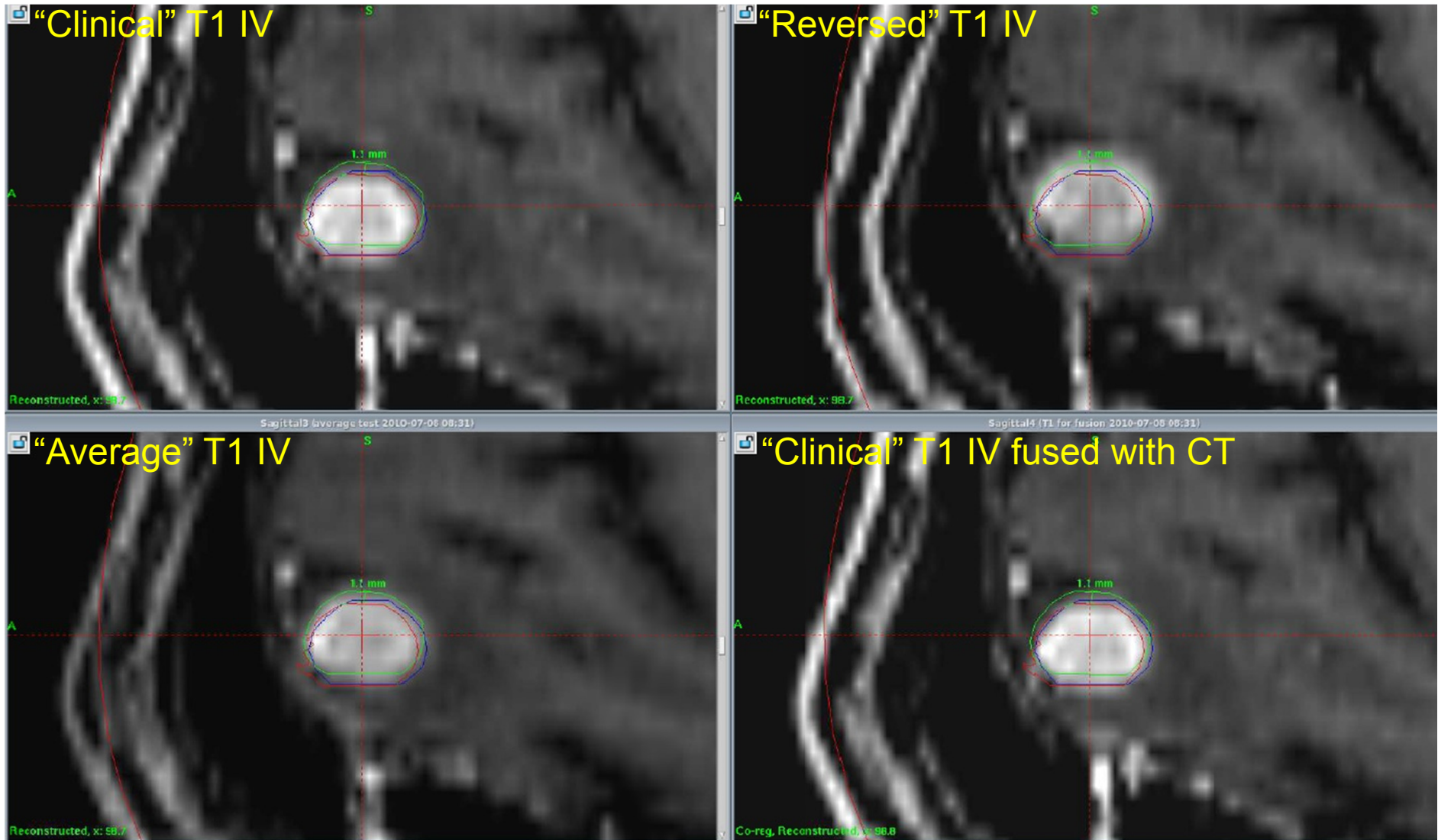
## Patient 3 : multiple metastases (target-1 contoured in T1 IV)



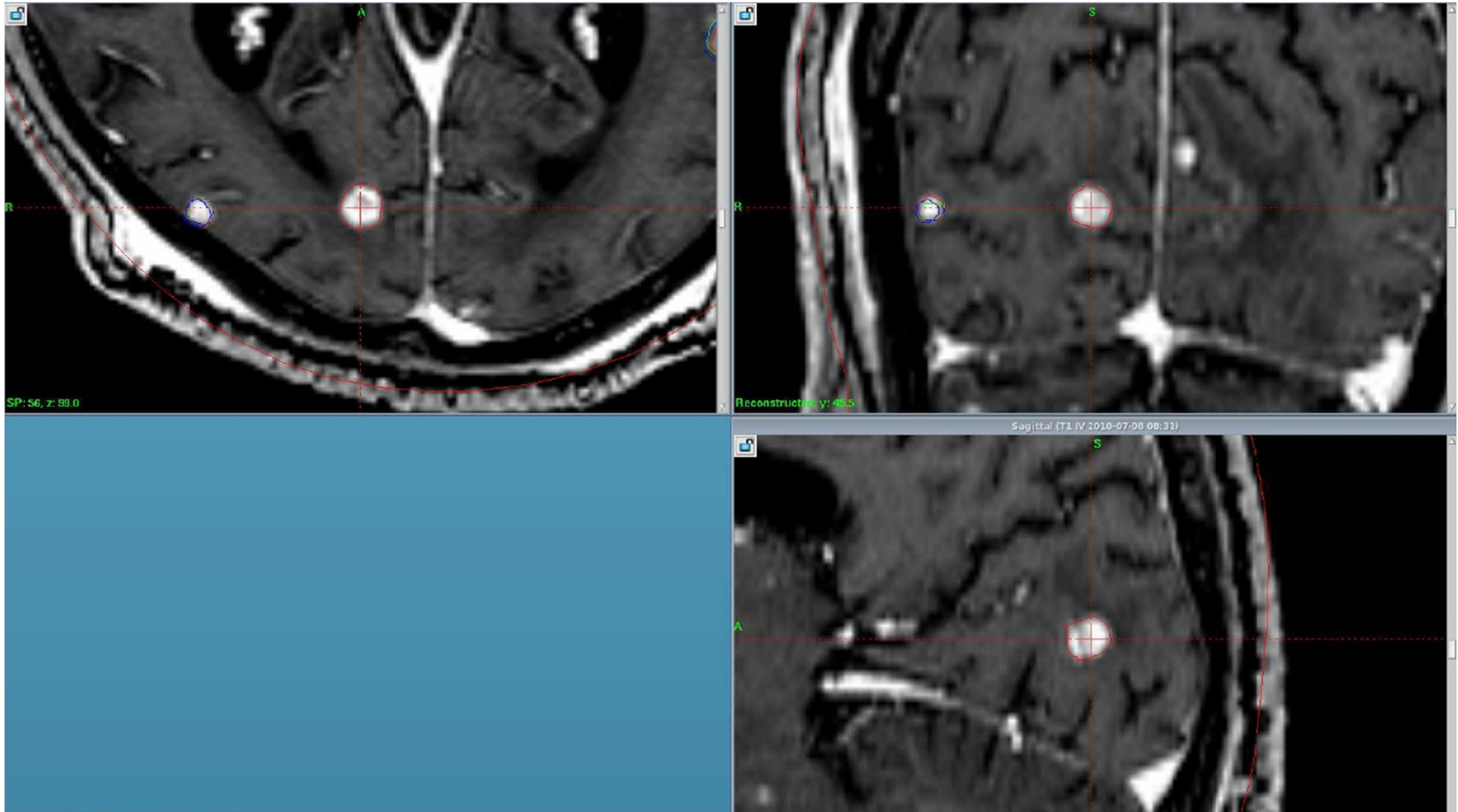


## Patient 3 : multiple metastases

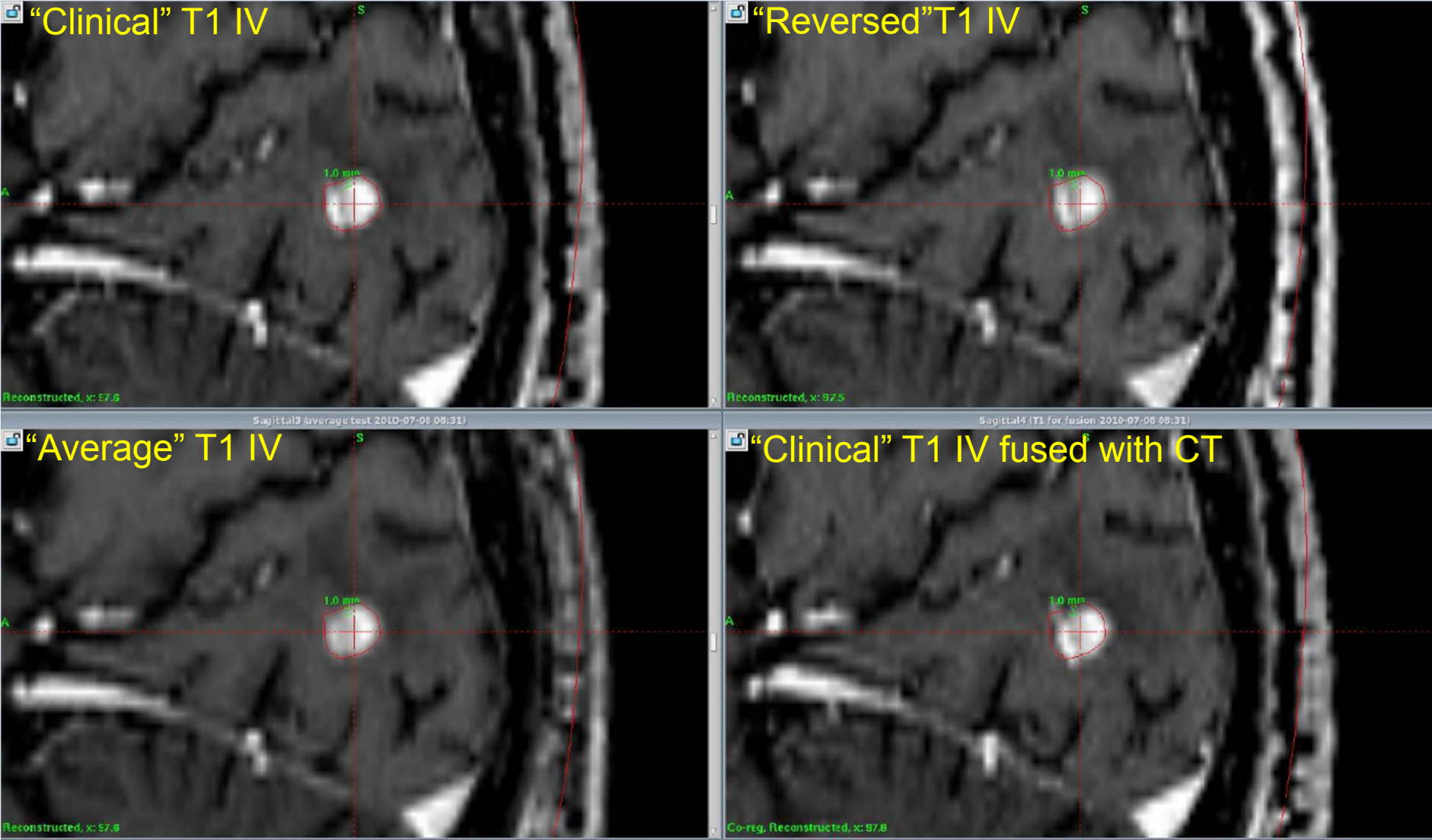
target-1 contoured in T1 IV (red), “Average” T1 IV (green) and T1 IV fused with CT (blue)



## Patient 3 : multiple metastases (target-2: < 0.5 cm diameter)

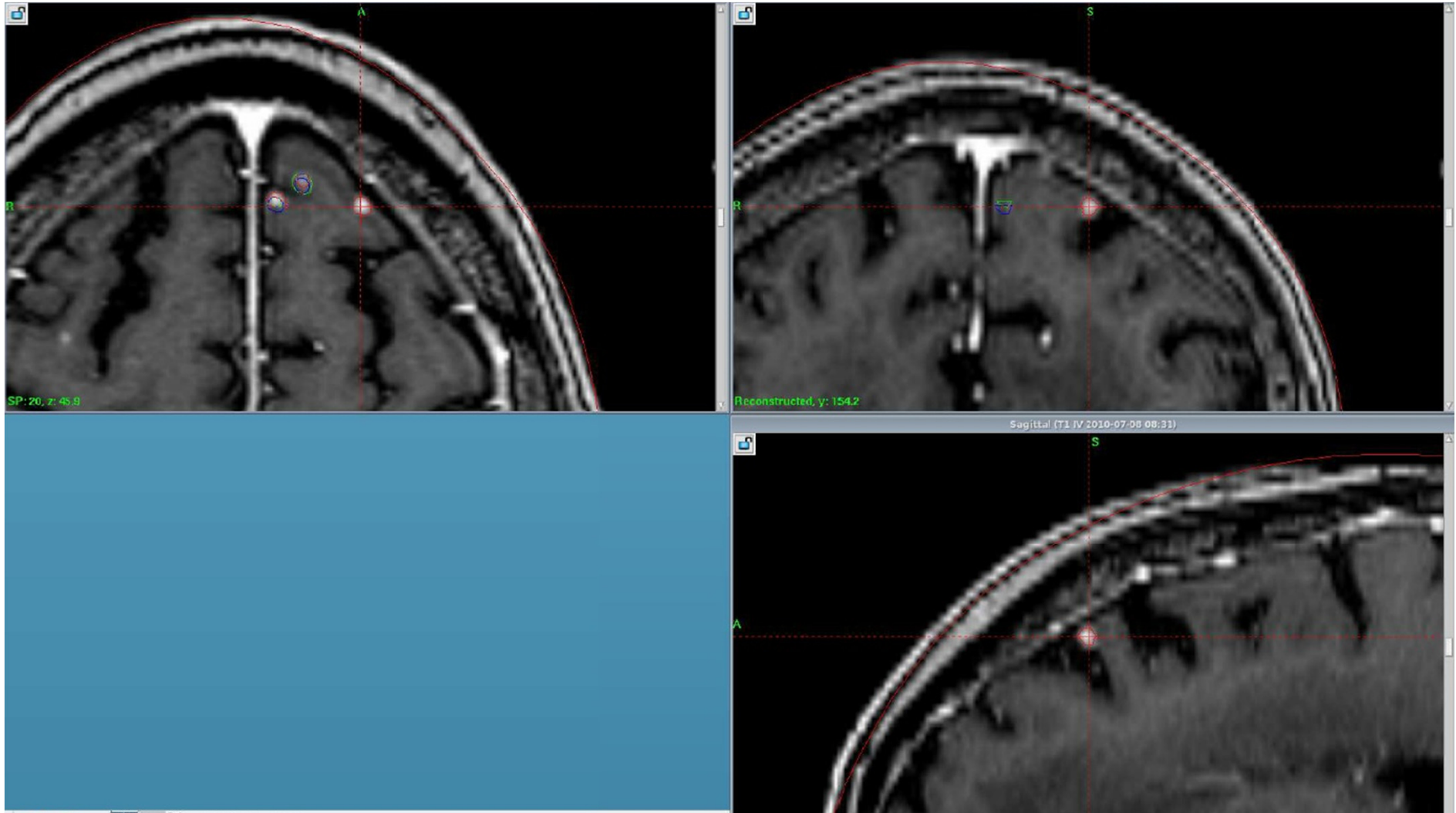


# Patient 3: multiple metastases (target-2 contoured in T1 IV)

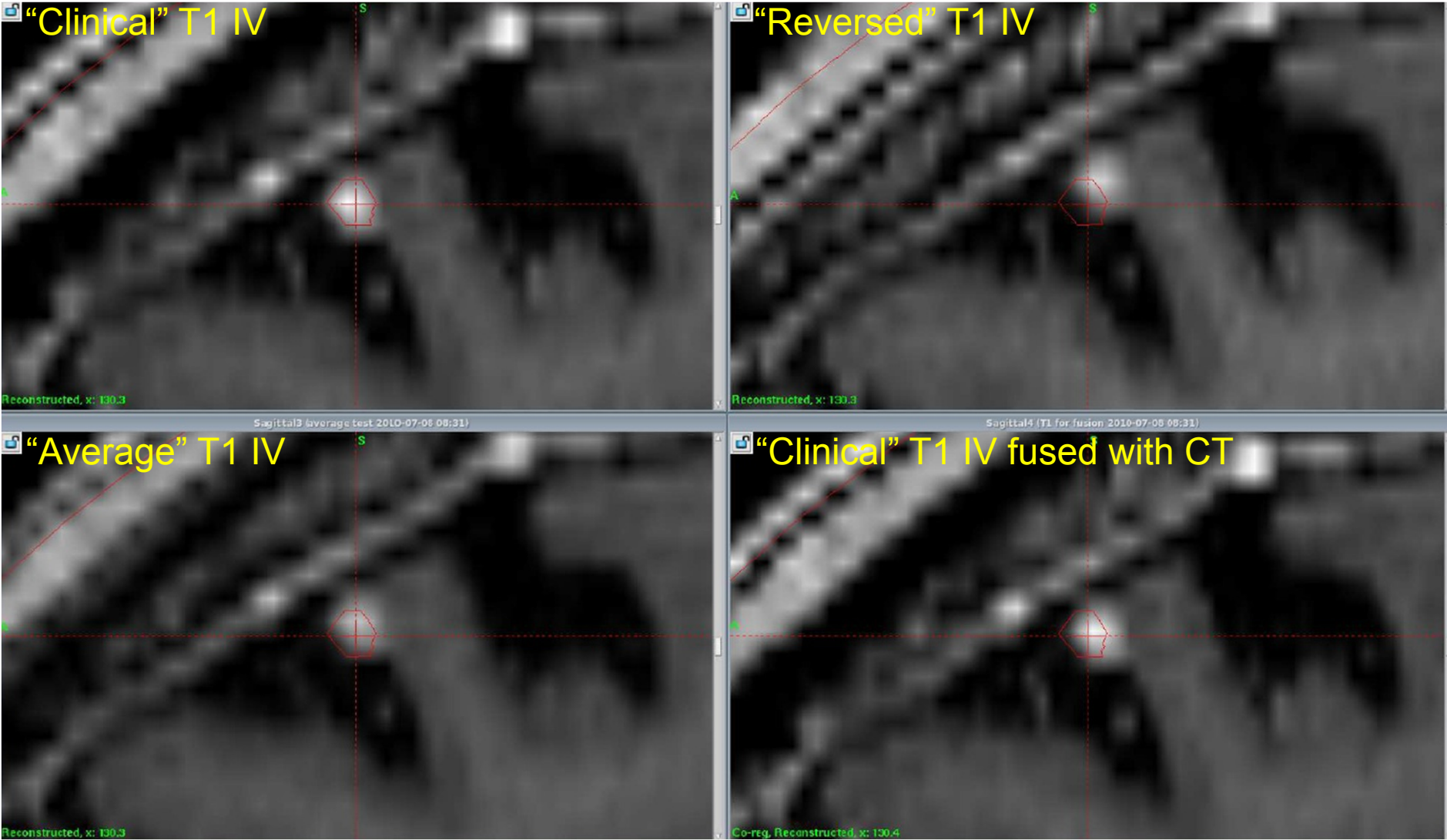




## Patient 3 : multiple metastases (target-3: < 0.5 cm diameter)

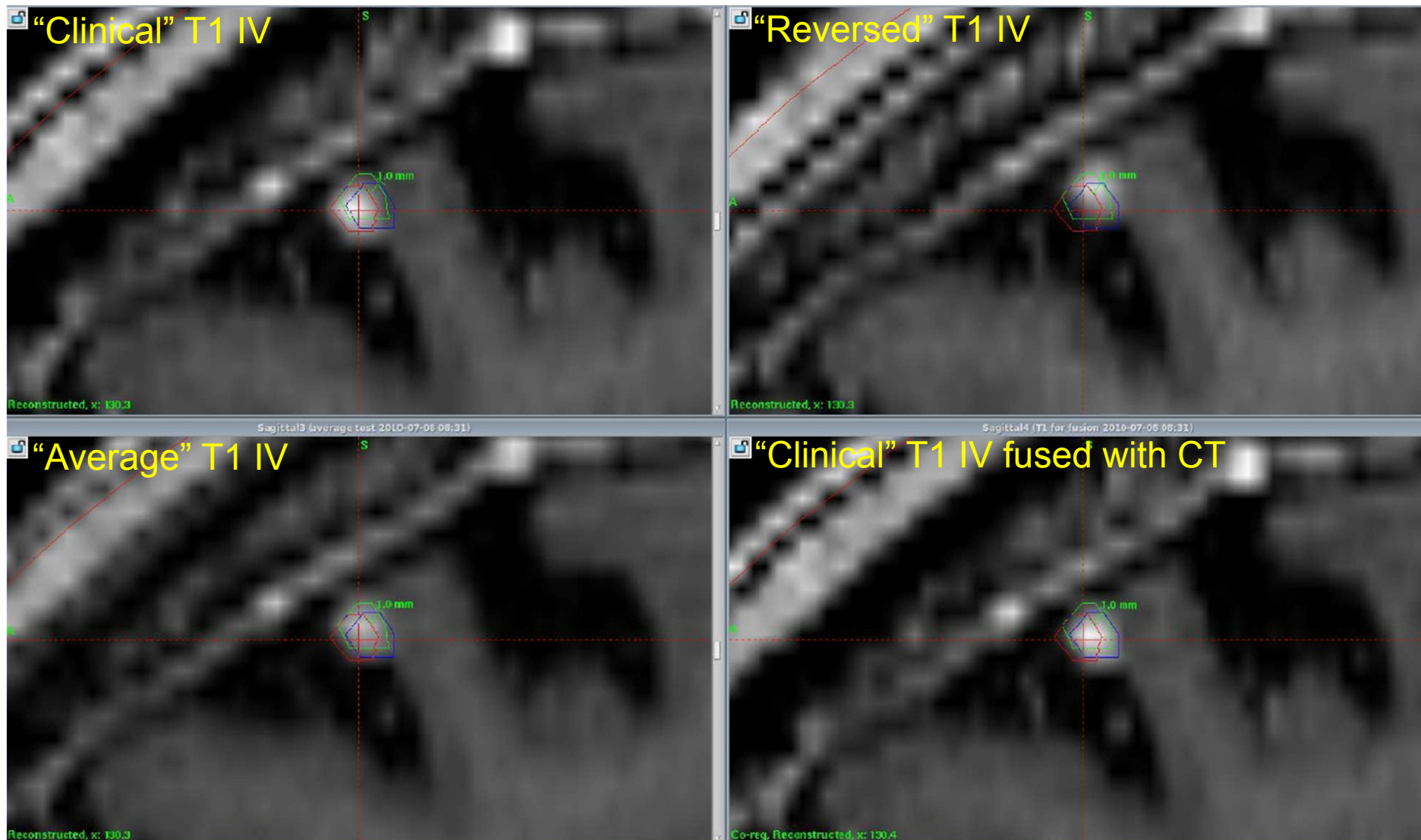


# Patient 3: multiple metastases (target-3 contoured in T1 IV)



## Patient 3 : multiple metastases

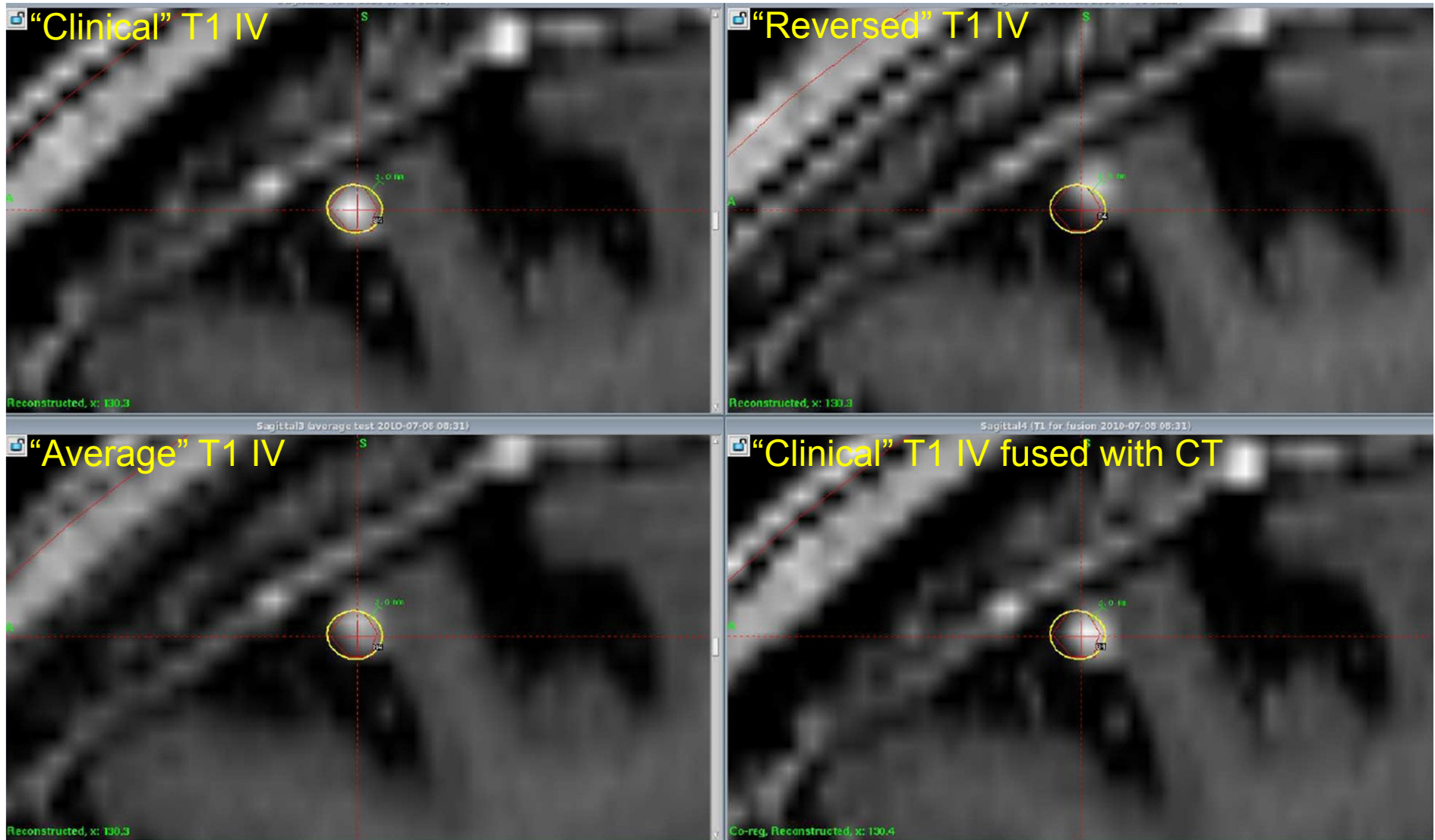
target-1 contoured in T1-IV (red), in “Average” T1-IV (green) and in T1-IV fused with CT (blue)



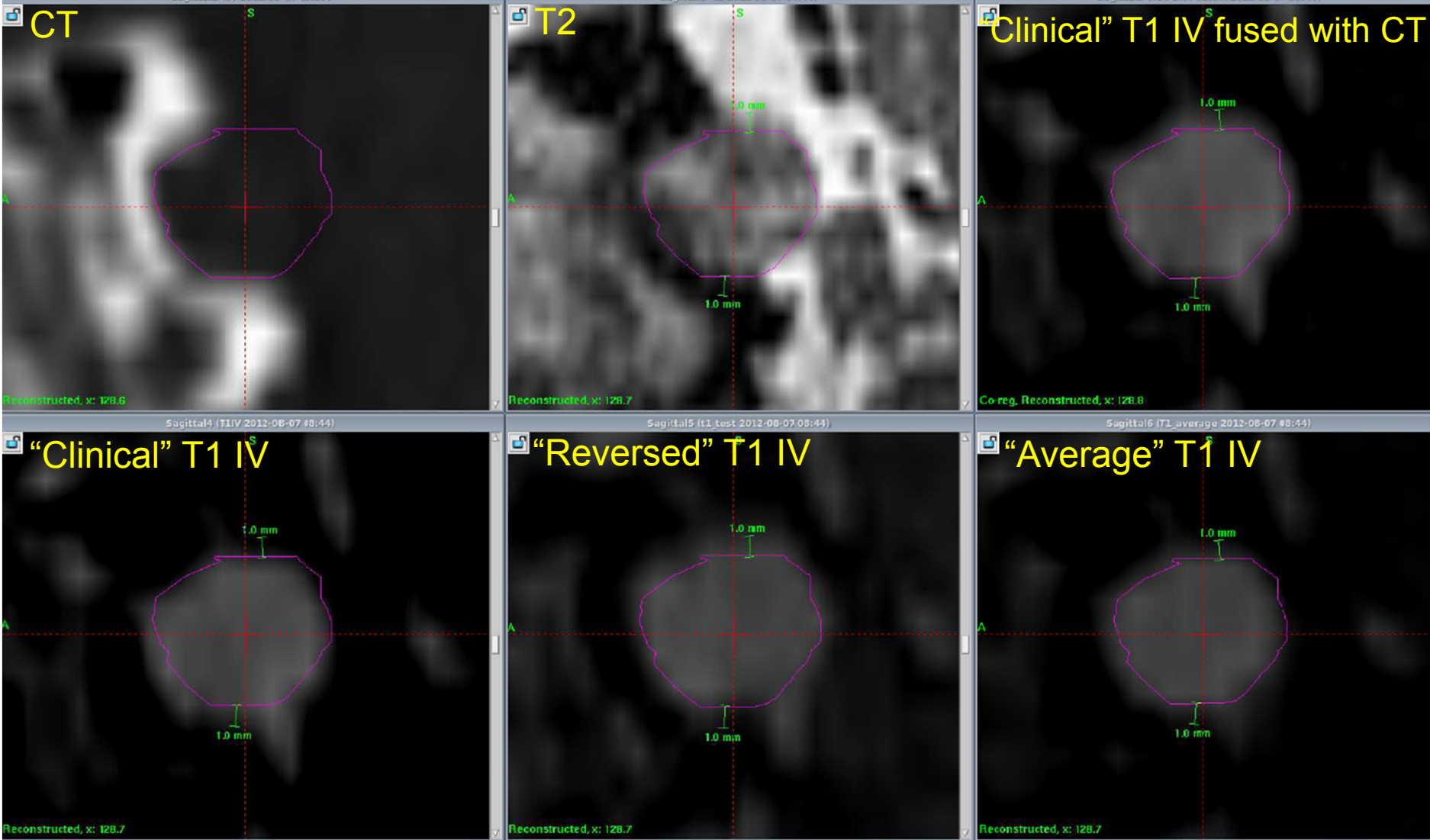


# Patient 3: multiple metastases

(target-3 contoured in T1IV and plan based on T1IV)

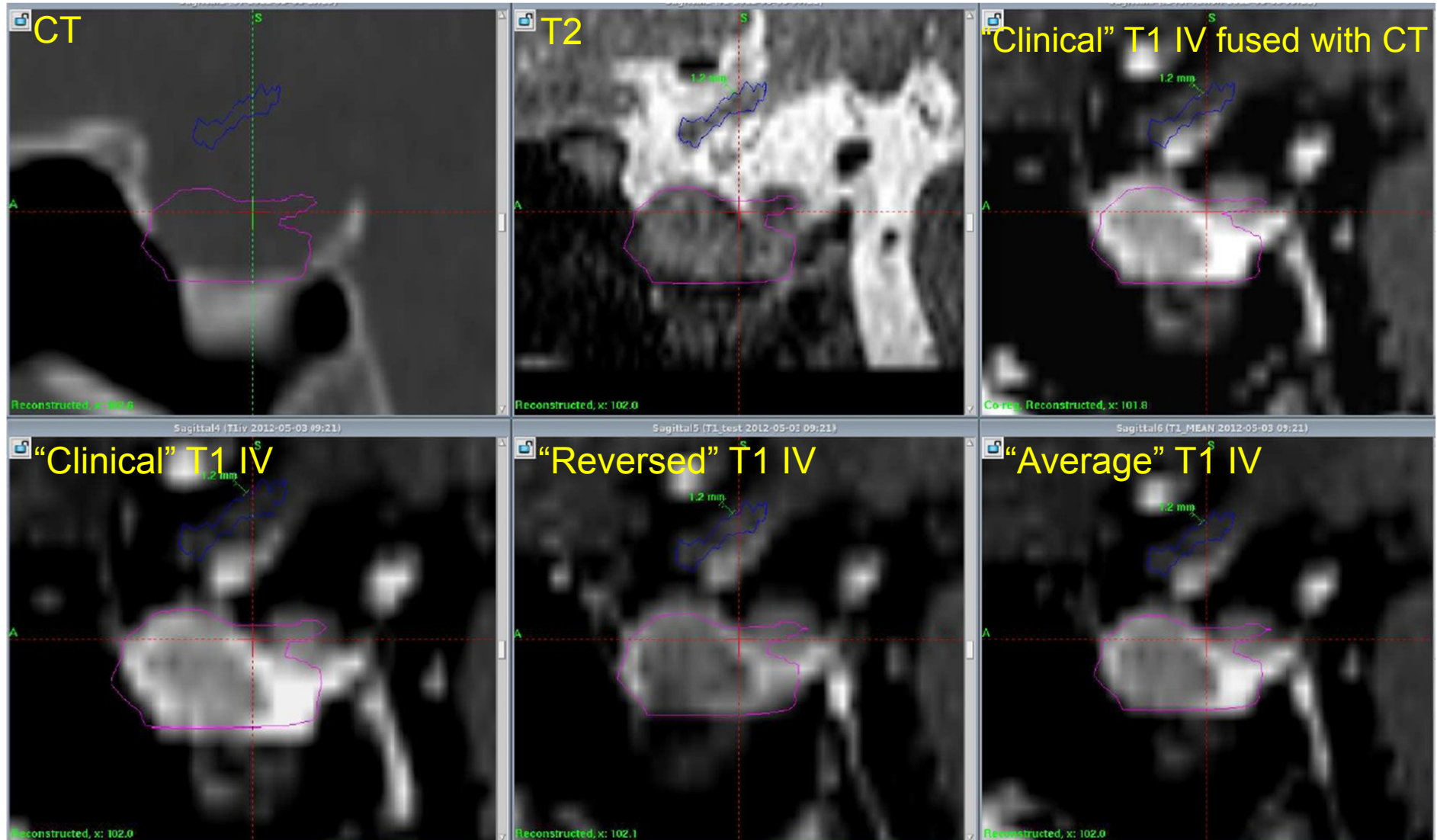


# Patient 4 : acoustic swanoma (target contoured in T2)

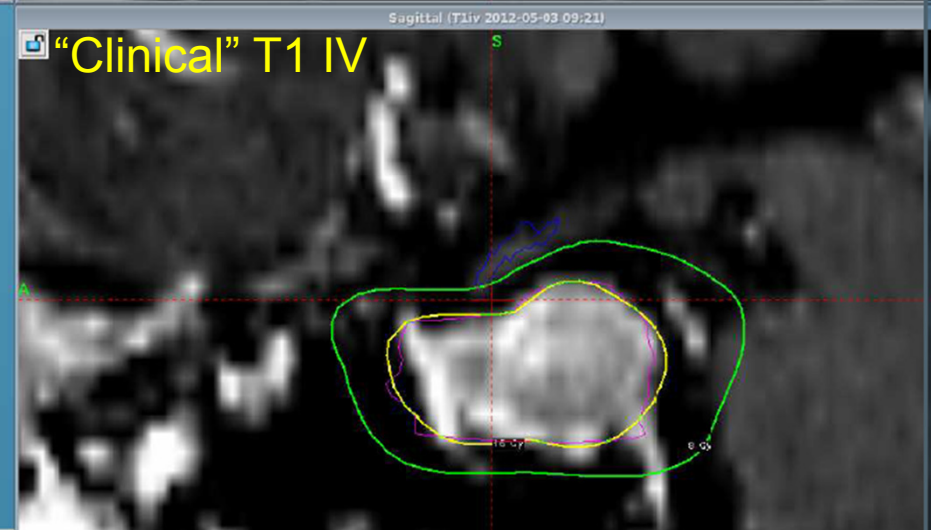
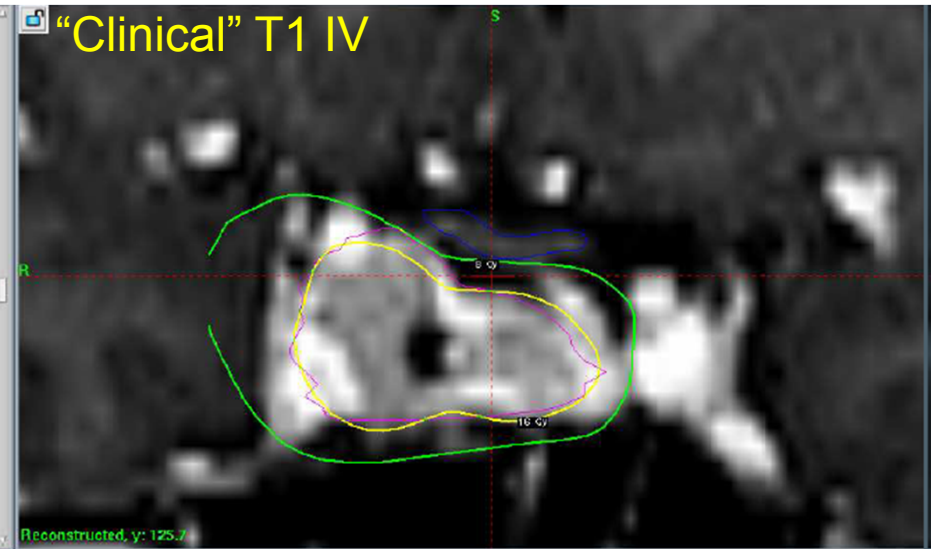
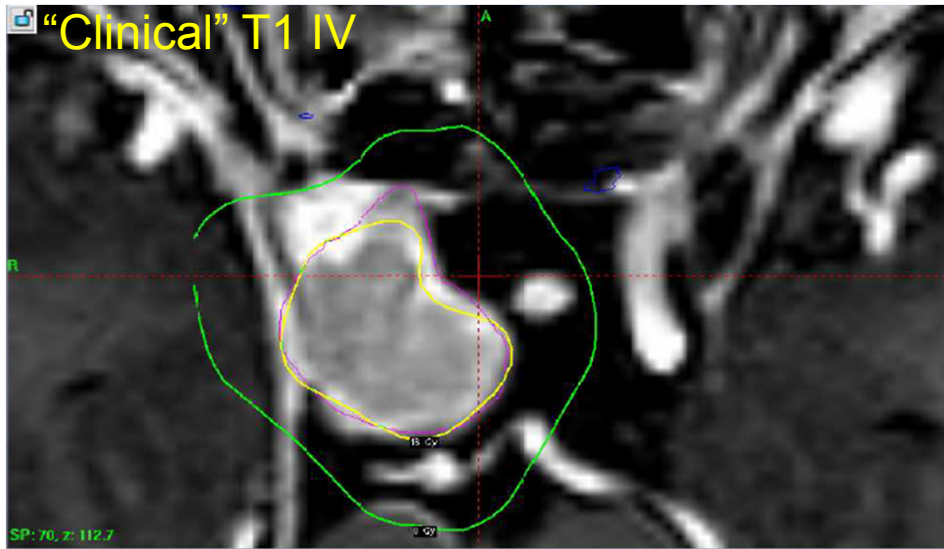




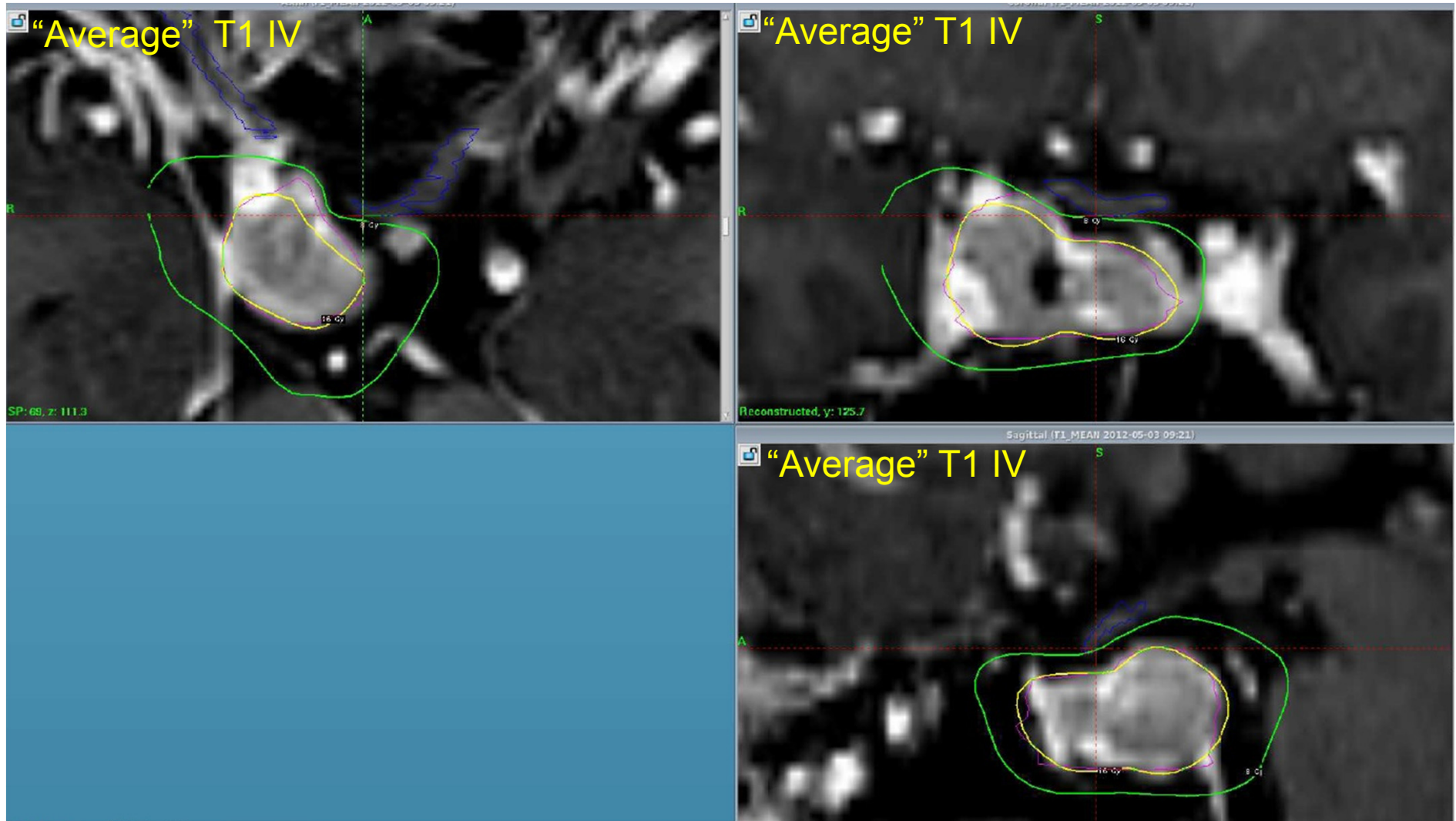
## Patient 5 : pituitary adenoma (target contoured in T2)



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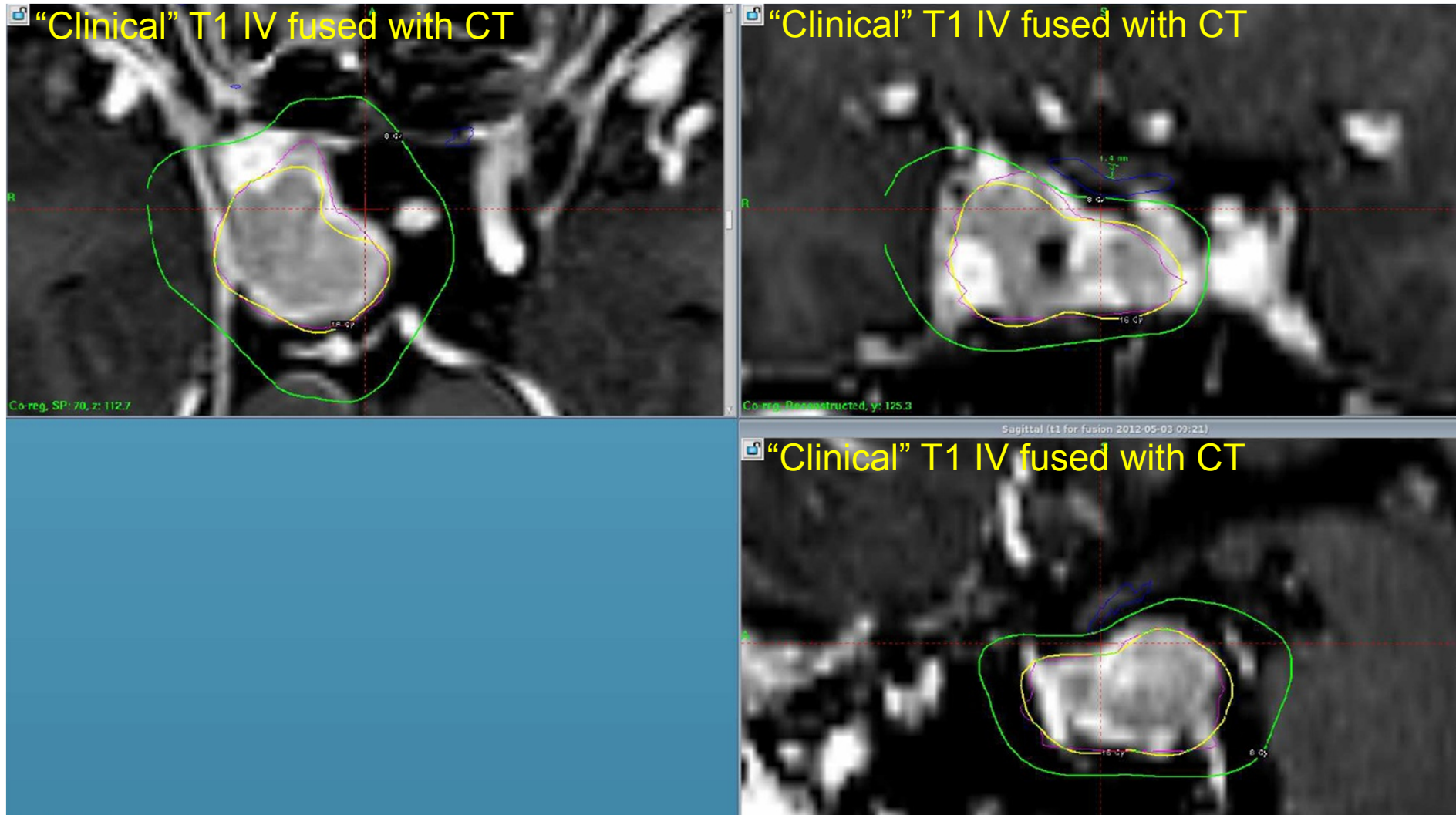


## Patient 5 : pituitary adenoma (target contoured in T2)





## Patient 5 : pituitary adenoma (target contoured in T2)



# Summary / Conclusions

- ❑ The presented polymer gel based methodology:
  - ✓ facilitates multi-point assessment of the total geometric uncertainty ascribed to GK radiosurgery (including the MR imaging related spatial distortions) in an extended region of the stereotactic space within a single experiment.
  - ✓ Allows for the semi-quantitative assessment of the total spatial uncertainty by the user directly in the TPS environment .
  
- ❑ The proposed “Average MR image series” technique was found to substantially improve the total clinical accuracy.
  - Fusion with registered CT images which are known to present minimal geometric distortion do not decrease the total geometric uncertainty since it introduces an additional co-registration uncertainty which is  $> 1$  mm.

# Limitations

- ❑ An extra MR sequence is needed for the implementation of the proposed “Average MR series” method and, thus, imaging time is increased.
- ❑ Although the “Average MR series” method does improve the total geometric accuracy, residual inaccuracies depend on the specific MR sequence and scanner employed.

**Thank you...**