Stereotactic Radiation Surgery (SRS) and Stereotactic Body Radiation Therapy (SBRT)

Part II. technical details in image-guided planning and optimization

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One can compare SRS & SBRT by

$$TCP = \prod_i \left(1 - e^{-\alpha BED_i + \gamma T}\right)^{c_i v_i} \approx \left(1 - e^{-\alpha BED_{\min} + \gamma T}\right)^{c_{\min} v_{\min}}$$

$$NTCP(OAR) = 1 - \prod_s \prod_i \left[\left(NTD_2 d_i / NTD_2 D_{50s}\right)^k + 1\right]^{-v_i / V_s}$$

Flickinger, IJROBP, p879,1989 & Withers, IJROBP, p549, 1995

Relating to conventional radiotherapy, SRS and SBRT have increased the biological equivalent dose, BED, and decreased the elapse time T so that TCP is increased.

While hypo-fraction SBRT has smaller NTD_2d_i/NTD_2D_{50s} then that of SRS so that less impact of increased dose on the NTCP.

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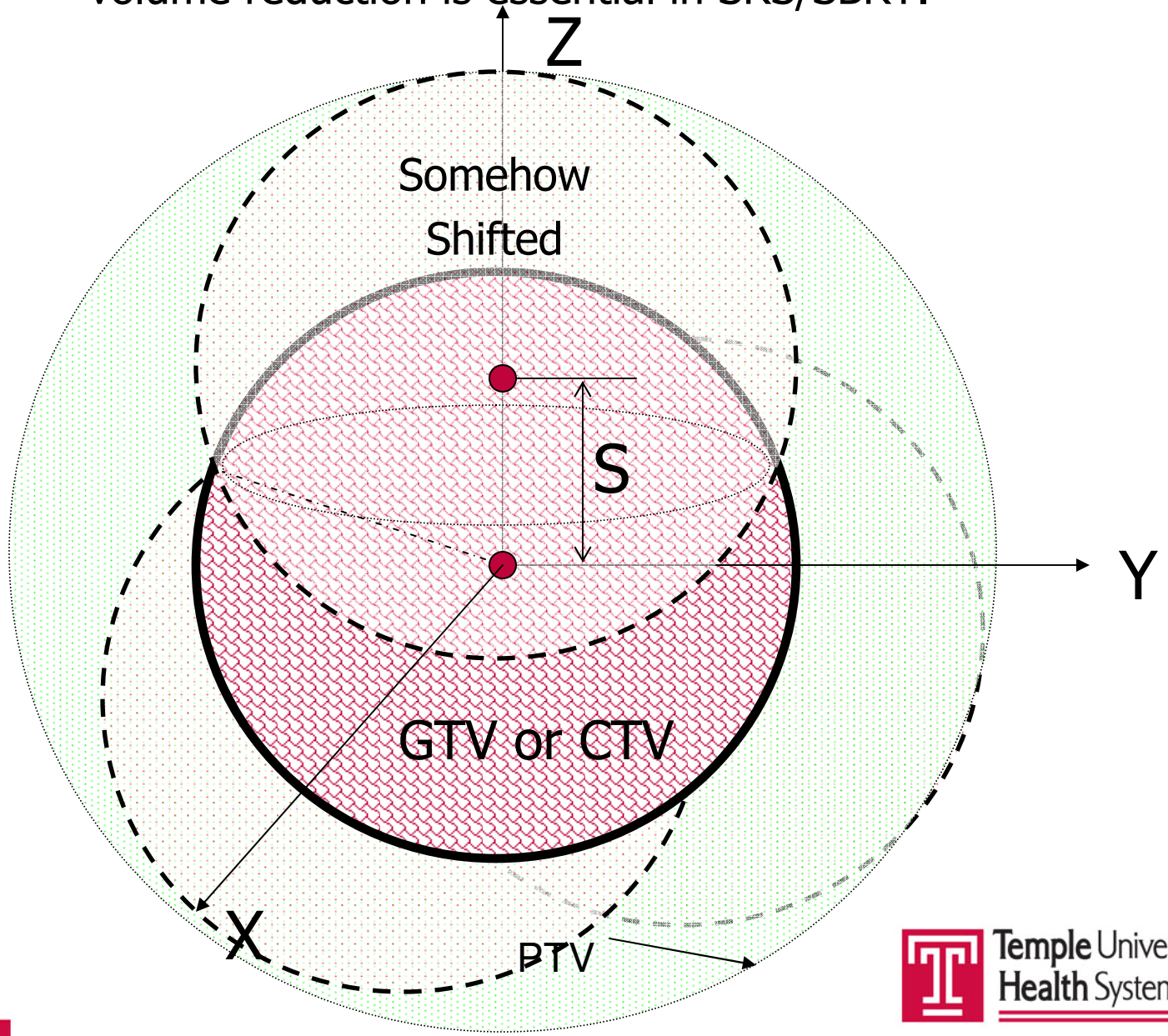
In addition to the radiobiological consideration, target volume reduction is essential in SRS/SBRT.



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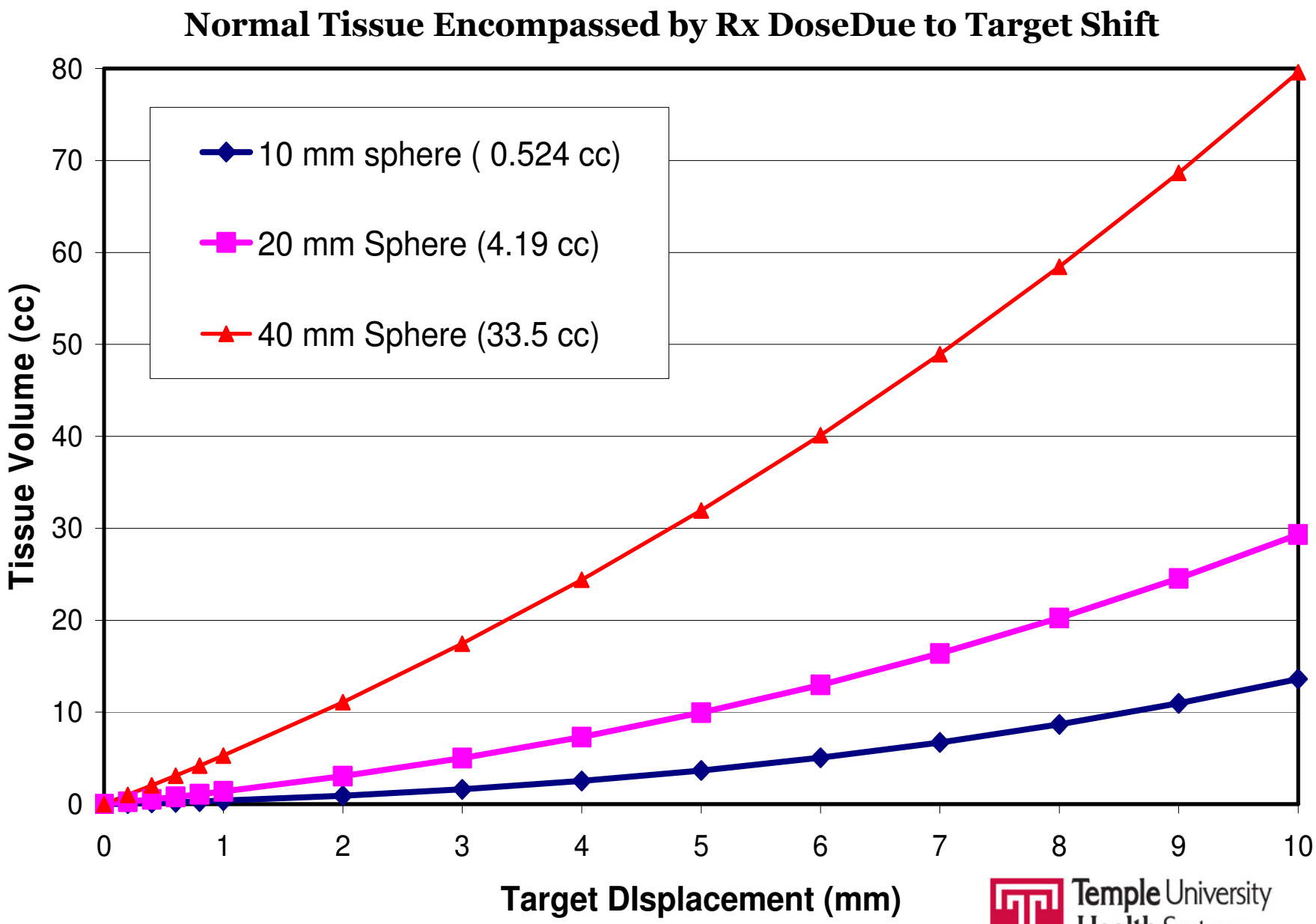

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How to reduce margin of target in

- treatment simulation,
- treatment planning, and
- dose delivering?

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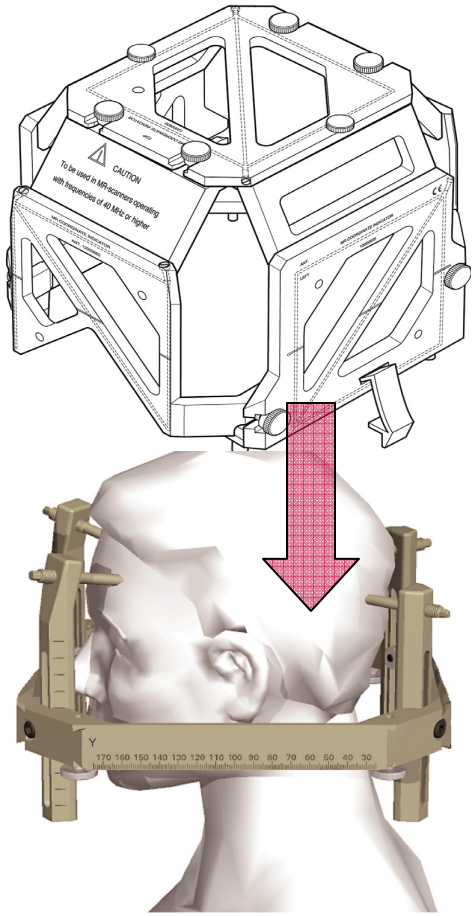
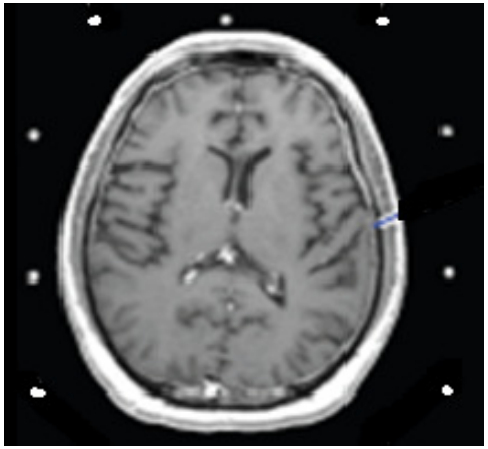
1. Simulate patients as actual treatment setup &
2. Use immobilization devices if allowed

Left shows a SBRT patient of NSCLC within SBRT body frame and abdomen compression. Right: a large patient can't fit to the frame

3. Add a localizer to remove errors in image registration



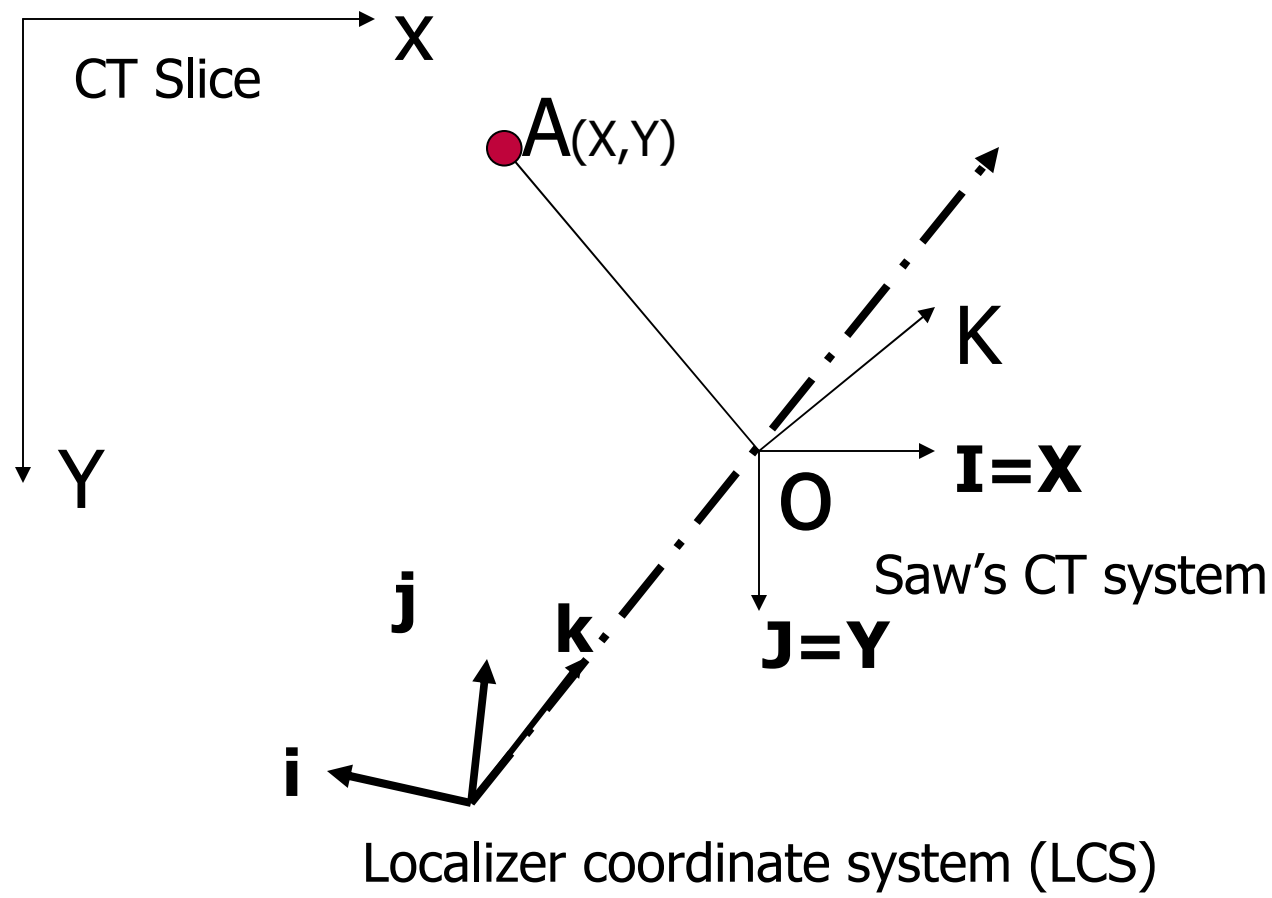


A head-frame is fixed to the patient skull for Gamma-knife (GK) SRS. A MRI localizer was attached to the frame at scans. Localized MRI slices provide accurate head position in GK.

Know the limits of stereotactic localization algorithms

Saw *et al* (Med Phys P1042-7, 1987)

$$\vec{A} = X\hat{e}_X + Y\hat{e}_Y = x\hat{e}_i + y\hat{e}_j + (z - z_o)\hat{e}_k \qquad (1)$$



Point O(z_o) is defined by localizer pins in the CT slice. Equation (1) can determine (x, y, z) in LCS

Note: localizer orientation k has to be close to CT axial direction K.

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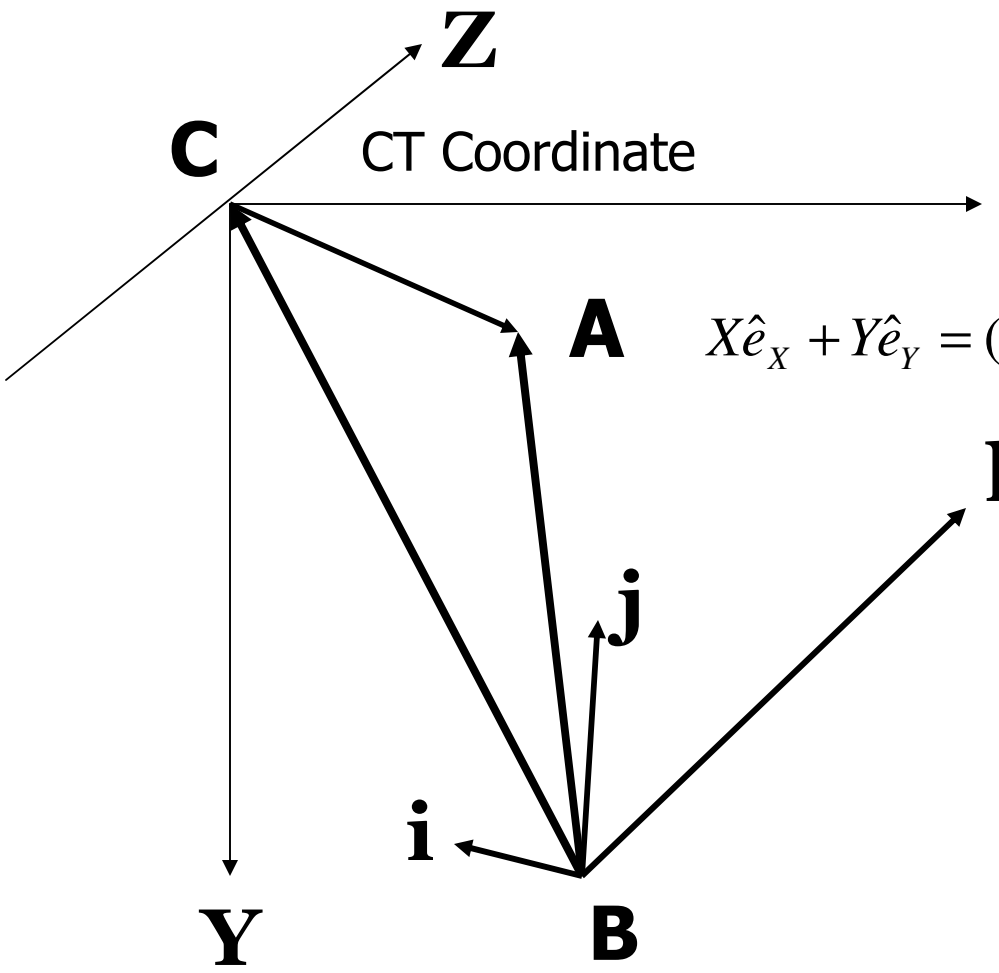
Algorithm of Li *et al* (Med. Phys. P518-25, 1999)



$$CA = BA - BC \quad \textit{or}$$

$$X\hat{e}_X + Y\hat{e}_Y = (x - x_B)\hat{e}_i + (y - y_B)\hat{e}_j + (z - z_B)\hat{e}_k$$

No approximation but requires two separate slices to define the LCS origin of the point B

Localizer Coordinate System (LCS)

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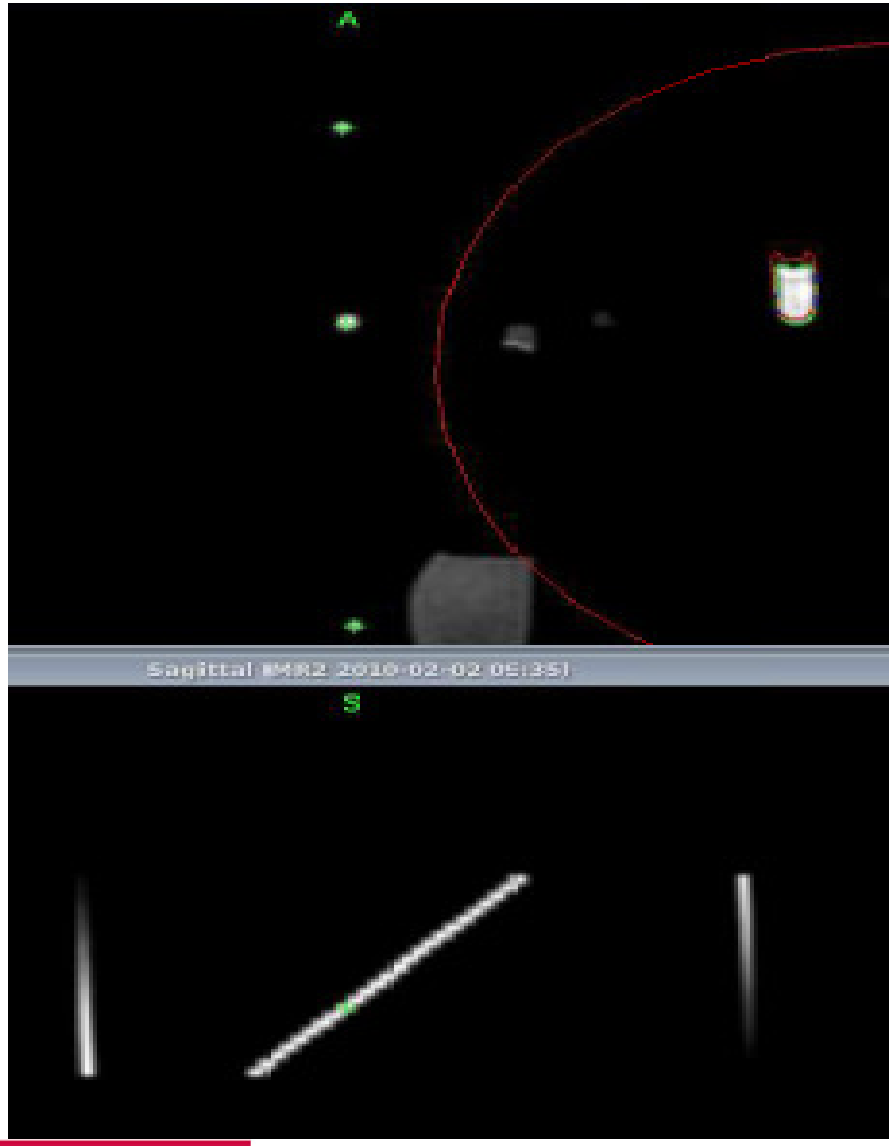
One can also check localizer's pins after image registration in the LCS




```
Point Laksall: 5.7, 159.6, 112.5 mm
 Contribution from shots in target A:1 only
 Plan          = Plan1
 Dose          = 0.0   %

Point Laksall: 5.6, 112.5, 112.8 mm
 Contribution from shots in target A:1 only
 Plan          = Plan1
 Dose          = 0.0   %

Point Laksall: 5.7, 38.5, 113.3 mm
 Contribution from shots in target A:1 only
 Plan          = Plan1
 Dose          = 0.0   %
```

Accuracy of our available localizers in LCS

Pins in	Max	Mean	Global	Center
CT	0.5	0.3	0.4	0.3
MRI	0.9*	0.7*	0.5	0.5
XA	0.4	0.4	0.4	0.4

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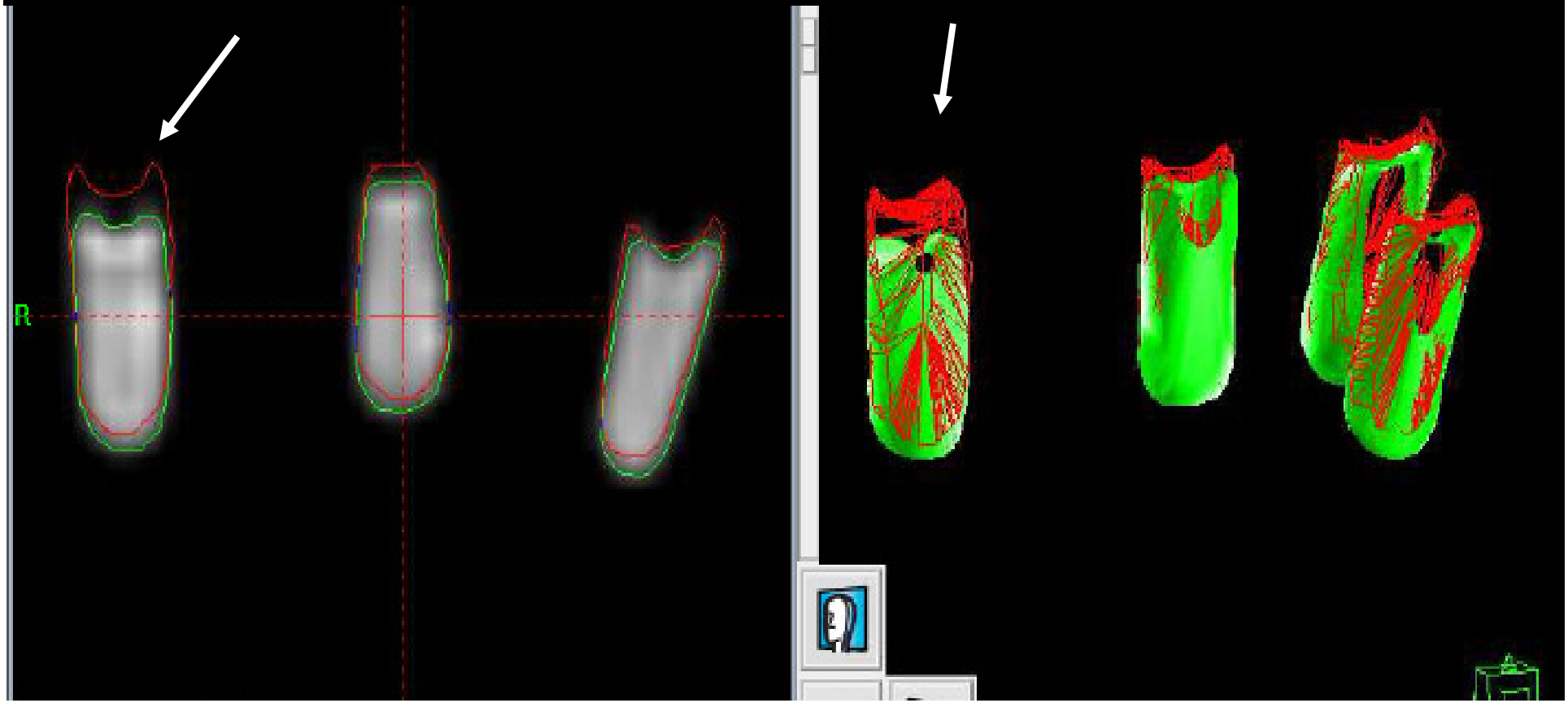
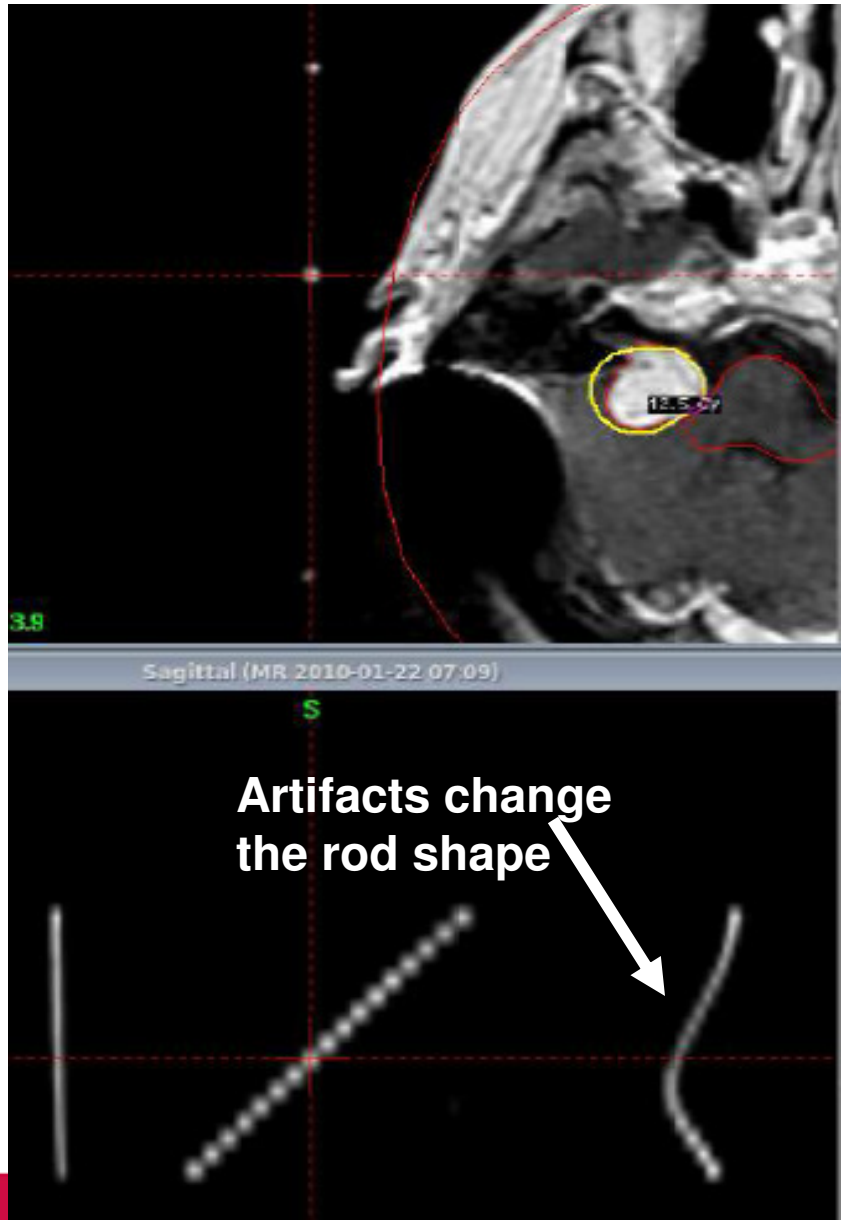
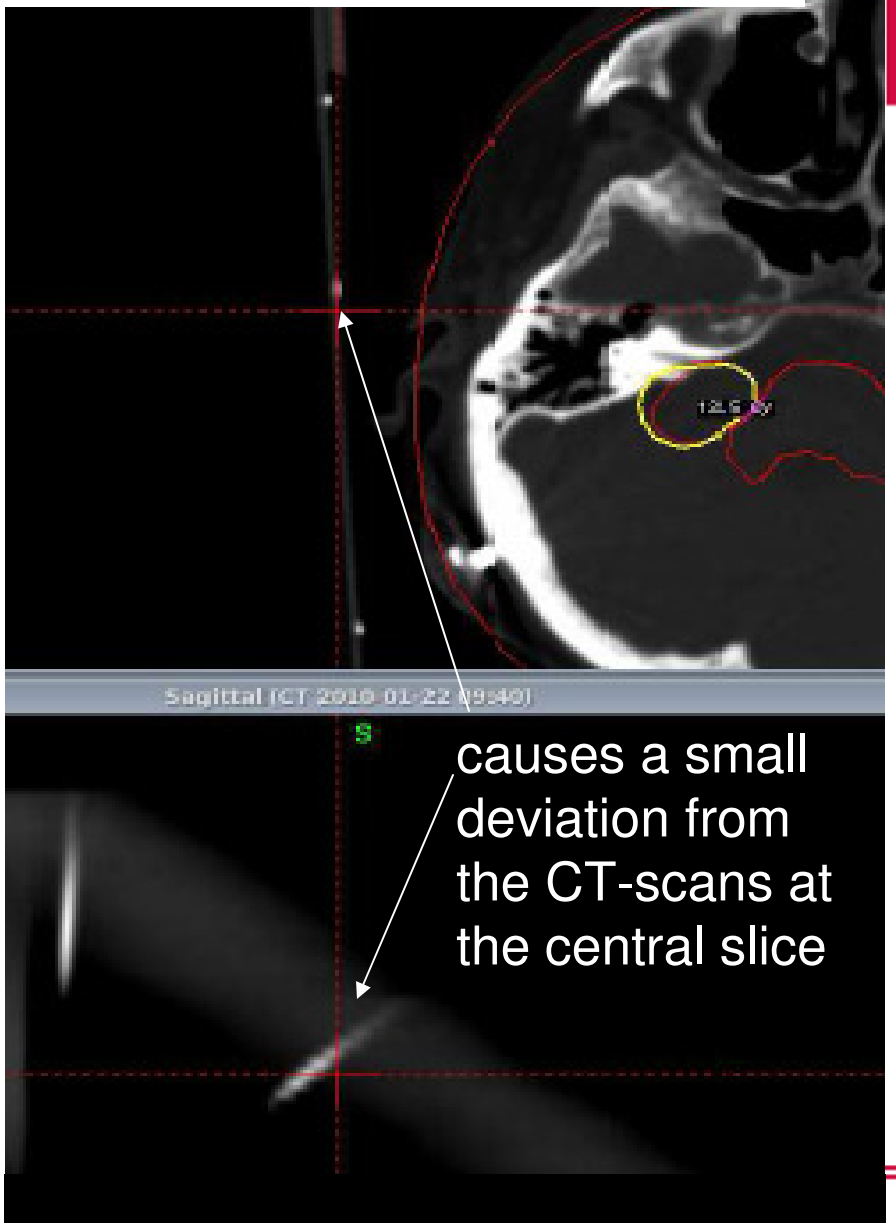
4. Scans using fine section (2 or 3 mm), small FOI, and proper contrast.

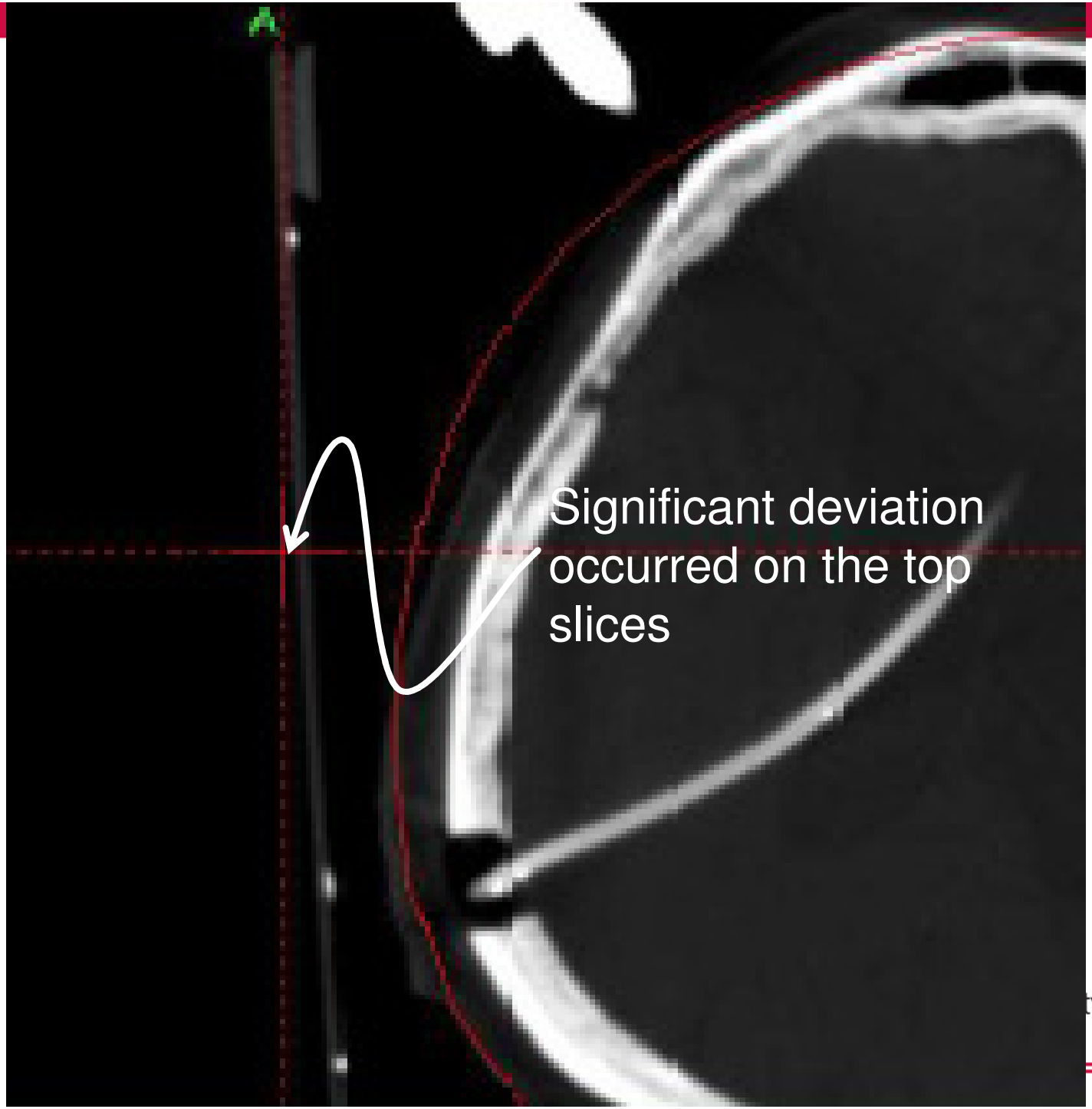
Contrast and partial volume effects are demonstrated on the 2D (left) and 3D (right) displays of auto-contours from MRI (green) & CT (red) both are registered in LCS



5. Avoid any image artifacts that affects registration - A case presents MRI artifacts






Significant deviation occurred on the top slices

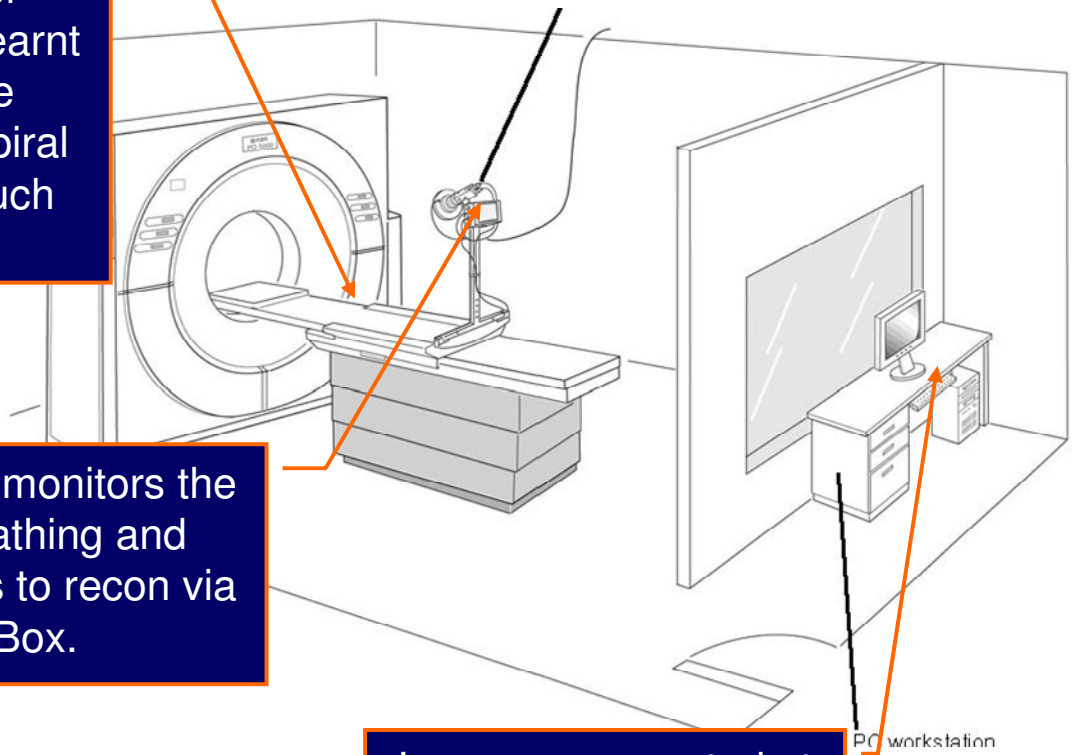
6. Combine images for better target definition.

A case with ITV (red) is best defined by union of glass opacity GTV and high SUV area in PET . PTV = ITV+3 mm (in green).

7. Detect organ motion using 4D or gated scans for gated Tx

Pulmonary Toolkit – Oncology Workflow Basics

The patient breathes normally and his/her respiration pattern is learnt by the system. The scanner performs a spiral scan at very slow couch speed (low pitch).



An apparatus monitors the patient breathing and sends triggers to recon via the I-Box.

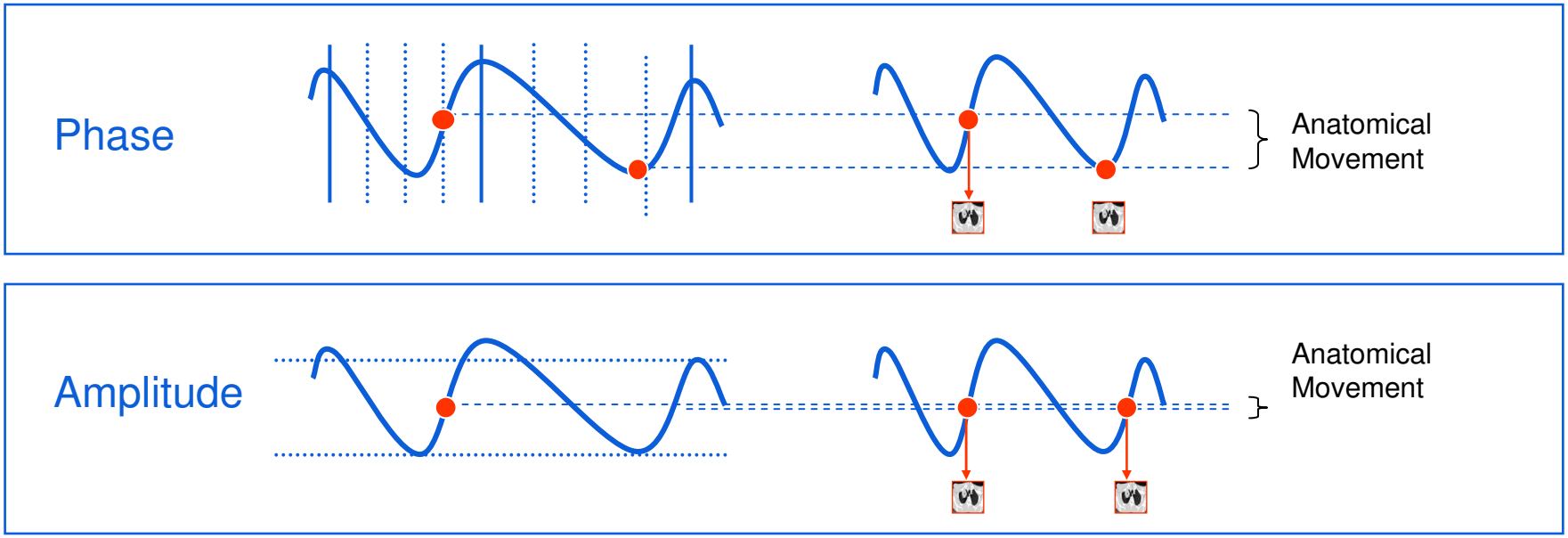
Images are created at the various phases of breathing.

courtesy of Philips

Amplitude Binning for 4D correlated imaging

...when Accuracy and Efficiency Matter

Amplitude Based Respiratory Correlated Binning



Reconstruction at 75% of the breathing cycle. Amplitude based binning produces greater spatial coherence than phased binning.

courtesy of Philips

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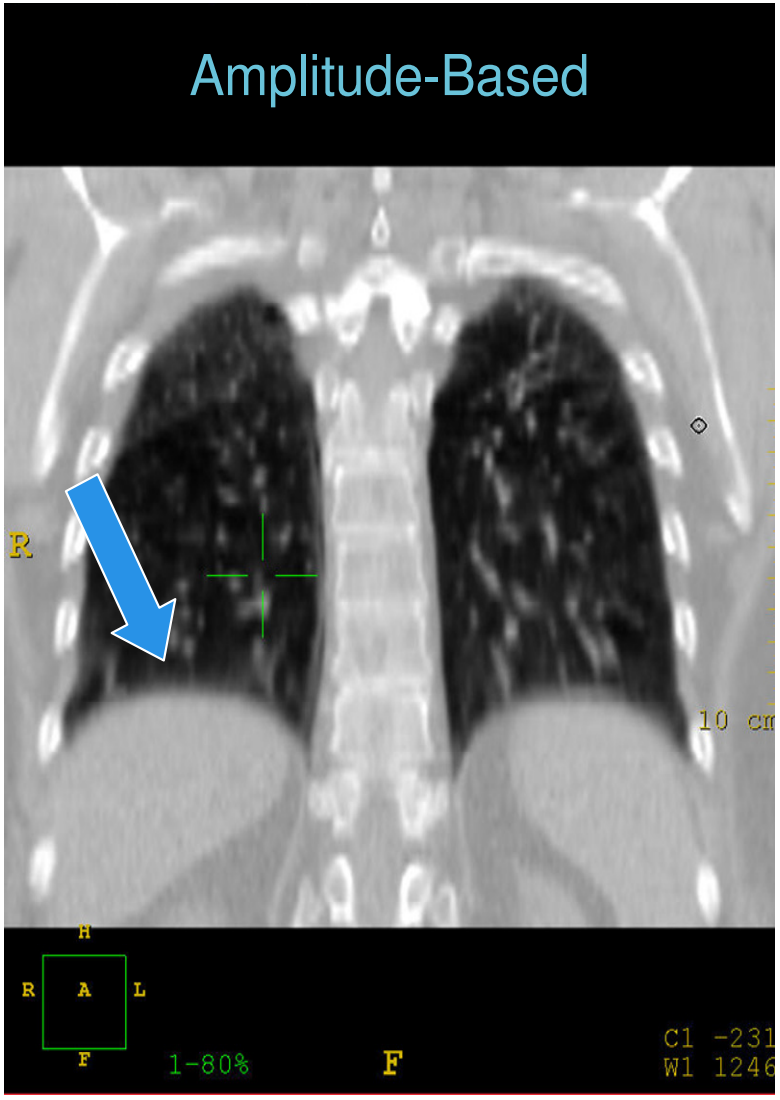
Amplitude Binning for 4D correlated imaging

...when Accuracy and Efficiency Matter

courtesy of Philips



8. Include slow scans for SBRT

Lagerwaard et al, IJROBP, 2001, 932-7

- Scan parameters (slice thickness of 3 mm)

	mAs	Pitch	Sec/rev.
Fast Scan	~175	~2	≤1
Slow Scan	~50	~1	≥4

- Fast CT scans are used as plan images and slow CT and PET scans are precisely fused with the fast CT scans
- GTV are contoured in all image sets, their union is ITV
- Daily setup errors is added to ITV for constructing PTV.
- Koste et al (IJROBP, 2003,1394-9) concluded that "Incorporation of a slow CT scan into a rapid planning CT scan improves the target definition for peripheral lung tumor."

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9. Choose optimal treatment plans

Some Tools for SRS/SBRT :

- ✓ Target Volume (TV) Coverage: >95%
- ✓ Conformity Index, CI
  - Shaw, et al, IJROBP, 1993 1231-9, define

$$CI_{old} = PDV/TV \text{ should have } 1<CI<2$$

  - Paddick, J Neurosurg, 2000,219-22, defines

$$CI = TV_{PDV}^{\ 2} / (TV \times PDV)_{0.6<CI<1}$$

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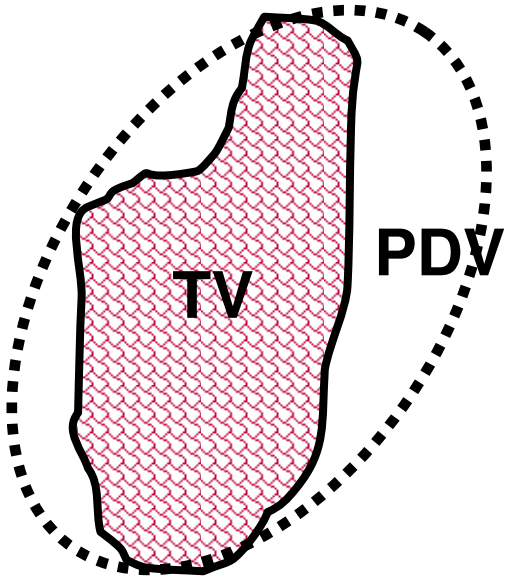
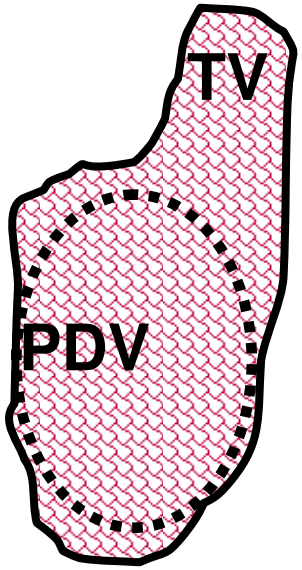
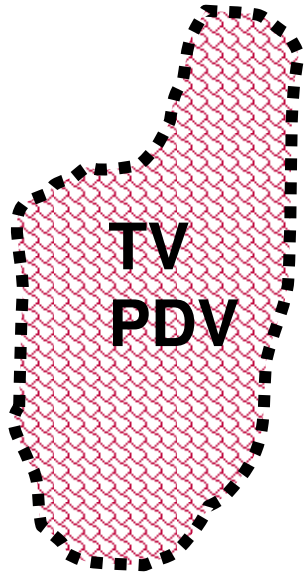






A non-conformal dose plan has

$CI_1 = TV_{PDV}/TV$

$= 1.0$

A non-conformal dose plan has

$CI_2 = TV_{PDV}/PDV$

$= 1.0$

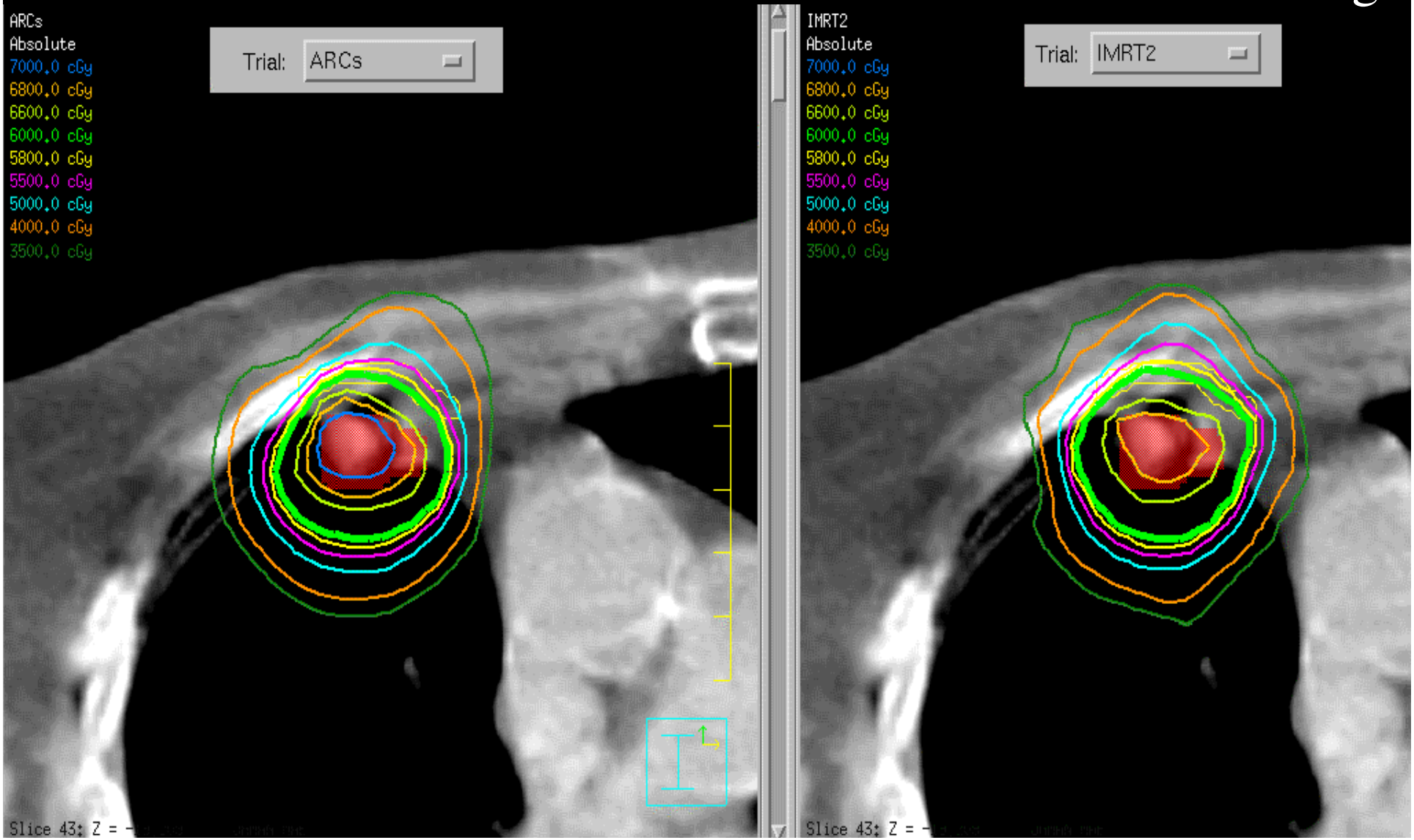
A conformal dose plan has

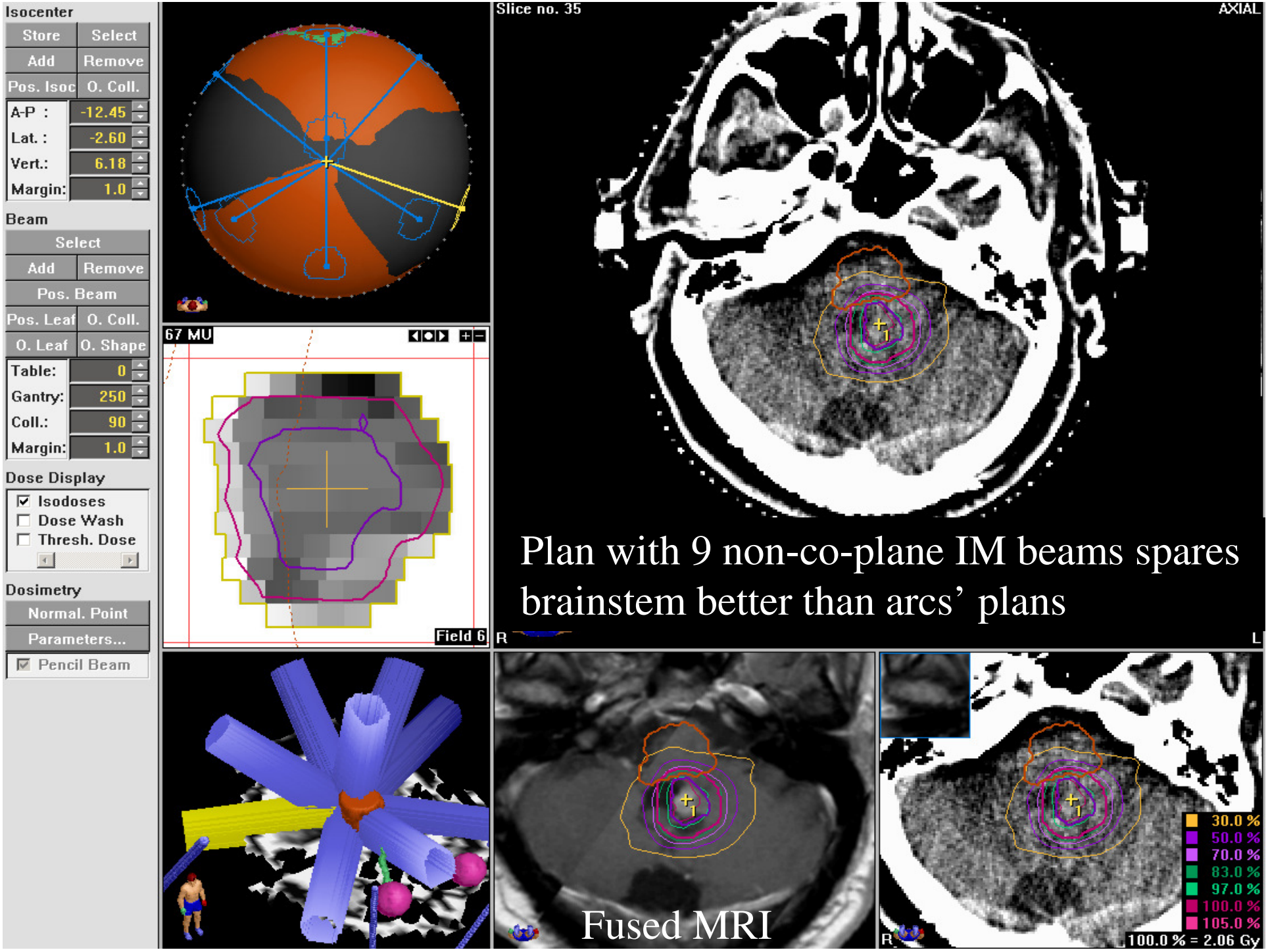
$CI_3 = CI_1 CI_2$

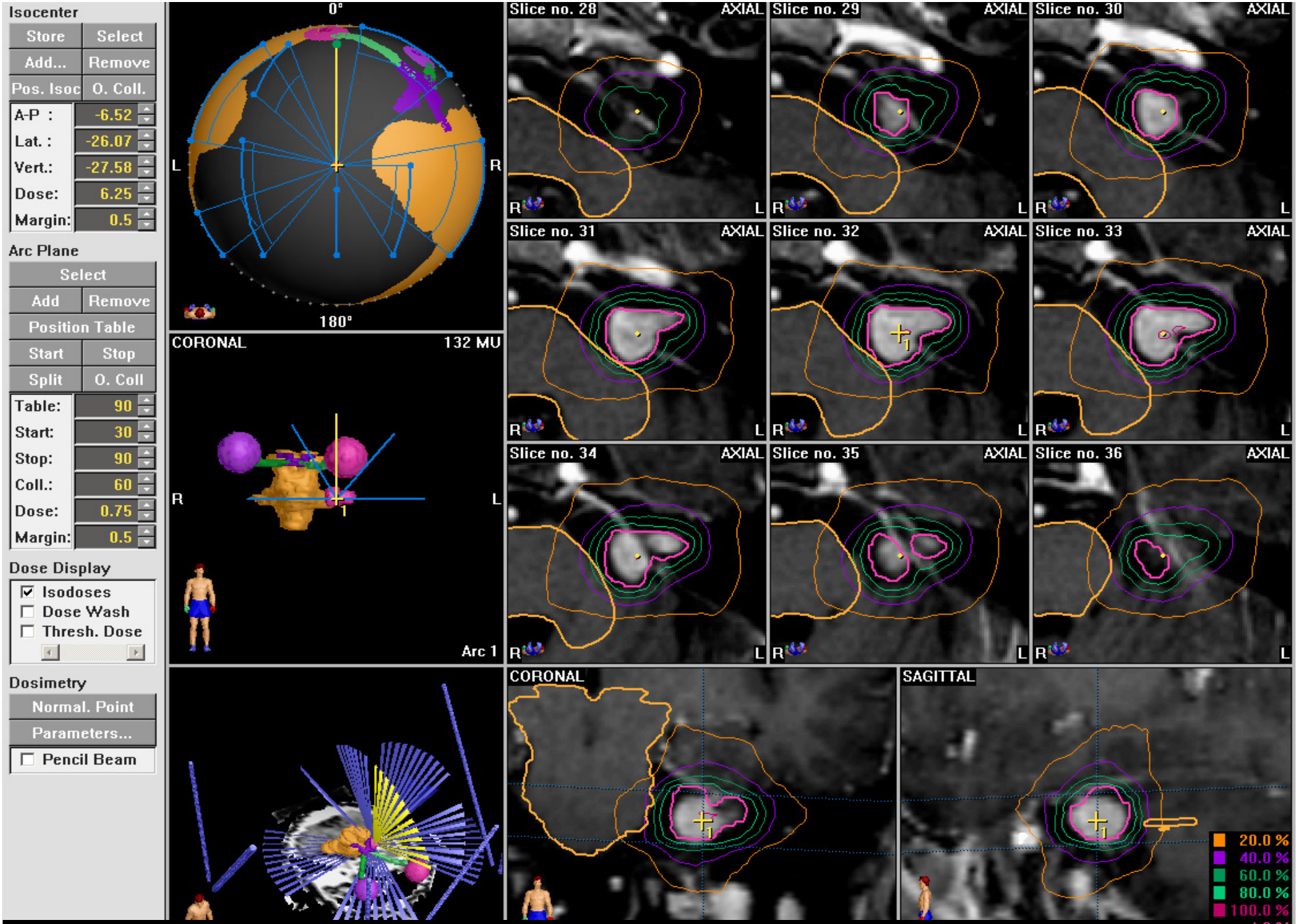
$= 1.0$

Pay attention to the detail. DVHs and dose profile across the ROI should also be checked.

Optimal plan was selected based on the dose distributions:
In this case, plan using 6 co-planner arcs (left) provide higher dose to the GTV while less dose to the chest wall and the lung




Isocenter
Store
Select
Add
Remove
Pos. Isoc
O. Coll.
A-P :
-12.45
Lat. :
-2.60
Vert.:
6.18
Margin:
1.0
Beam
Select
Add
Remove
Pos. Beam
Pos. Leaf
O. Coll.
O. Leaf
O. Shape
Table:
0
Gantry:
250
Coll.:
90
Margin:
1.0
Dose Display
Isodoses
Dose Wash
Thresh. Dose
Dosimetry
Normal. Point
Parameters...
Pencil Beam
67 MU
Field 6
Slice no. 35
AXIAL
Plan with 9 non-co-plane IM beams spares brainstem better than arcs' plans
R
L
Fused MRI
30.0 %
50.0 %
70.0 %
83.0 %
97.0 %
100.0 %
105.0 %
100.0 % = 2.06 Gy



Plan using multiple small-angle arcs provides excellent conformal isodose distribution

10. Perform image-guided patient setup and dose delivery

- List of frame-less image-guided techniques
  - Biplane radiograph-guided SRS/SBRT (Murphy and Cox, Med. Phy. 1996, 2043-9). Example: Cyber-Knife, Brainlab ExacTrack
  - Optic mark-guided SRS/SBRT (Bova et al, Med Dosim, 1998, 221-9). Example: Elekta Iguide, BrainnLAB, Cyber-Knife
  - Real-time optic-surface-guided SRS/SBRT (Li et al, Med Phys. 2006, 492-503). Example: VisionRT
  - Ultrasound-guided SBRT (Meeks et al, IJROBP 2003 1092-101)
  - CT-guided SRS/SBRT, (Mohan et al, IJROBP, 2005, 1258-66). Example: Varian, Elekta, and Siemens machines

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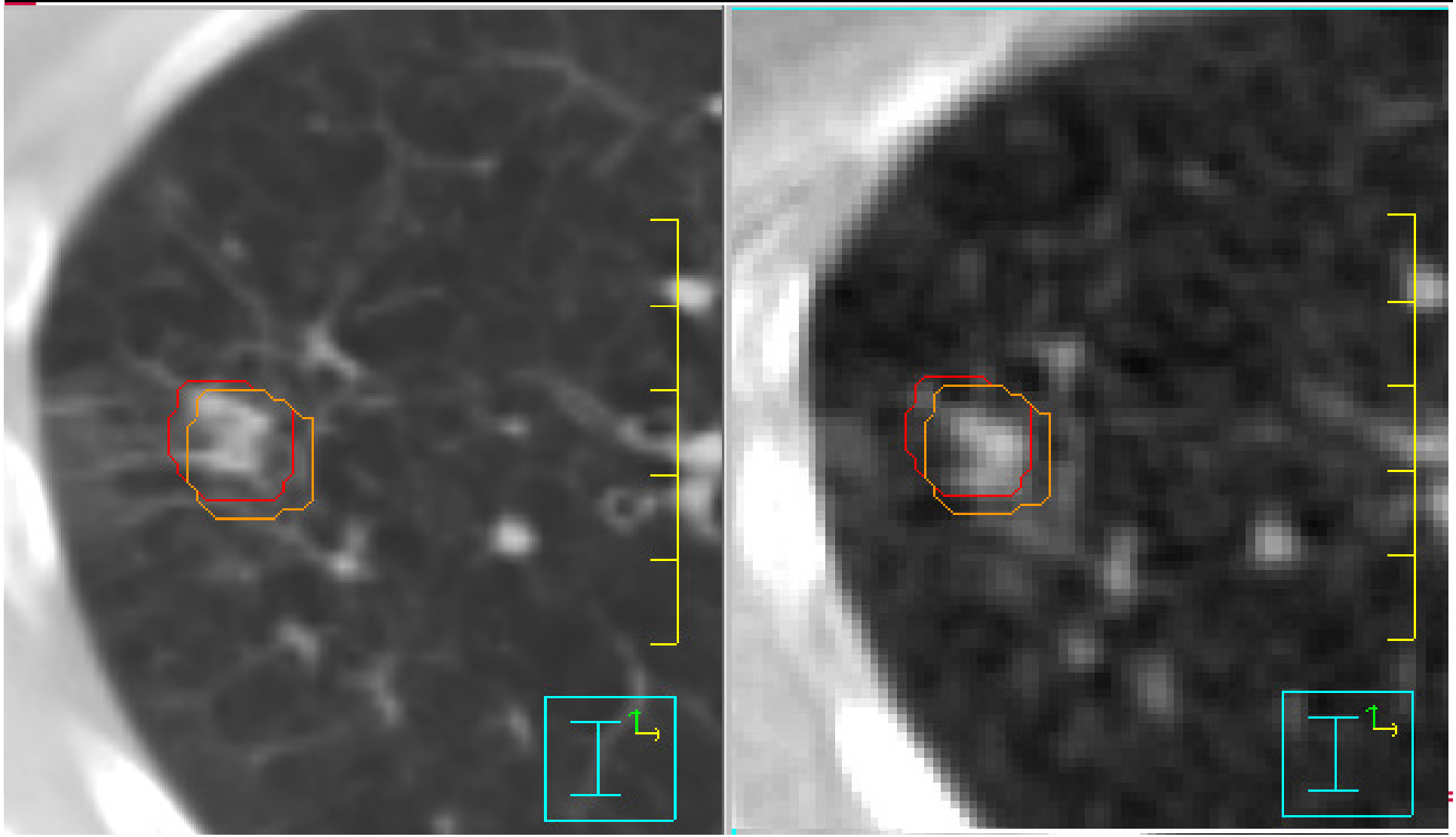
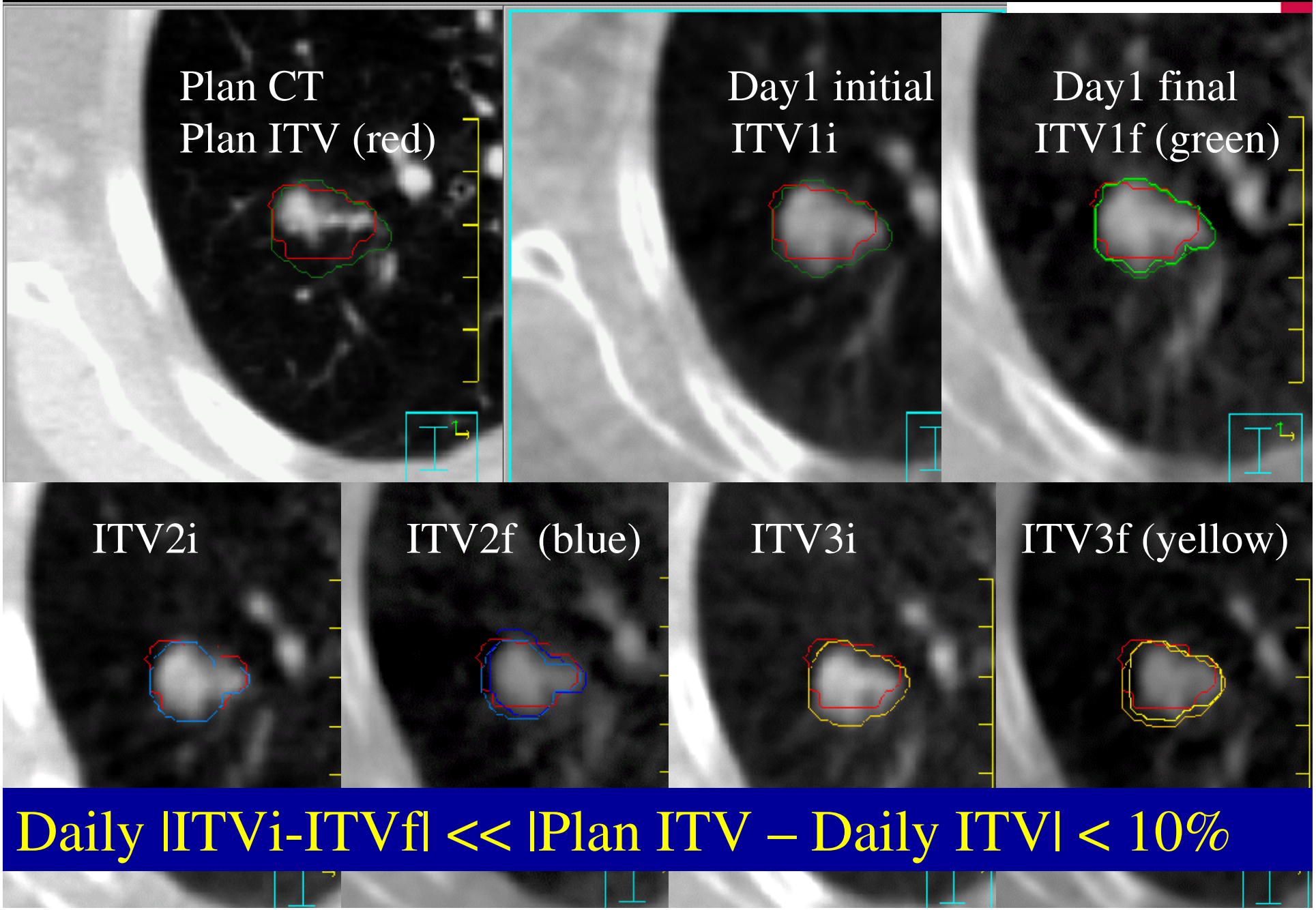
Use of daily CBCT (right) co-registered to plan CT (left) at the treated position with the ITV (brown) in daily CBCT that differs from the plan ITV (red).

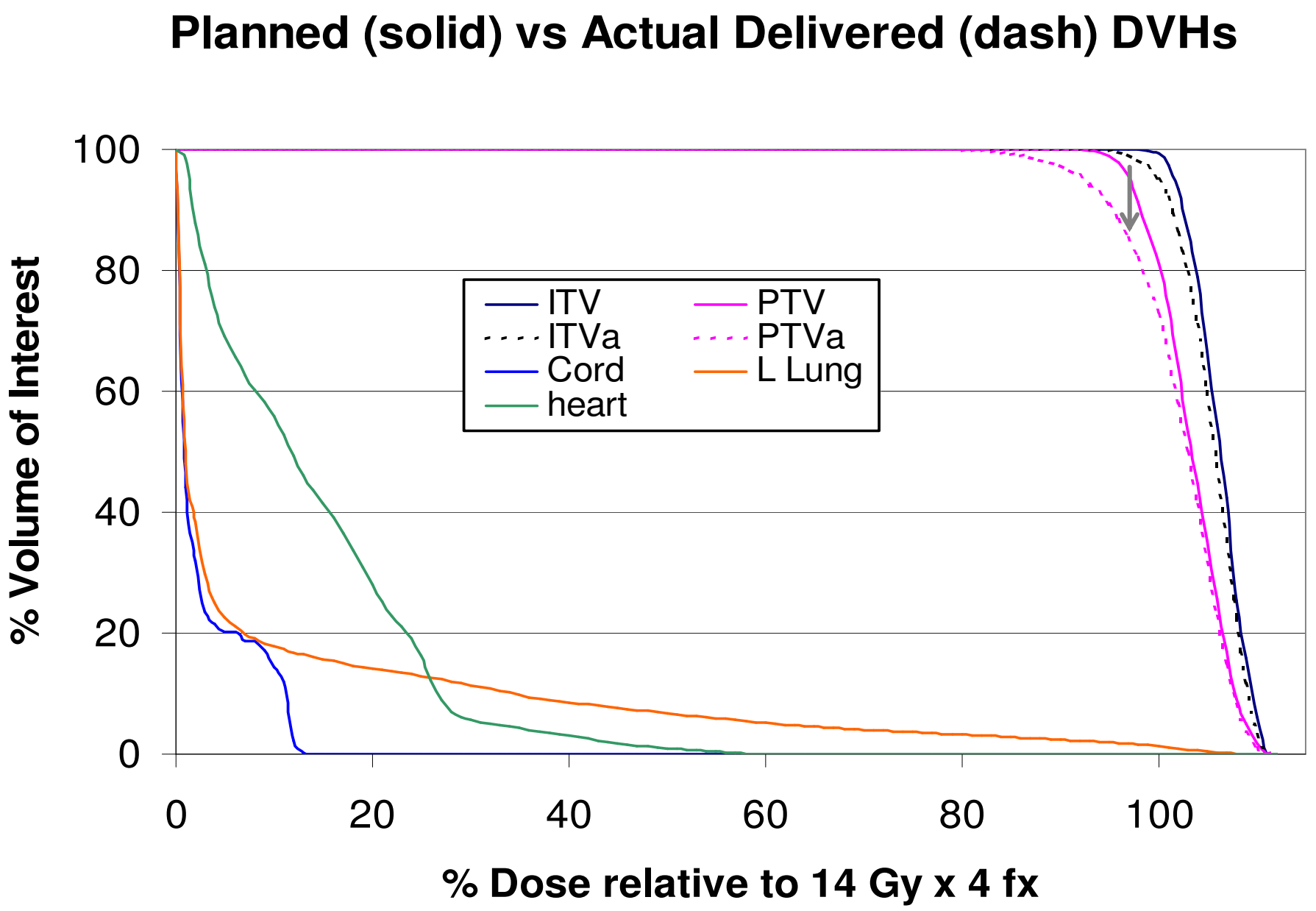


Two CBCT scans per Tx show reliable reposition



Daily |ITVi-ITVf| << |Plan ITV – Daily ITV| < 10%

A case with >10% PTV drops @100% but not ITV



Summary for SRS/SBRT

1. Simulation scans as actual treatment
2. Use stereotactic immobilization devices
3. Register images with a stereotactic localizer
4. Scan with fine section (slice thickness ≤ 2 mm for brain and ≤ 3 mm for body)
5. Avoid any image artifacts
6. Unfold organ motion with 4D or gated scans
7. Combine anatomic and function image sets
8. Include slow scans for SBRT of NSCLC
9. Choose plans with conformal dose distribution
10. Perform image-guided refixation and dose delivery

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