Computerized Treatment Planning for Stereotactic Radiosurgery

D.M. Shepard, M.C. Ferris[2]

University of Maryland School of Medicine

[2]University of Wisconsin - Madison

Stereotactic Radiosurgery

- The delivery of a single high dose of radiation to a volume within a patient's brain.
- The technique is designed to match the precision of a surgeon's scalpel.

The Gamma Knife

How does the Gamma Knife work?

The Gamma Knife uses many intersecting beams of gamma rays to destroy a tumor or vascular malformation within the head.

201 cobalt gamma-ray beam sources are arrayed in a hemisphere and aimed through a collimator to a common focal point.

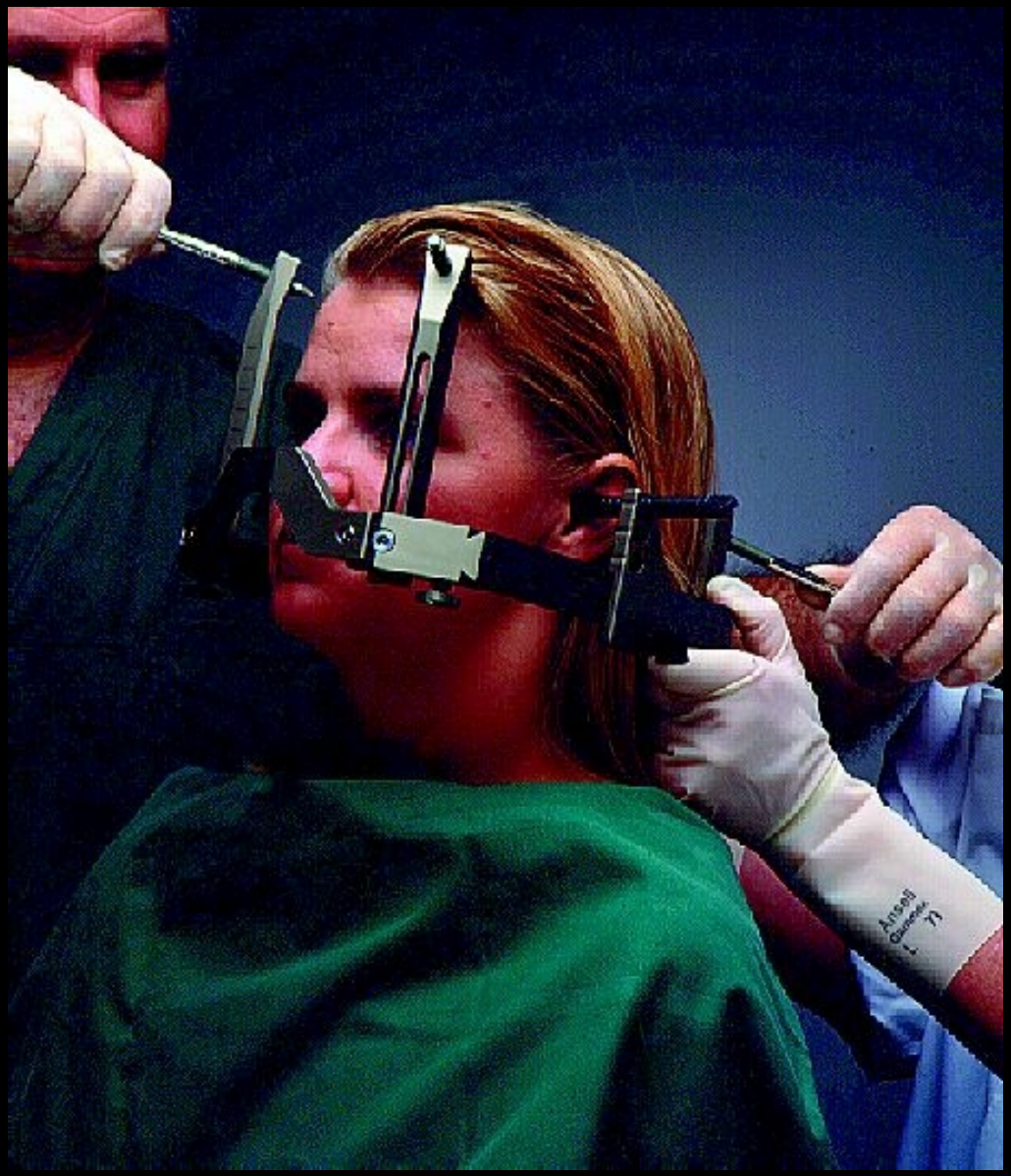
The patient's head is positions within the Gamma Knife so that the tumor is in the focal point of the gamma rays.

What disorders can the Gamma Knife treat?

- Primary brain tumors
- Secondary brain tumors
- Vascular malformations
- Functional disorders of the brain

Gamma Knife Statistics

- 120 Gamma Knife Units worldwide
- Over 20,000 patients treated annually.



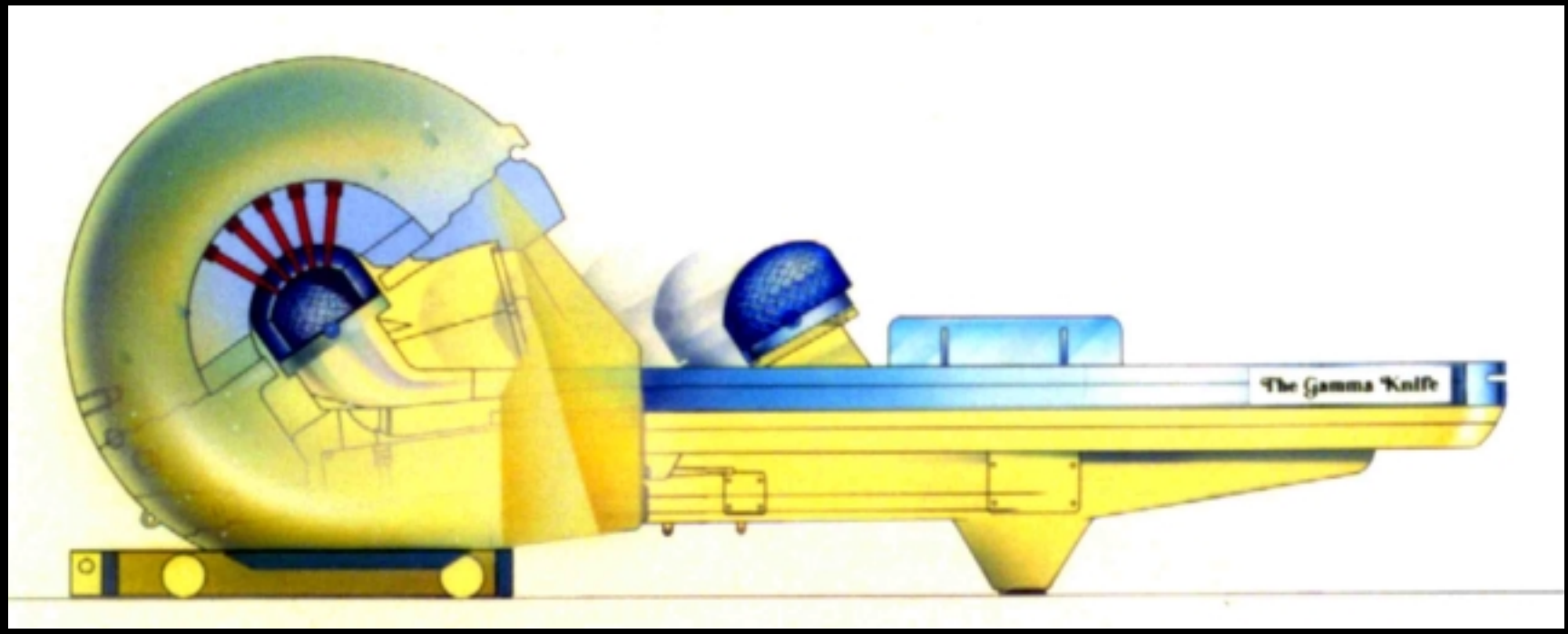
How is Gamma Knife Surgery performed?

Step 1: A stereotactic head frame is attached to the patient's head. A local anesthetic is used.

Step 2: The head is imaged using a MRI or CT scanner while the patient is wearing the stereotactic frame.

Step 3: A treatment plan is developed using the images.

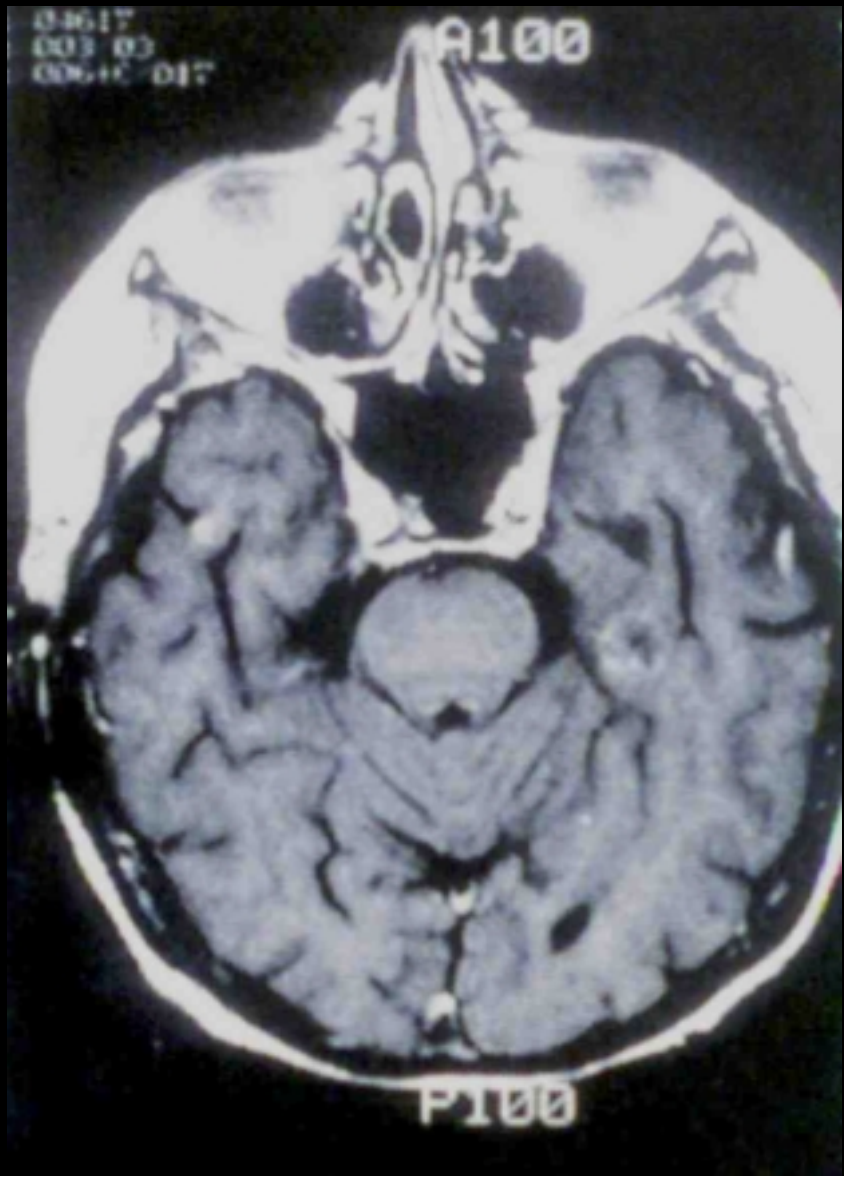
Step 4: The patient is positioned within the collimator helmet.



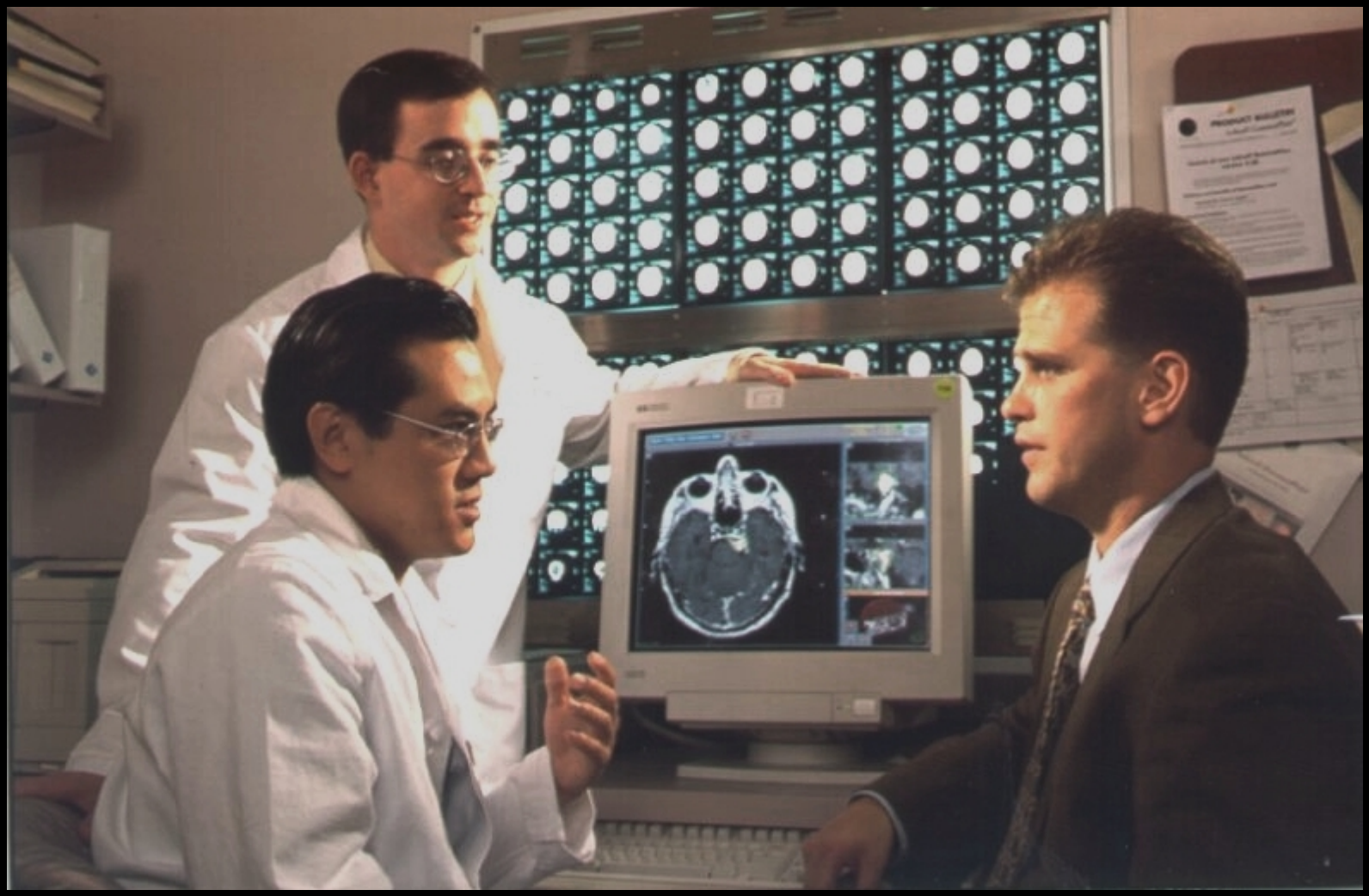
Step 5: The patient is advanced into the shielded treatment vault. A high dose of radiation is delivered to the area where all of the beams intersect. We refer to this as a shot of radiation.

Before

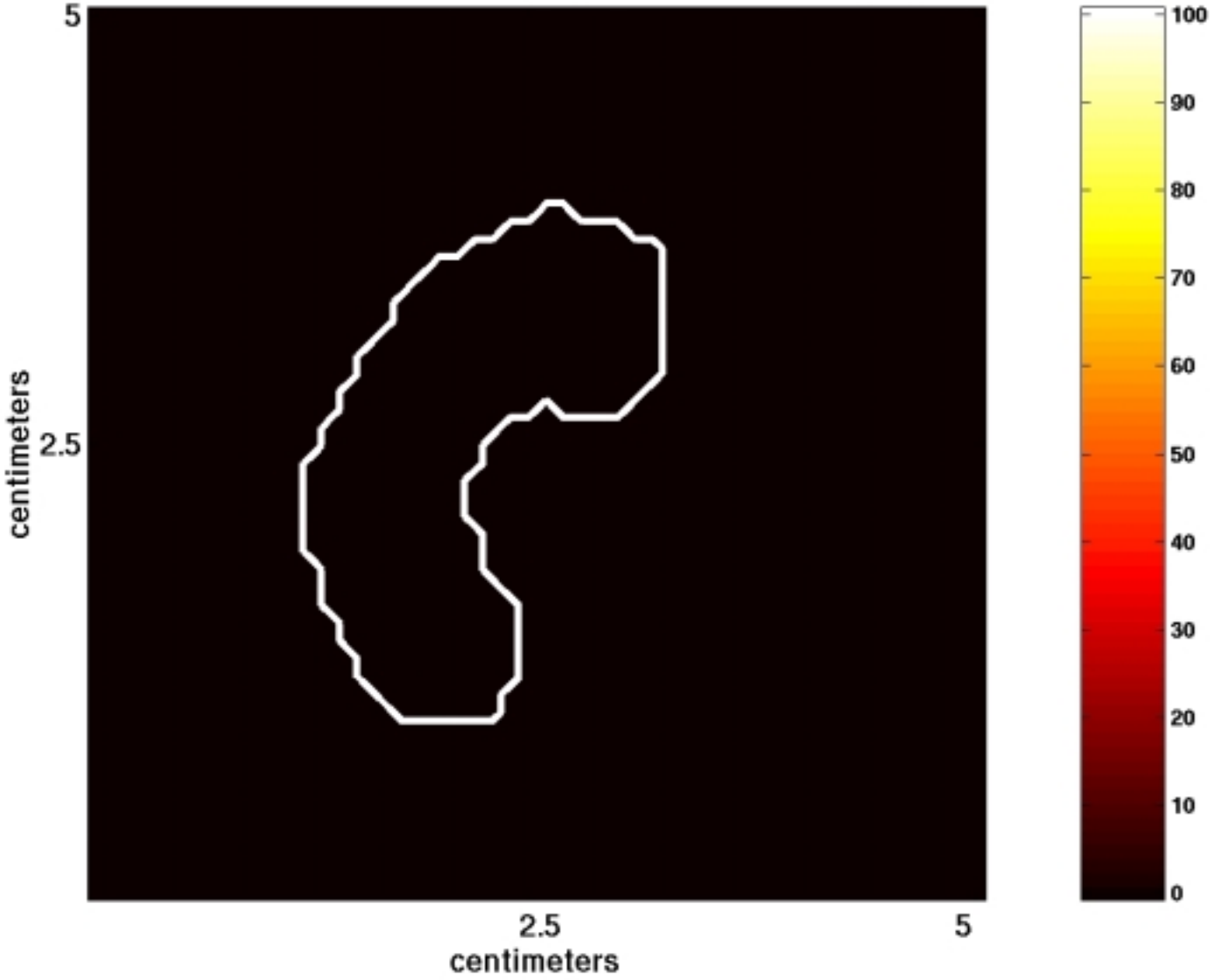
After



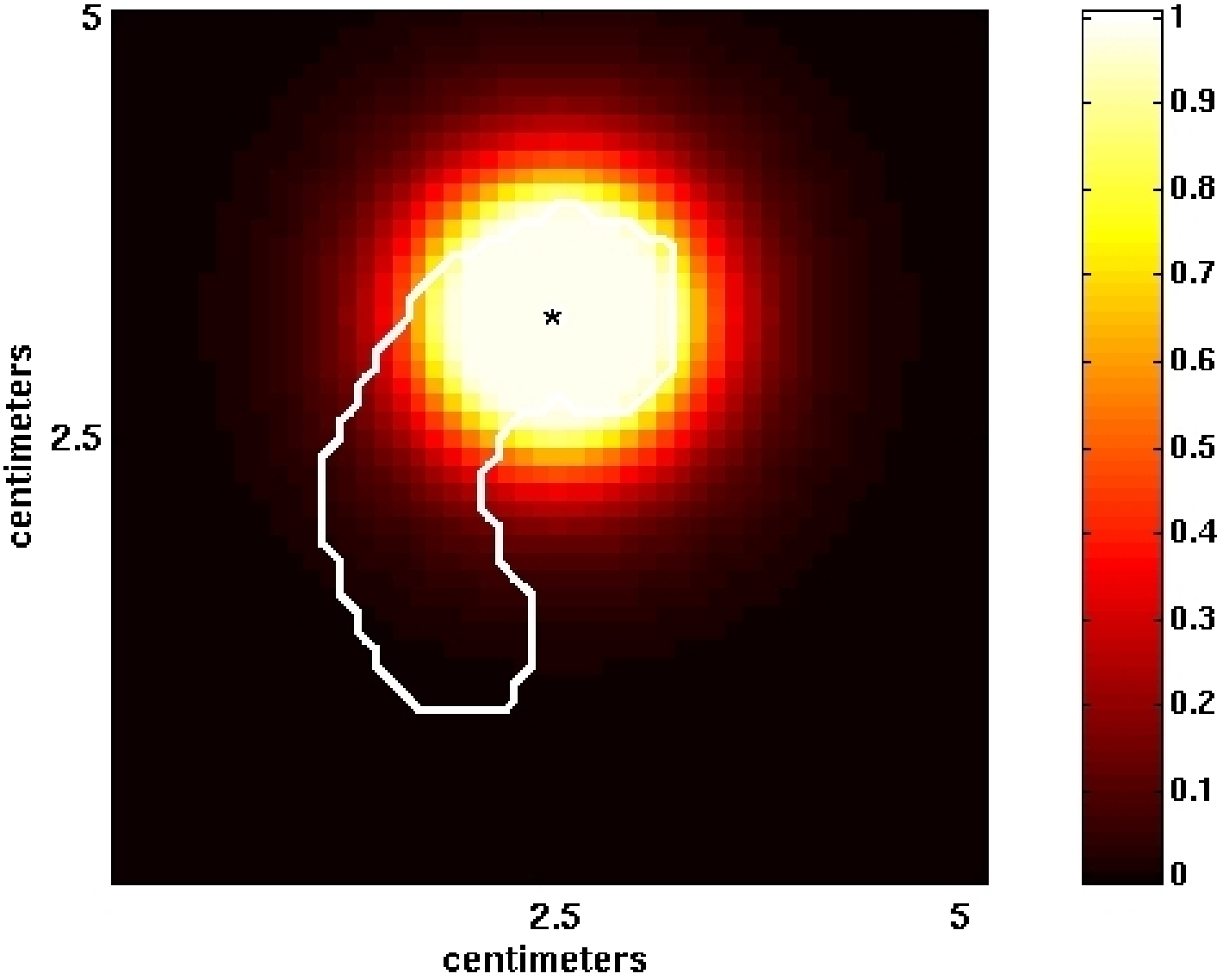
Treatment Planning



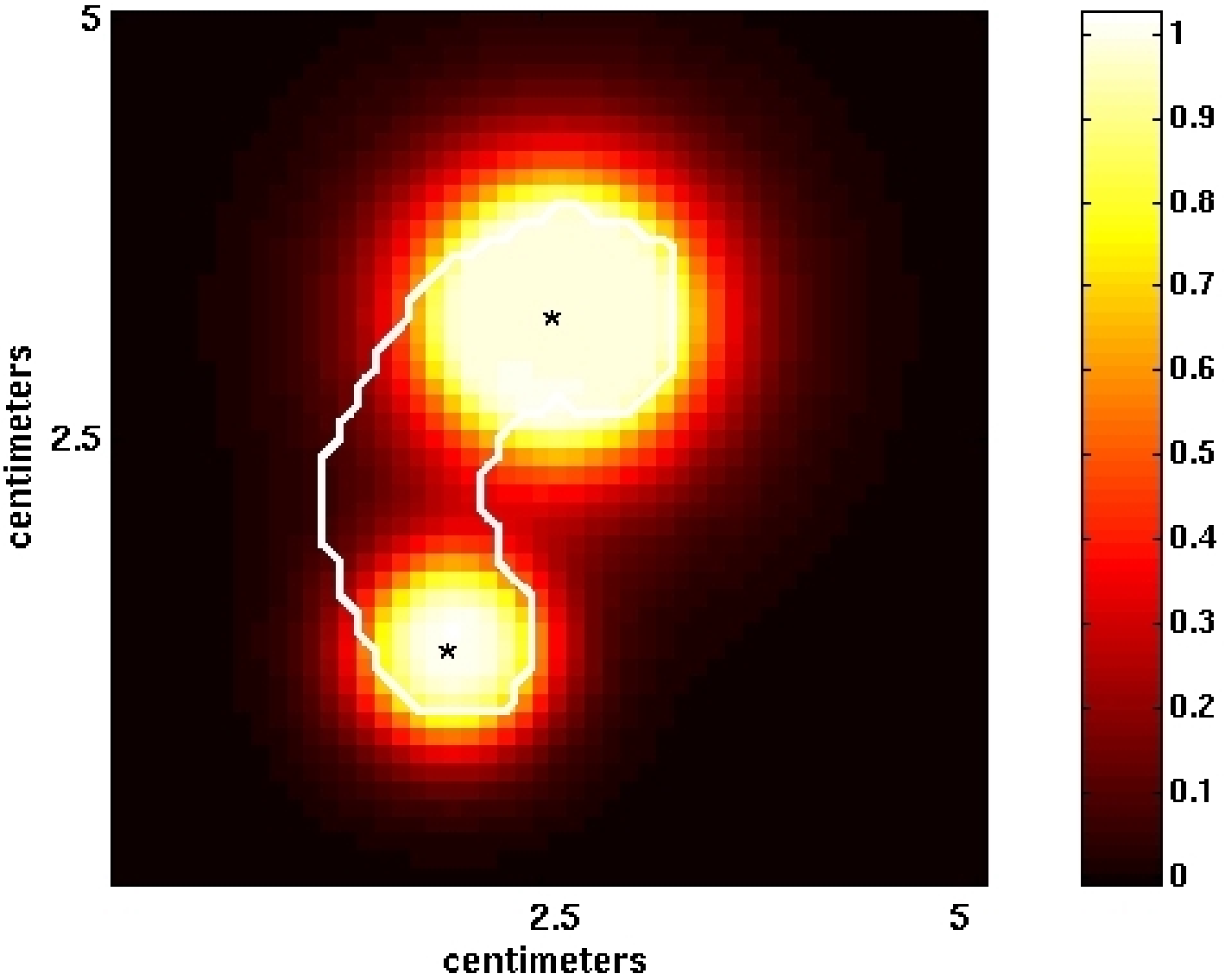
Target


5
2.5
centimeters
2.5
5
centimeters
100
90
80
70
60
50
40
30
20
10
0

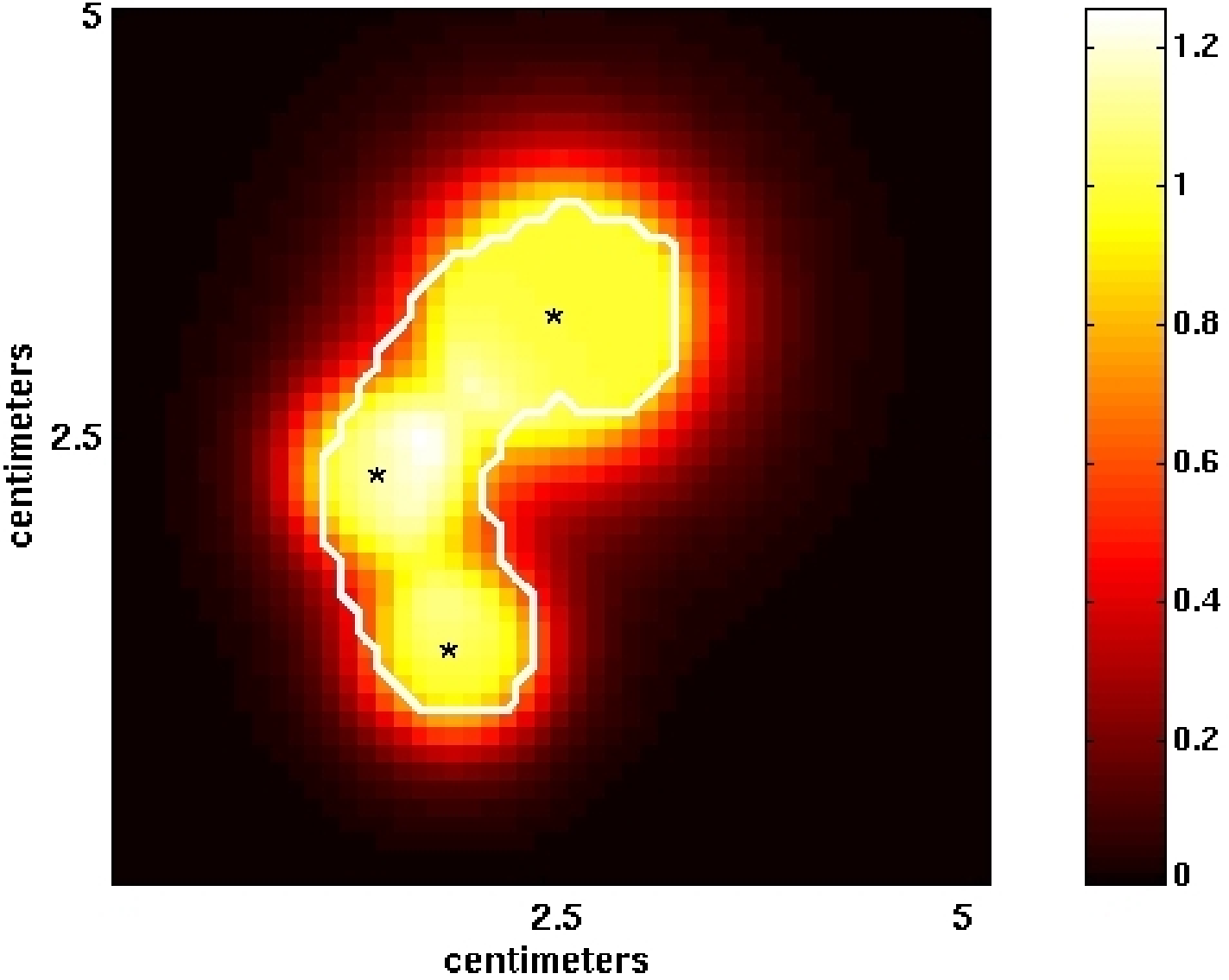
1 Shot



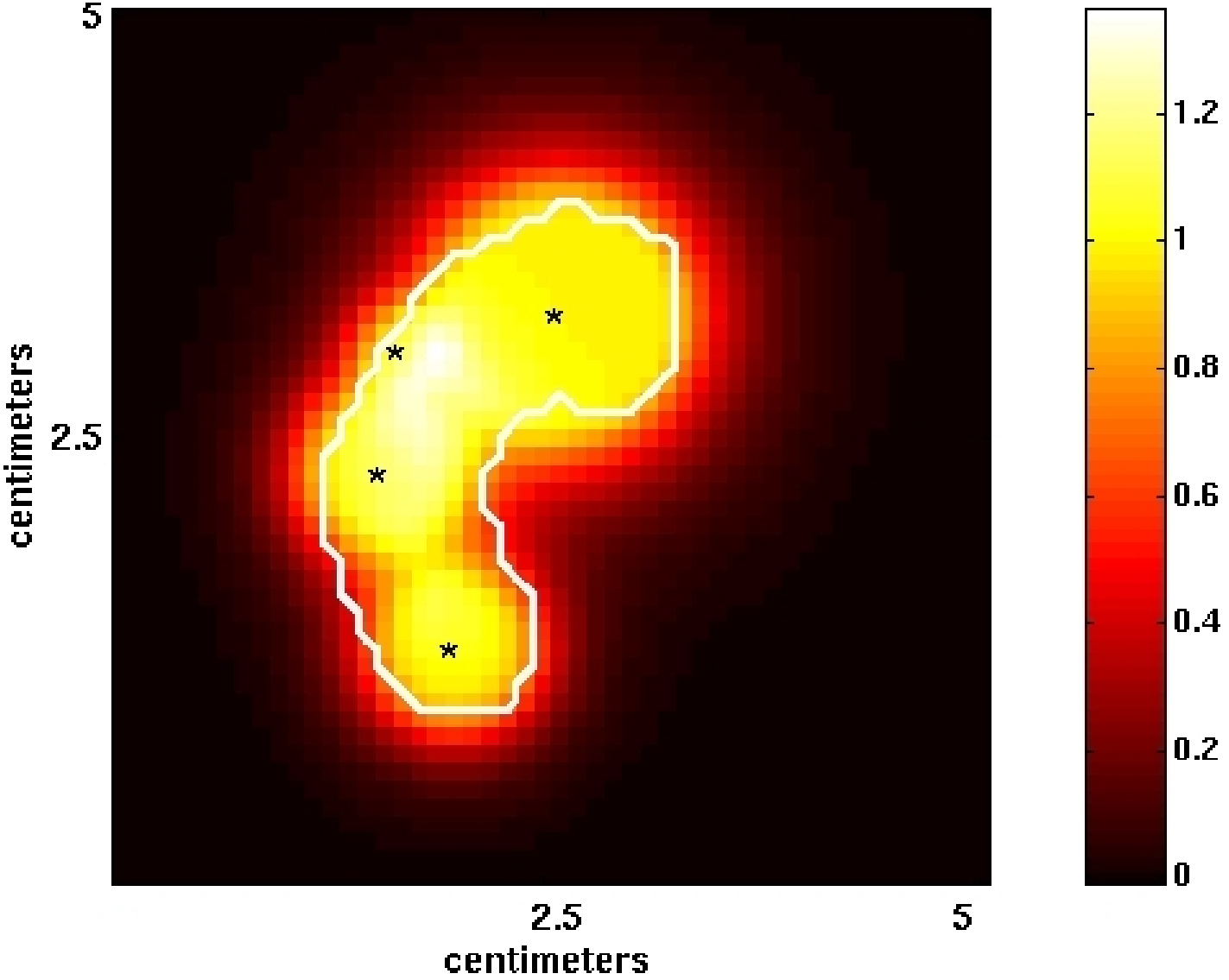
2 Shots



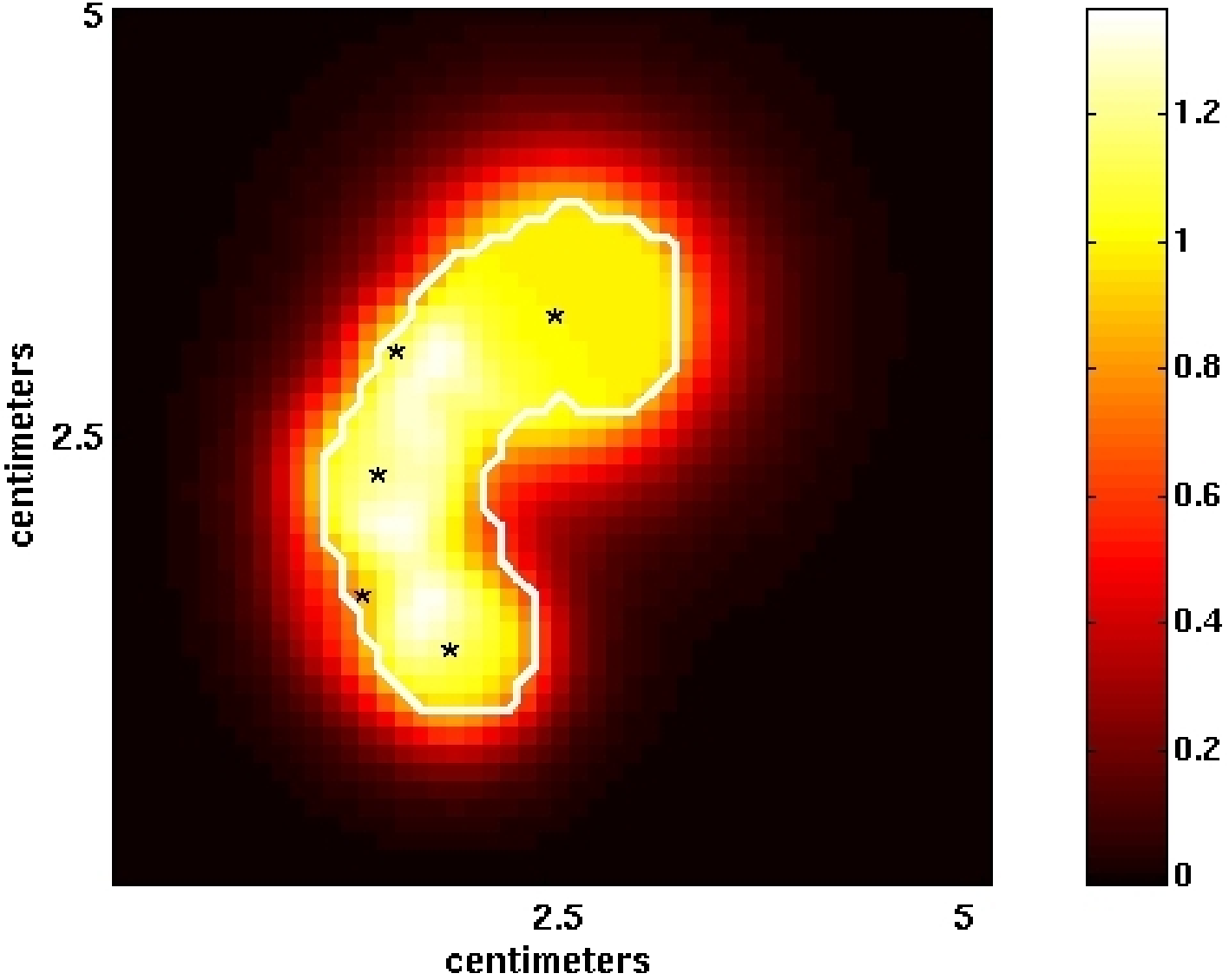
3 Shots



4 Shots



5 Shots



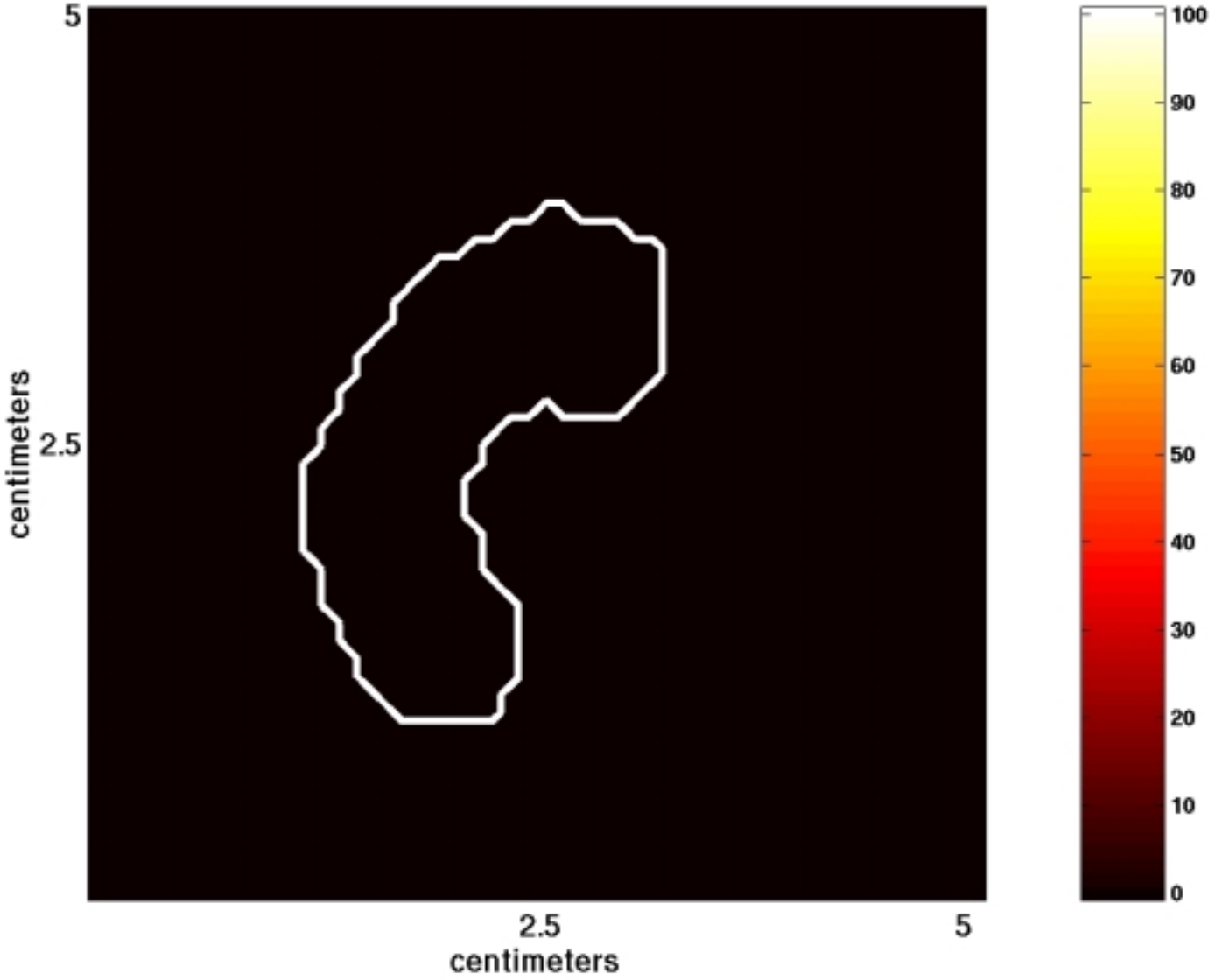
Treatment Planning

- An iterative approach is used to determine:
  - the number of shots
  - the shot sizes
  - the shot locations
  - the shot weights
- This process is tedious, and the quality of the plan that is produced can vary depending upon the experience of the user.

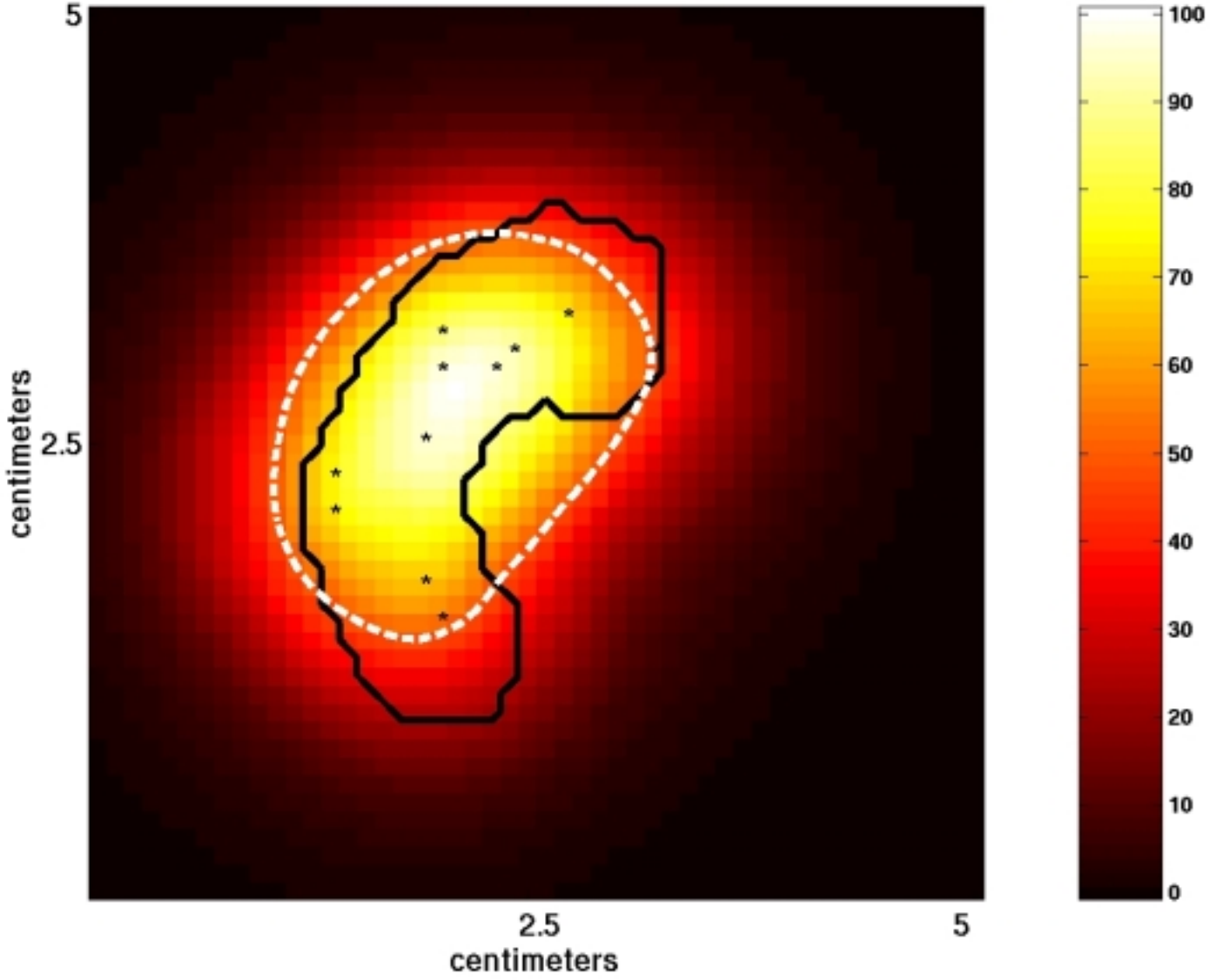
Automated Treatment Planning

- We have sought to develop a fully automated approach to Gamma Knife treatment planning.
- A nonlinear programming formulation is used along with migrating shot locations.

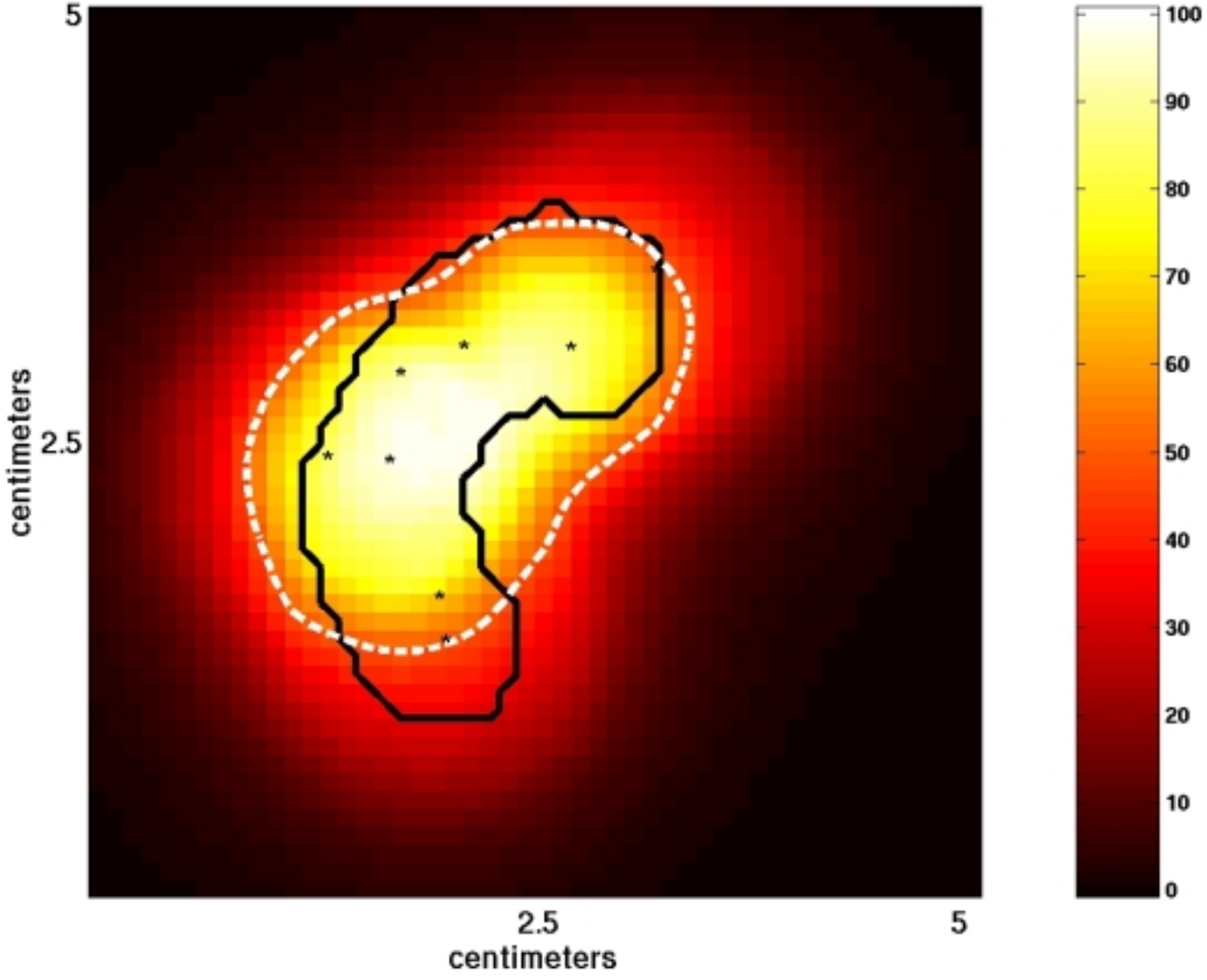
Target


5
2.5
centimeters
2.5
5
centimeters
100
90
80
70
60
50
40
30
20
10
0

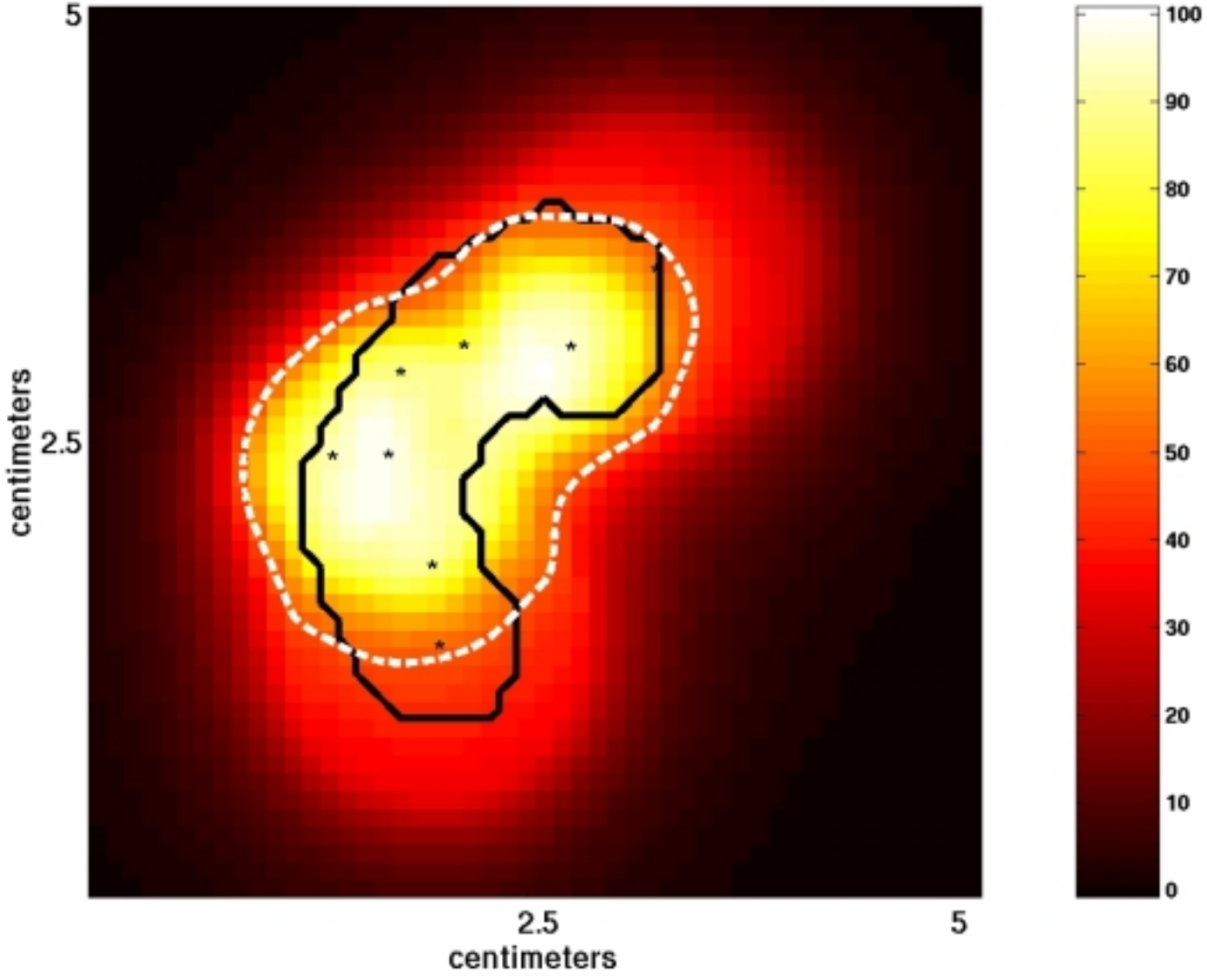
Starting Point



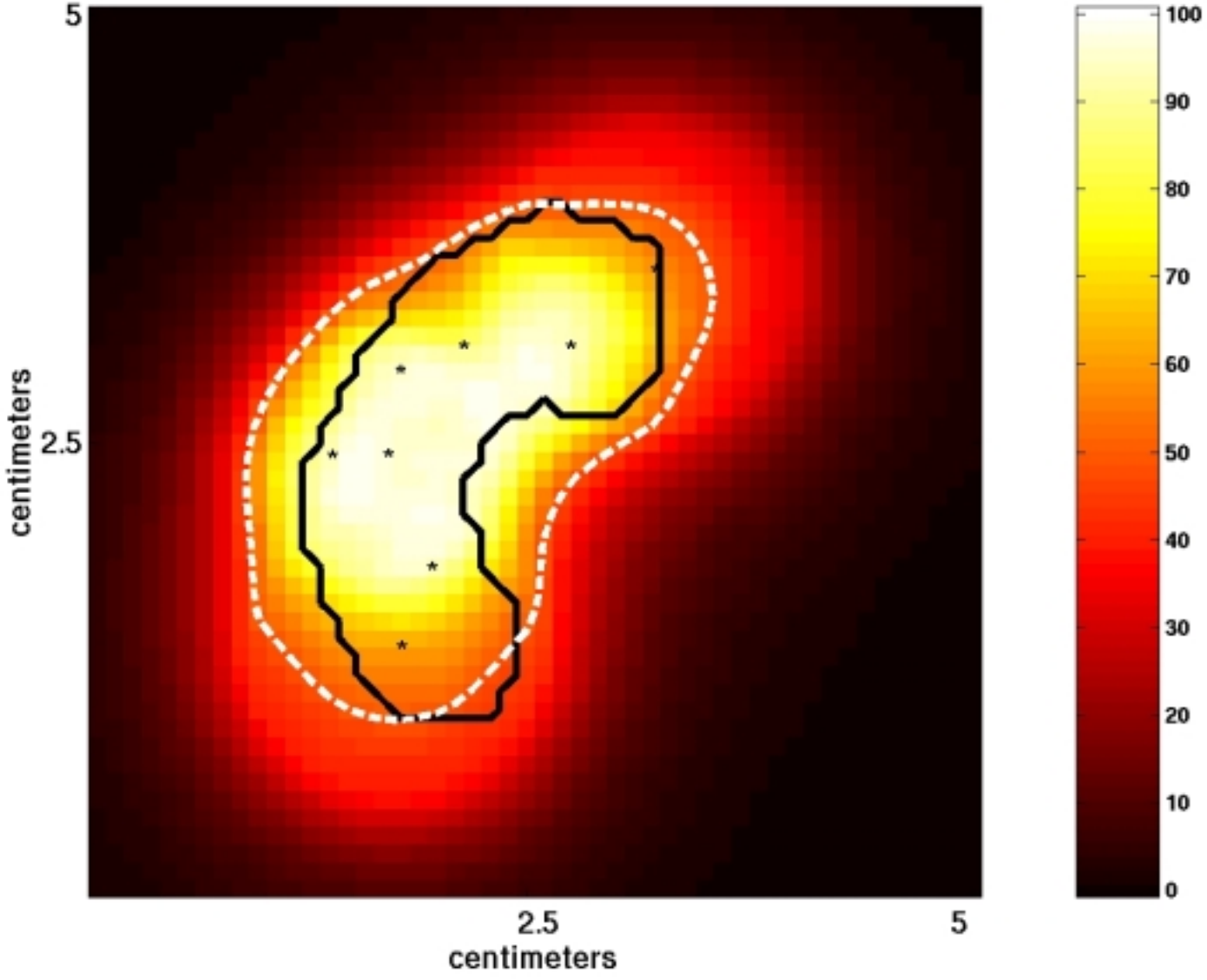
100 Iterations



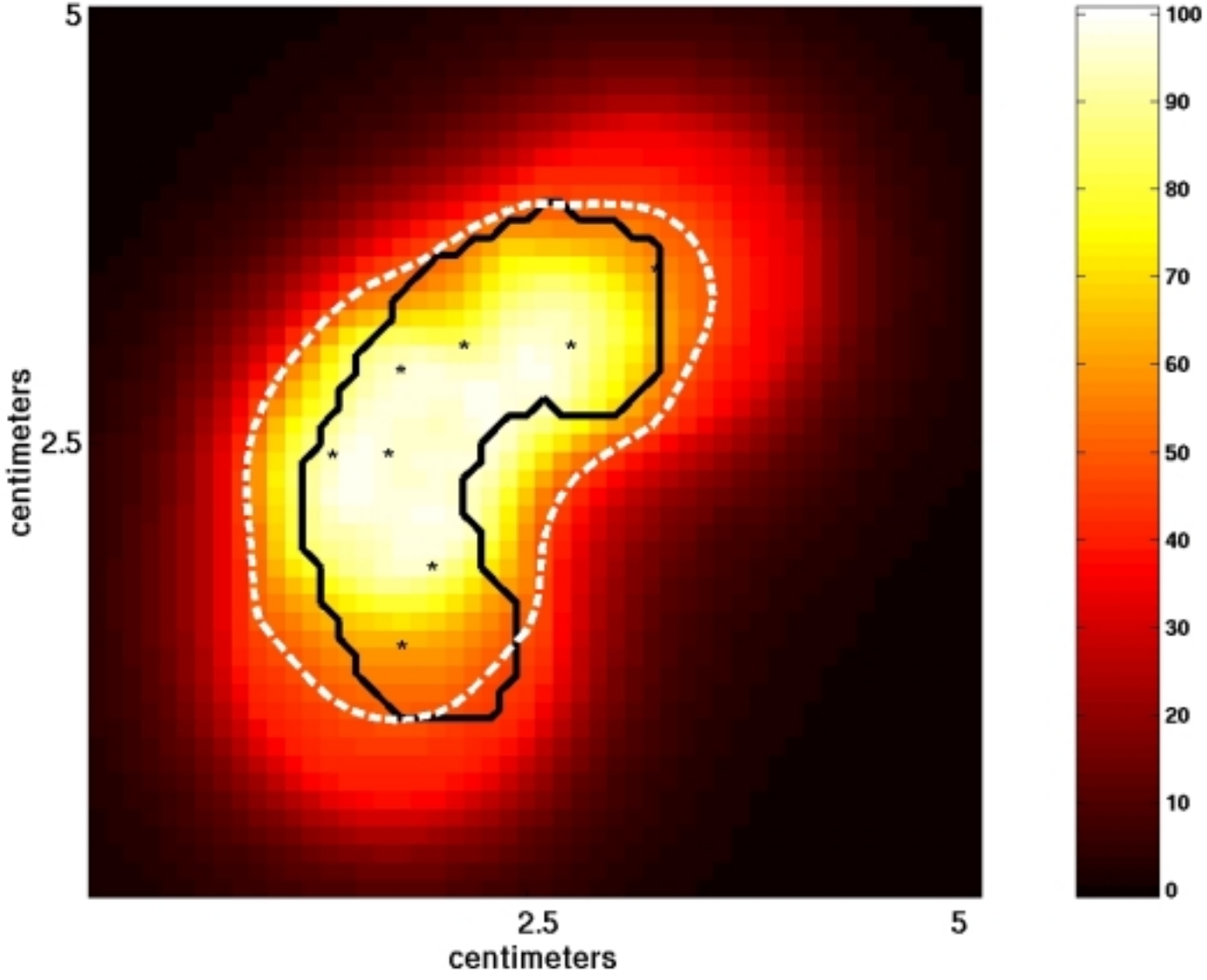
200 Iterations



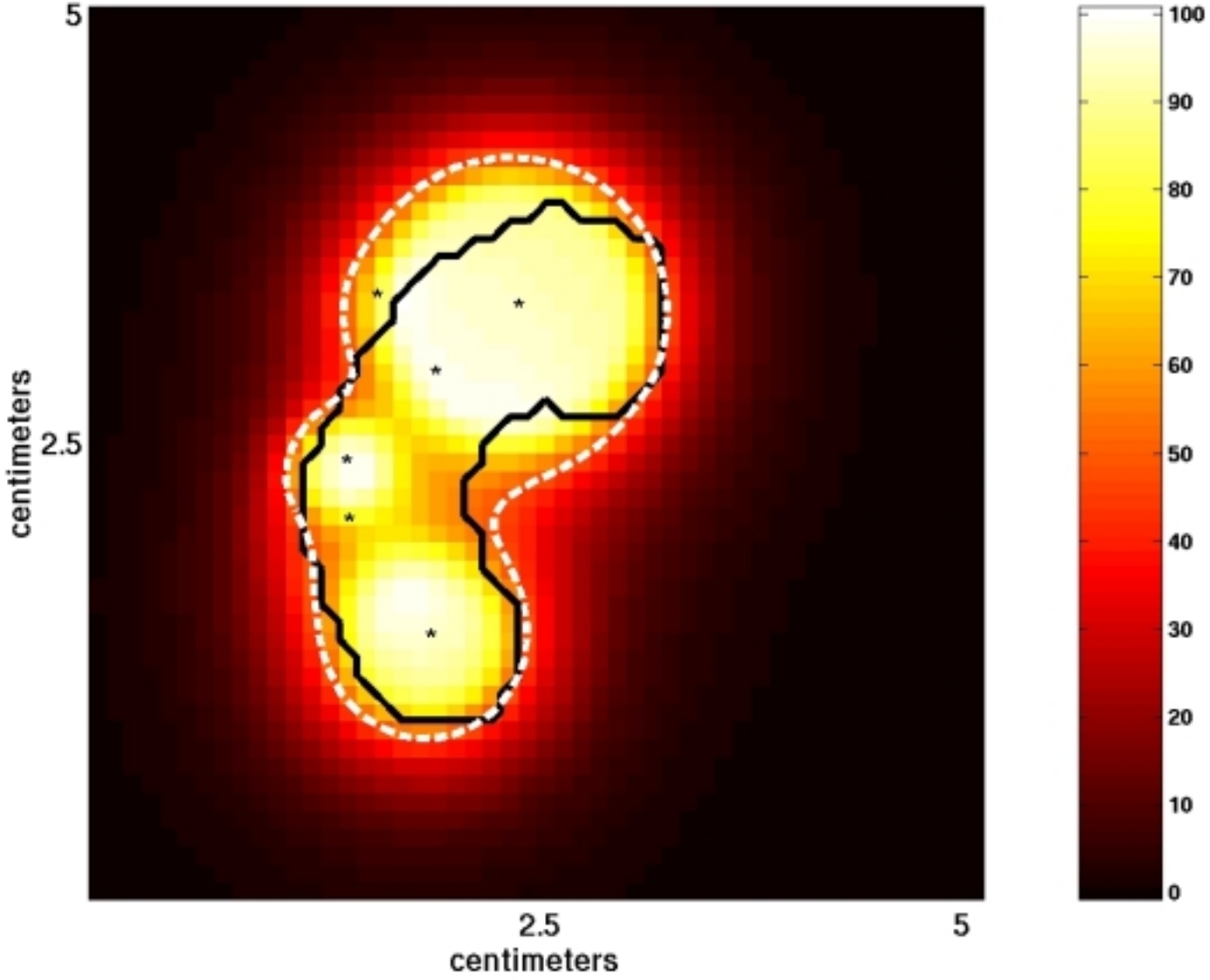
300 Iterations



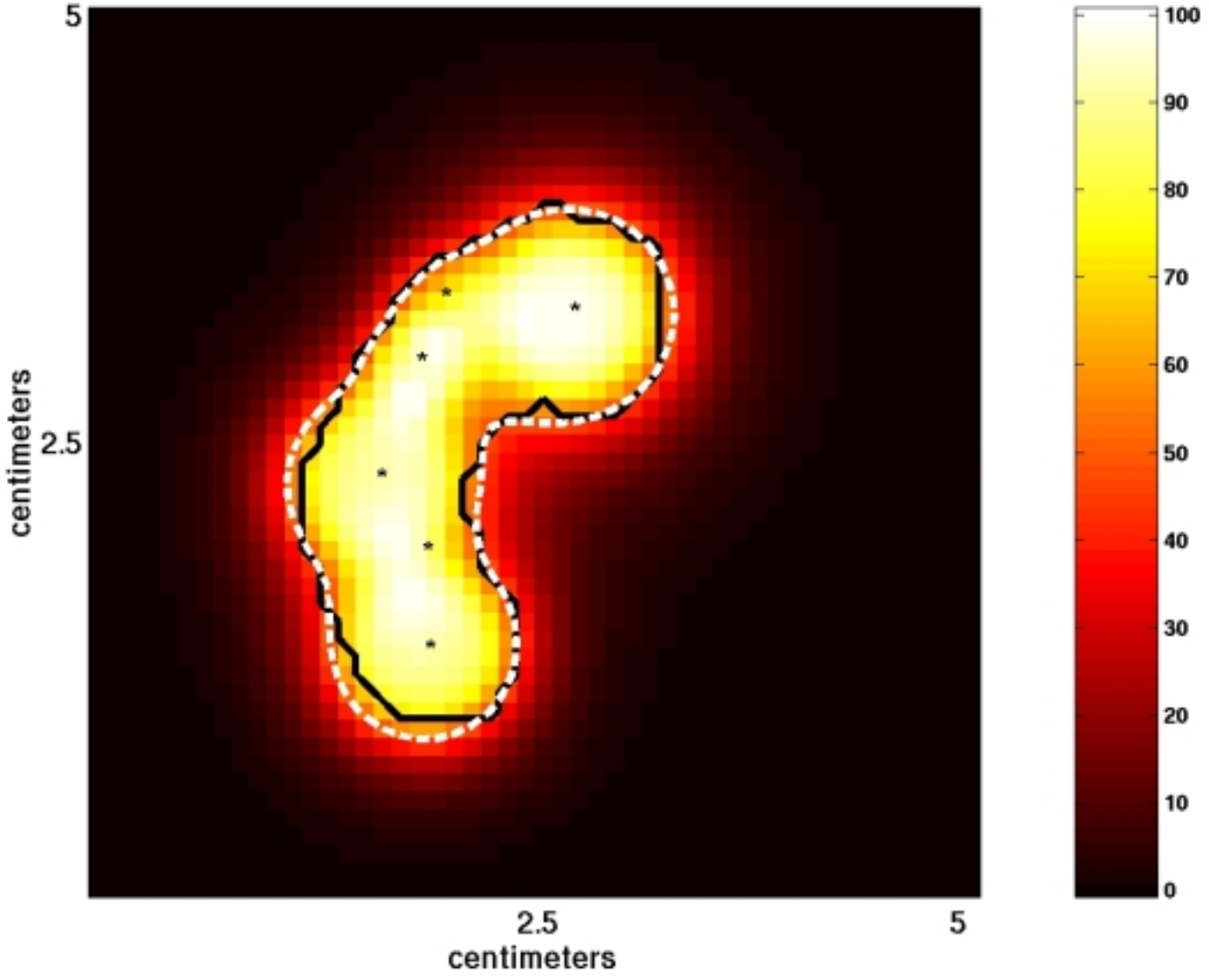
400 Iterations



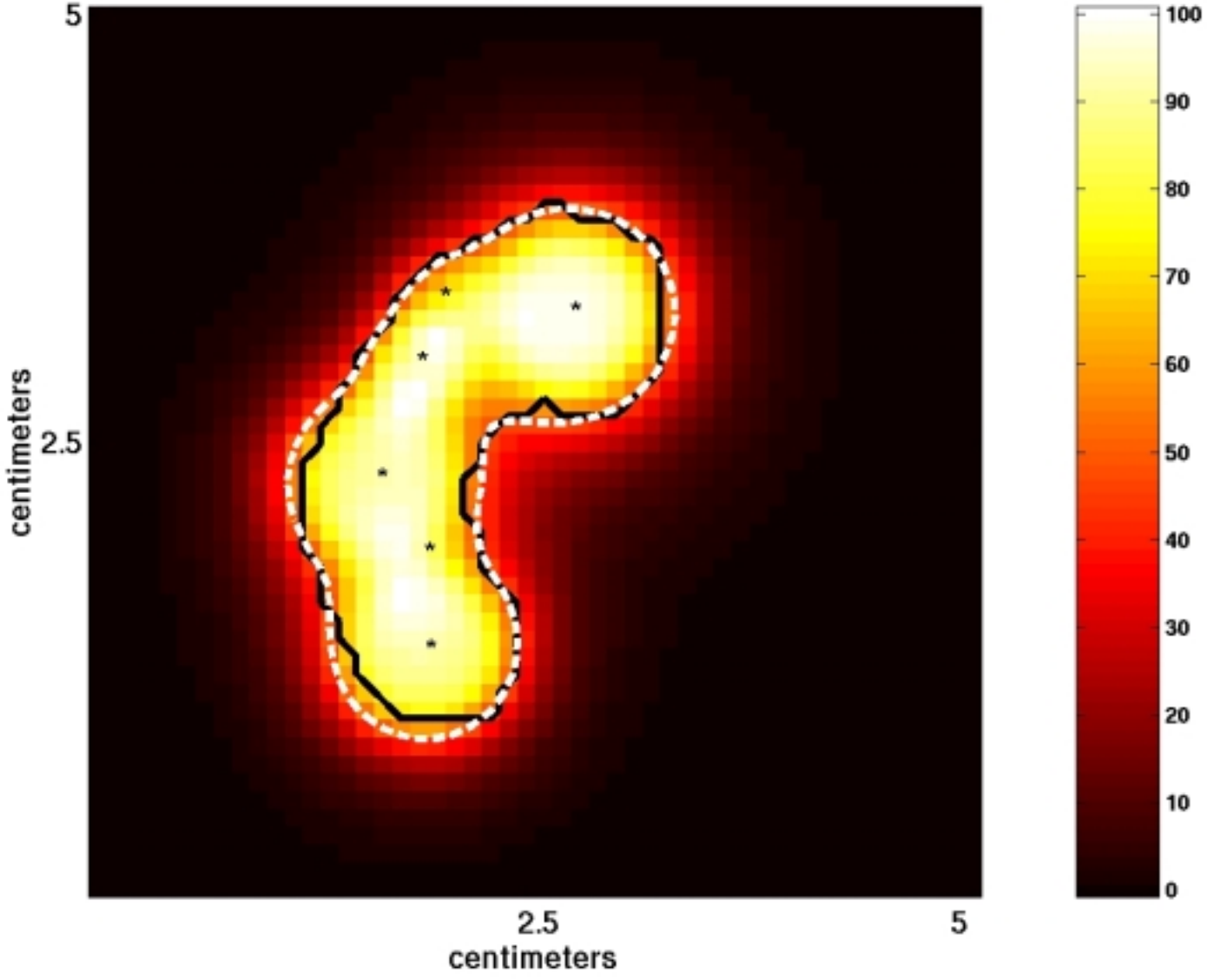
500 Iterations



600 Iterations



Final Solution



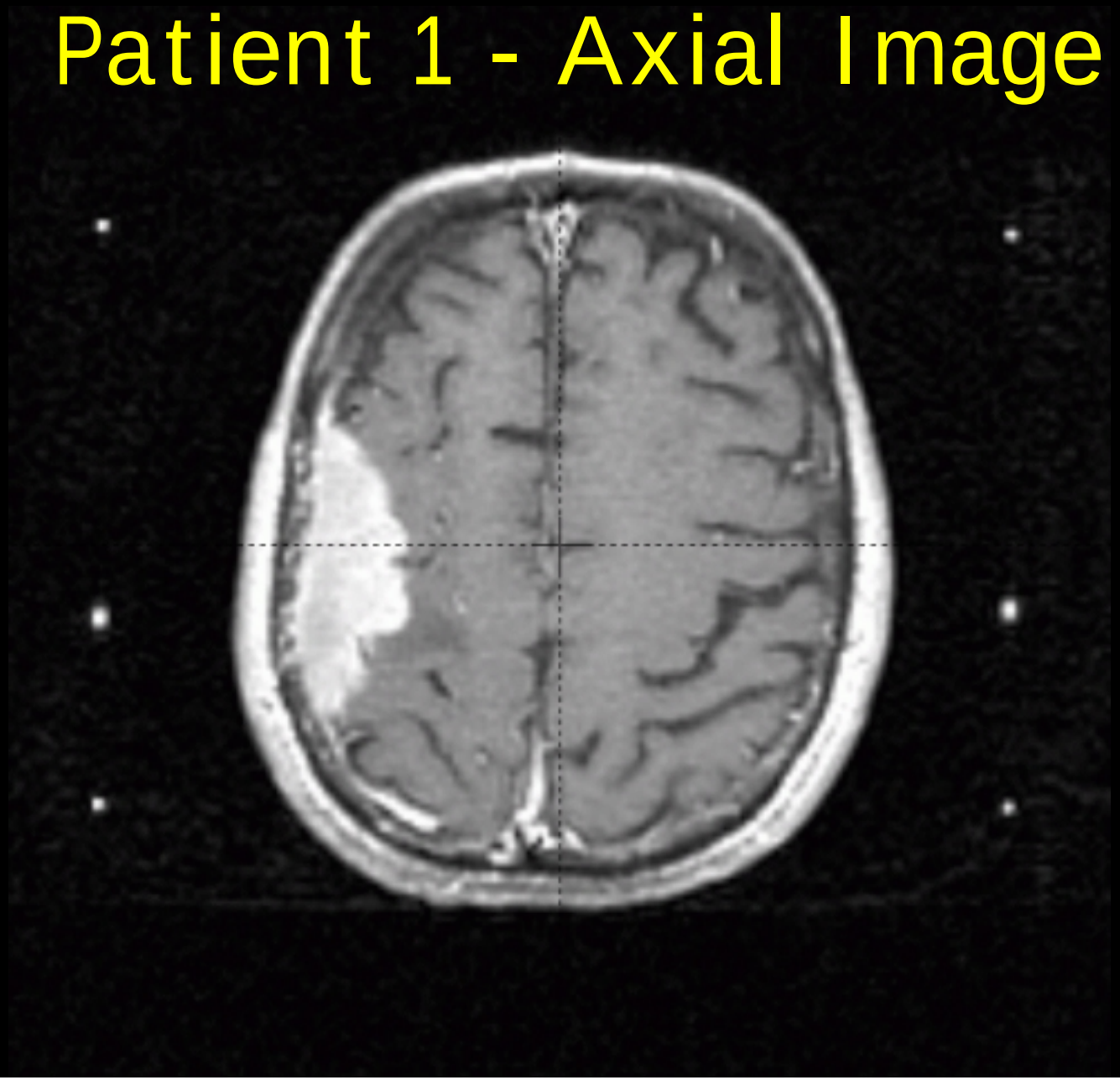
Software

- Constrained optimization were written in the modeling language of GAMS.
- The optimization were solved using the optimization algorithm CONOPT.

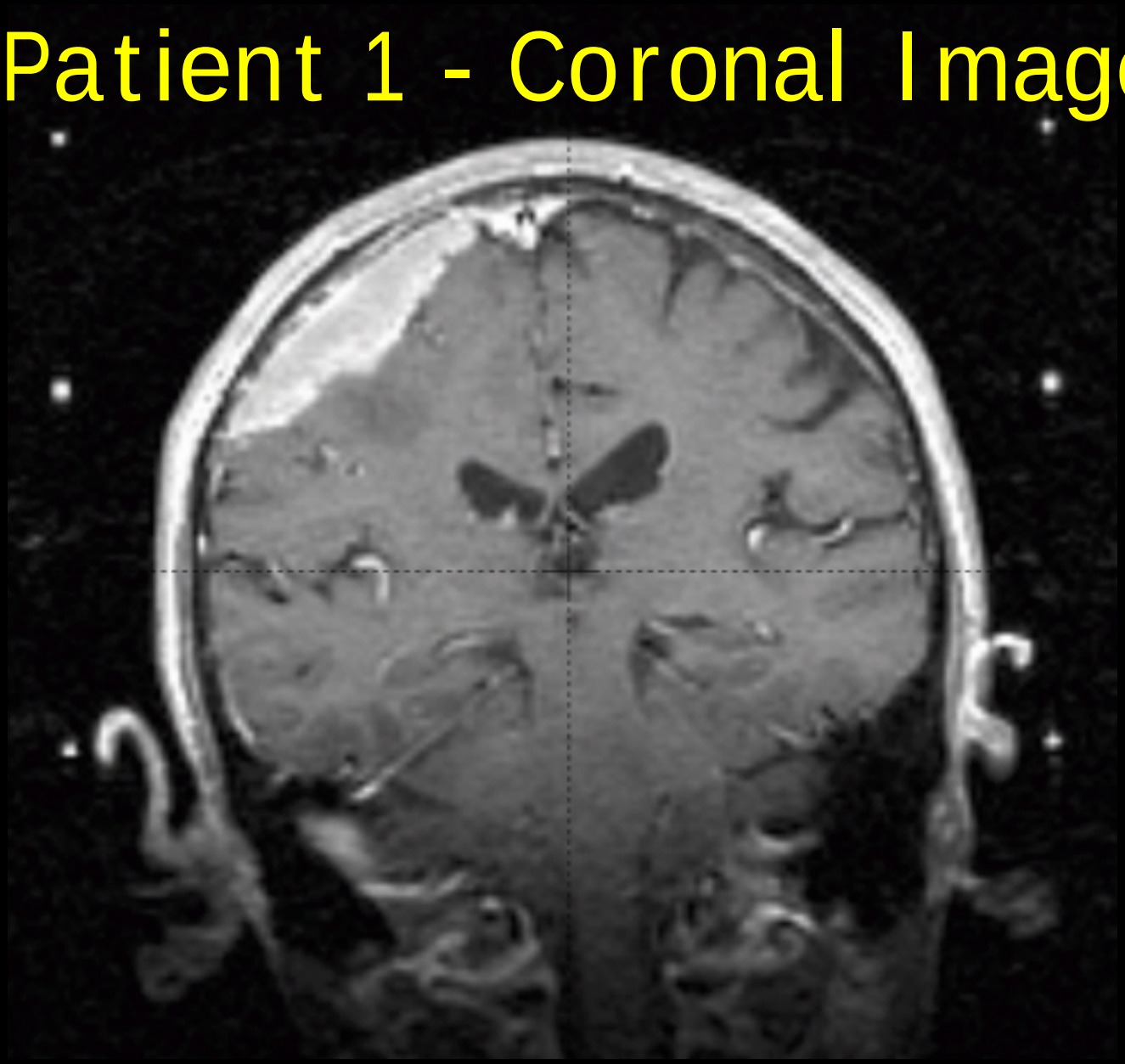
Automated Planning - Steps

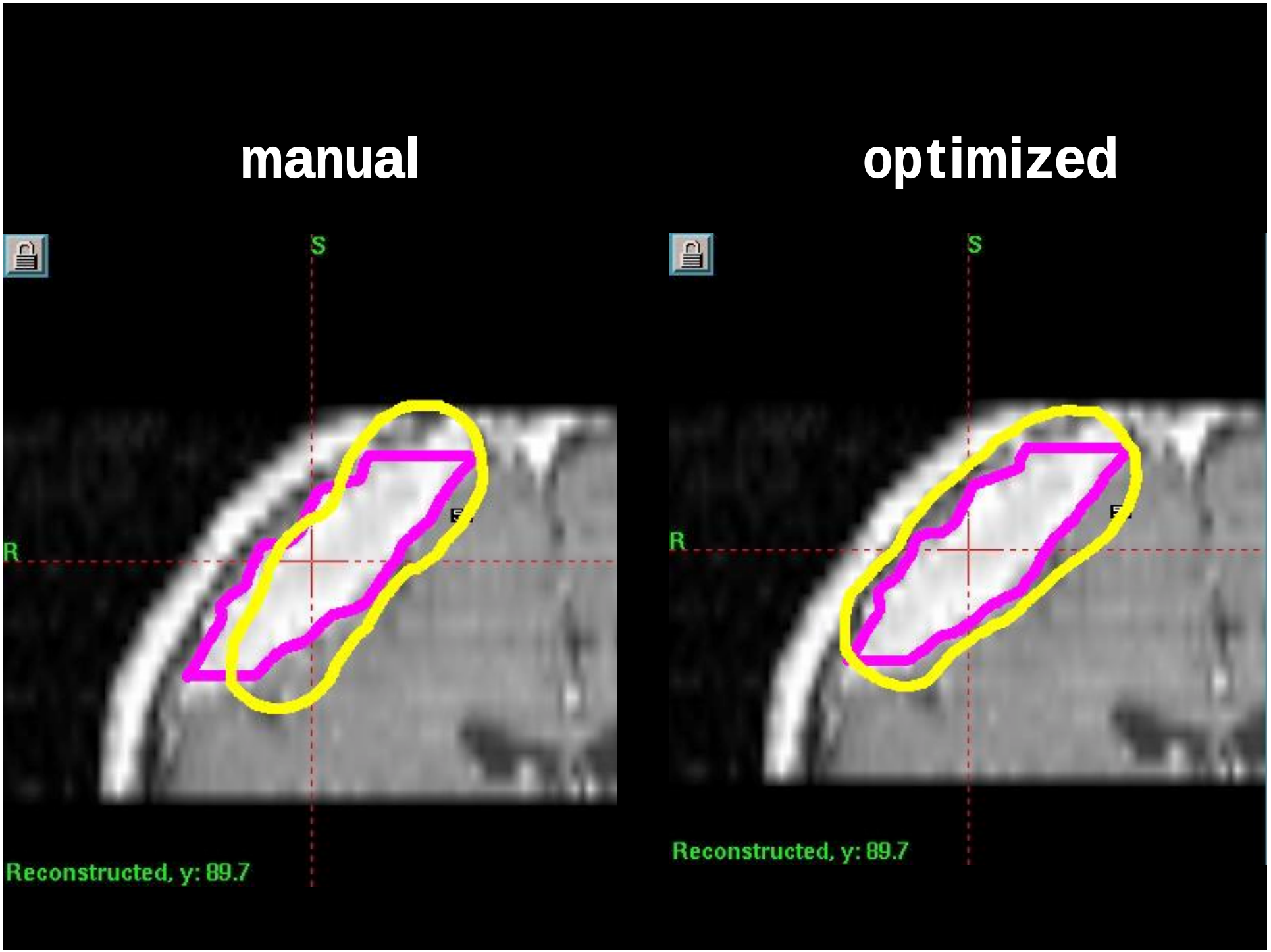
- Outline the tumor volume.
- Select a dose level that would ideally cover the entire tumor.
- Set a maximum dose to the tumor
- Set a maximum number of shots of radiation.

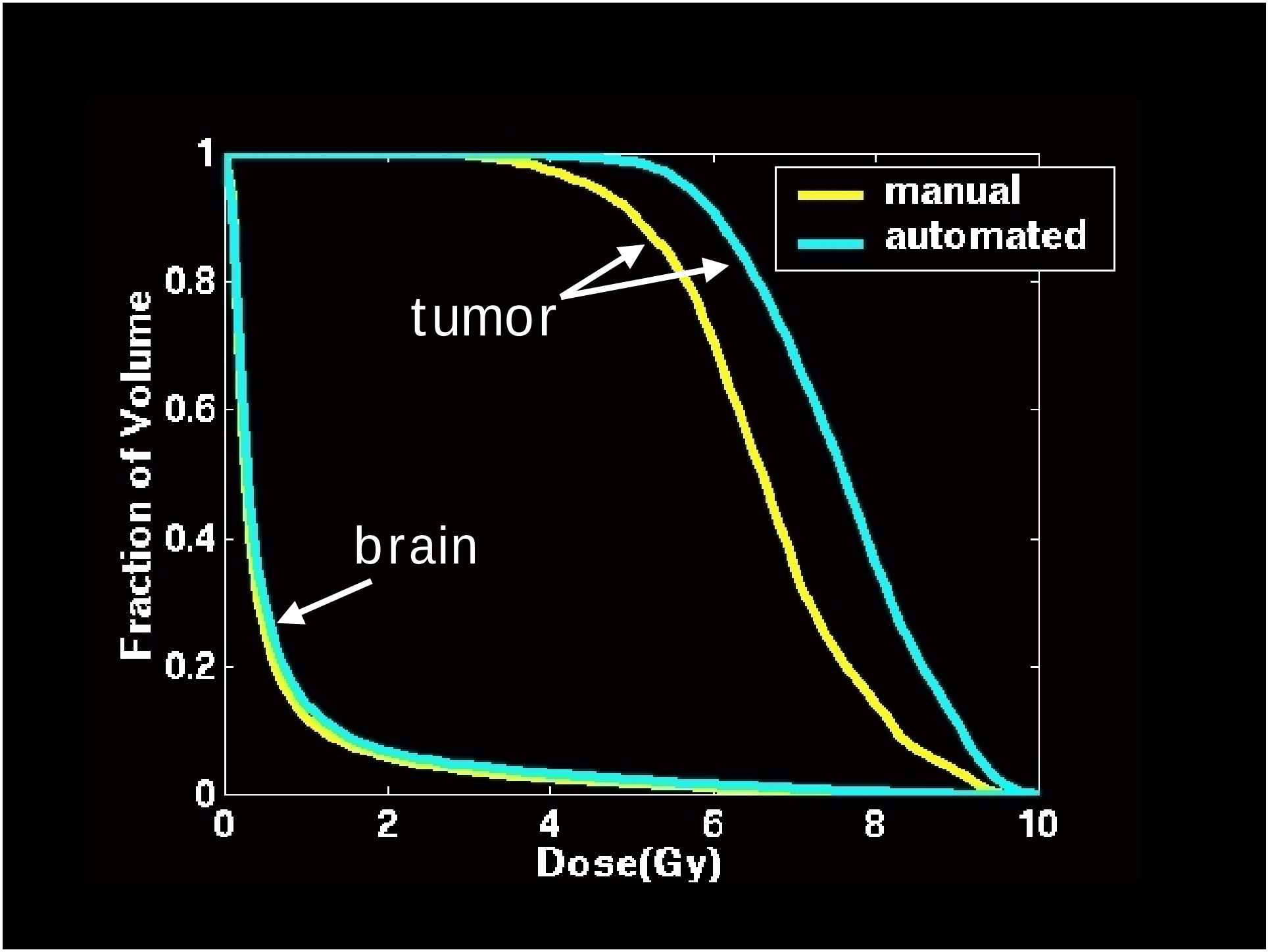
Patient 1 - Axial Image



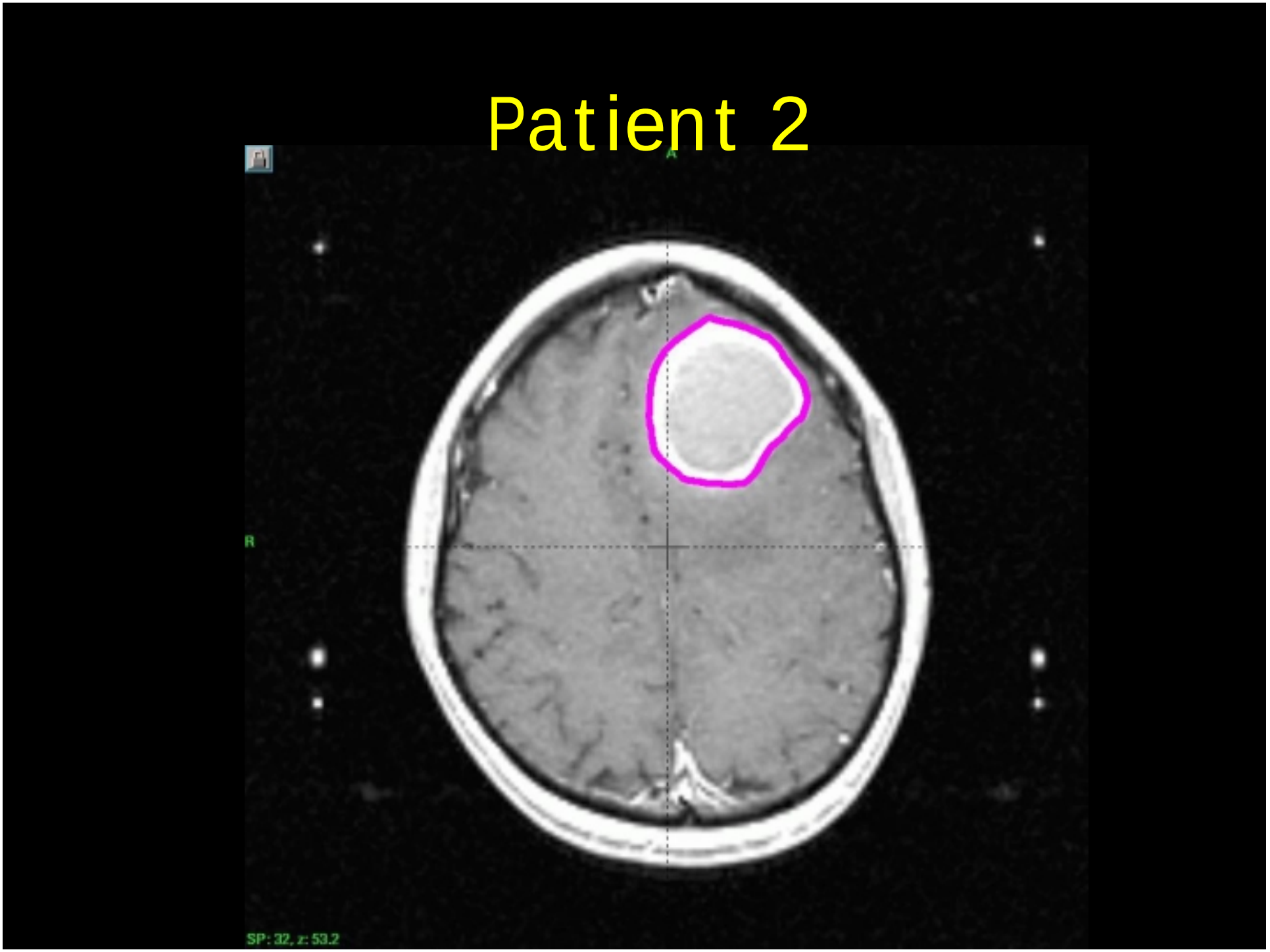
Patient 1 - Coronal Image




manual
optimized
S
R
Reconstructed, y: 89.7
S
R
Reconstructed, y: 89.7


manual
automated
tumor
brain
Fraction of Volume
Dose(Gy)
0
0.2
0.4
0.6
0.8
1
0
2
4
6
8
10

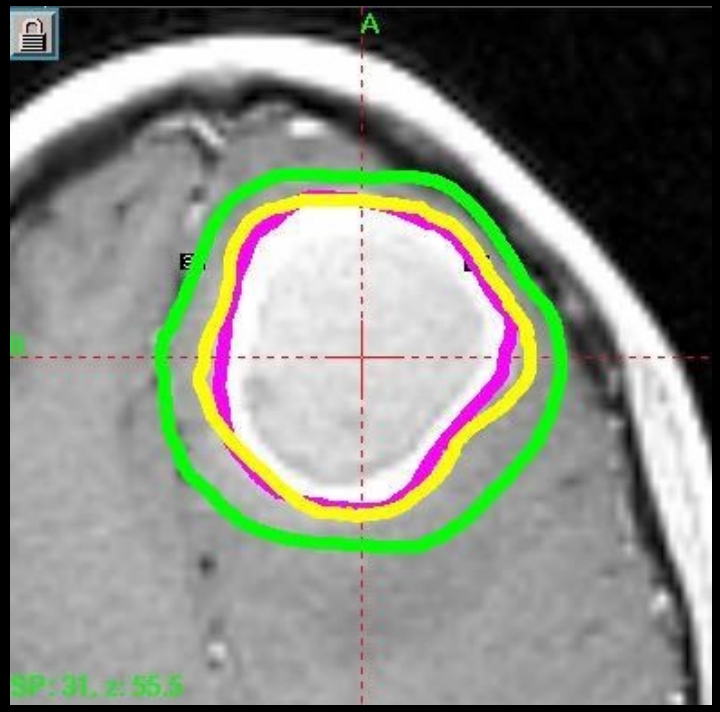
Patient 2



Patient 2 - Axial slice

15 shot manual

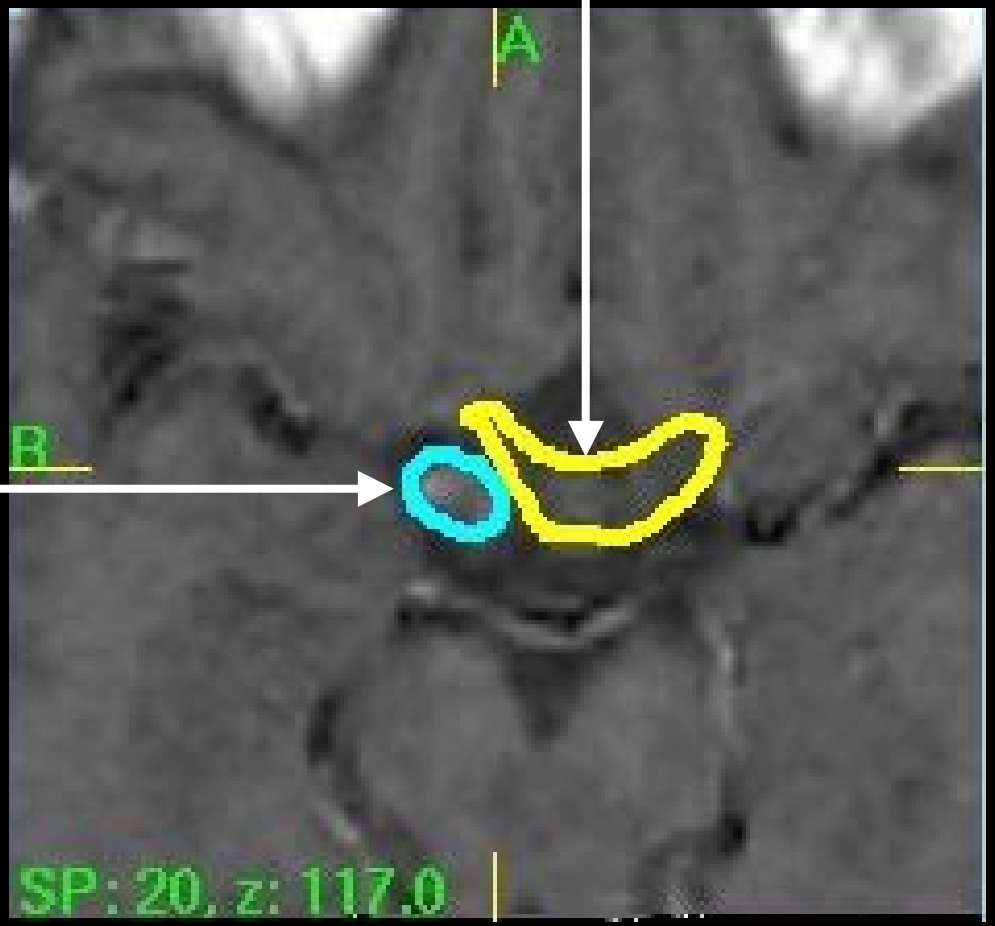
12 shot optimized

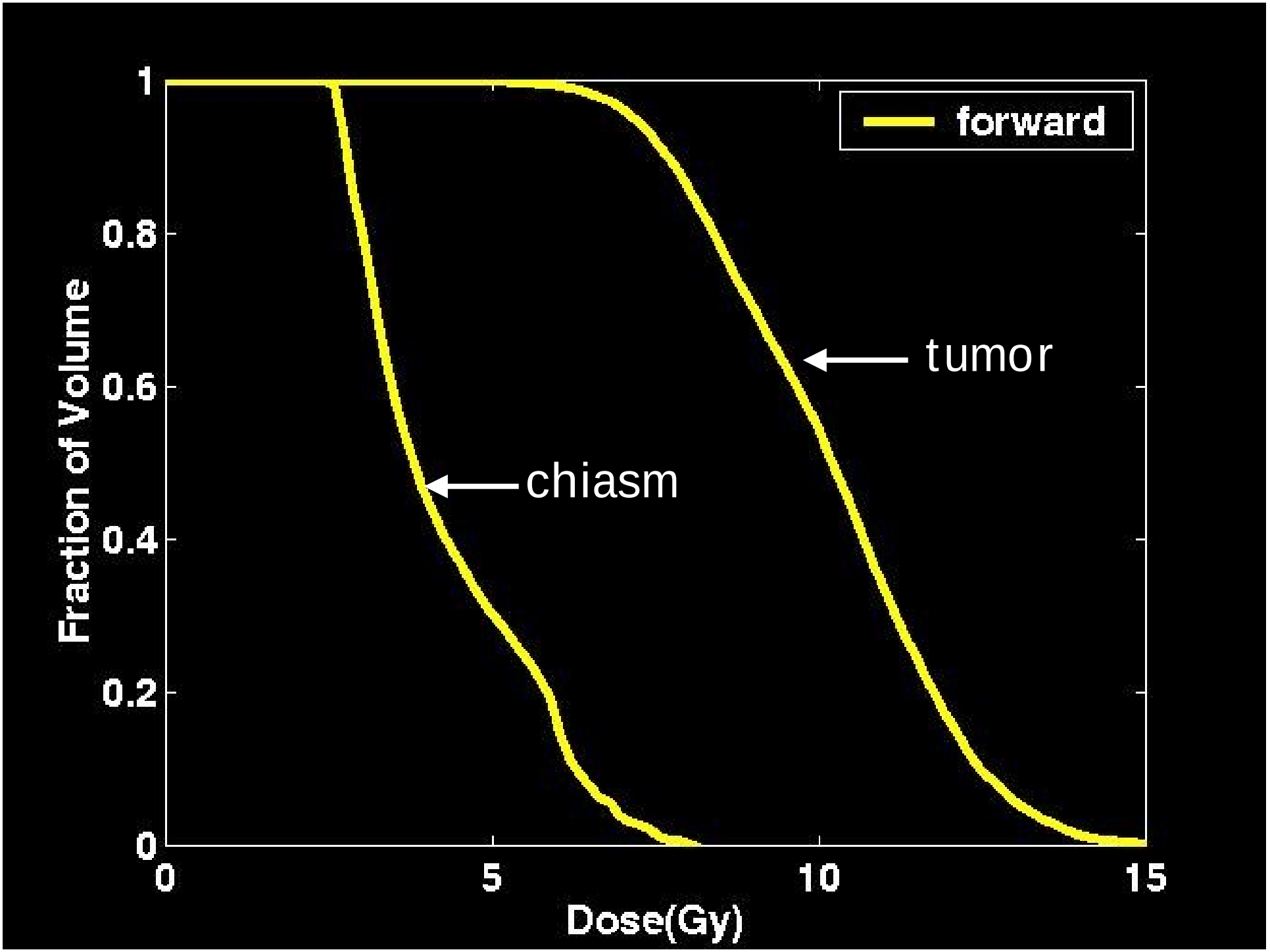


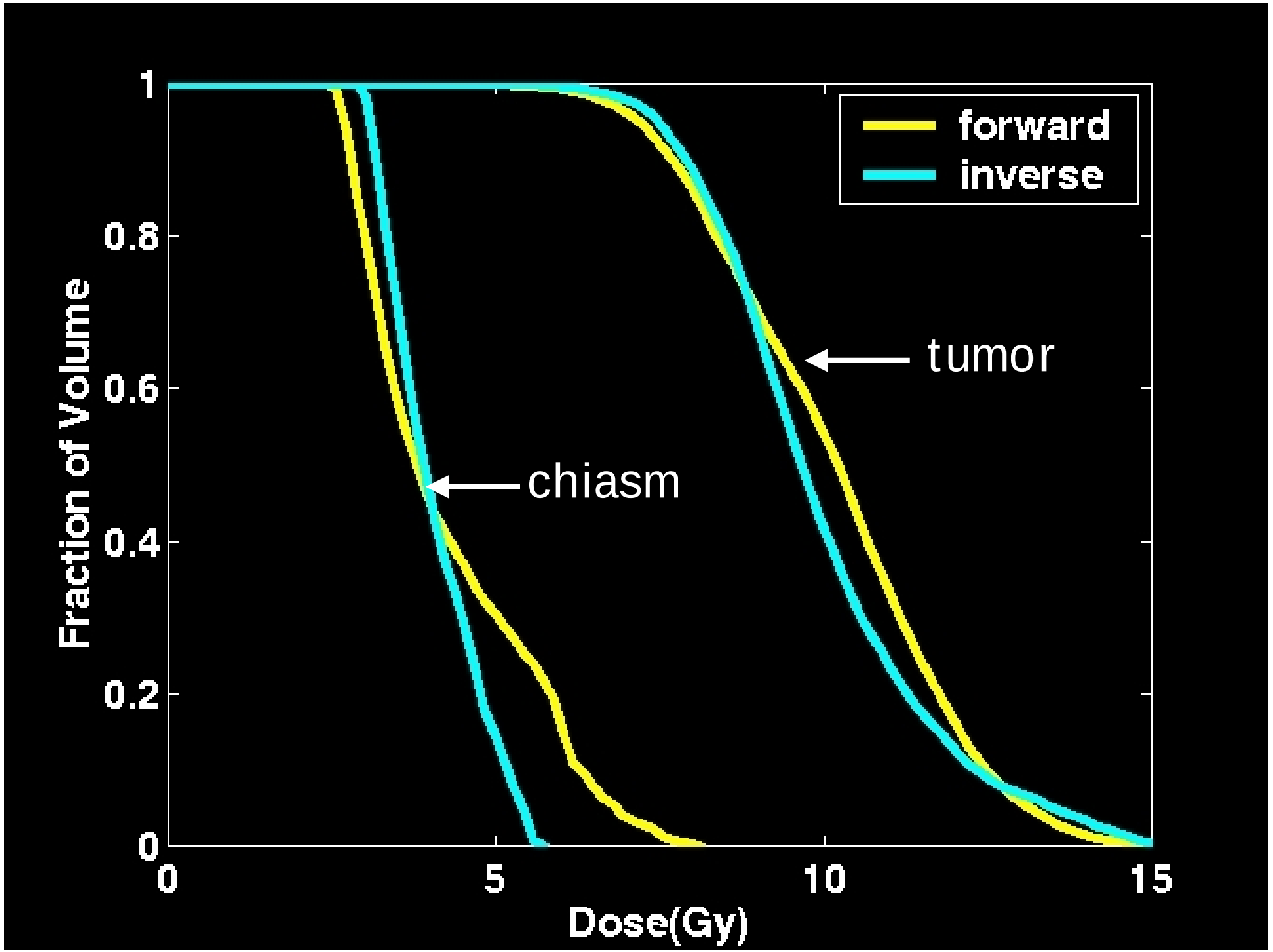
Patient 3

optic chiasm

pituitary adenoma




forward
tumor
chiasm
Fraction of Volume
Dose(Gy)
0
0.2
0.4
0.6
0.8
1
0
5
10
15


forward
inverse
tumor
chiasm
Fraction of Volume
Dose(Gy)
0
0.2
0.4
0.6
0.8
1
0
5
10
15

Status

- Automated plans have been generated retrospectively for over 20 patients.
- The automated planning system is now being tested head to head against the neurosurgeon.
- The first patient has been treated.

Speed

- In most cases, an optimized plan can be produced in 10 minutes or less on a 850 MHz PC running LINUX.
- For, very large tumor volumes, the process slows considerably and can take up to 45 minutes.

Benefits of Automated Planning

- Better tumor dose coverage.
- Reduced dose to normal tissue.
- More efficient treatments.
- Reduced time commitment for neurosurgeon and radiation oncologist.

Conclusions

- An automated treatment planning system for Gamma Knife radiosurgery has been developed using nonlinear programming techniques (GAMS and CONOPT).
- The system simultaneously optimizes the shot sizes, locations, and weights.
- Automated treatment planning should improve the quality and efficiency of our radiosurgery treatments.