Image Guided Radiotherapy at UCLA

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January 23, 2013

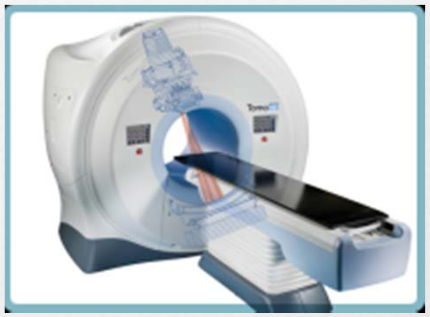
Overview

- What do we have?
- What do we do?
  - What IGRT method do we use for each anatomic site and why?
  - What do we align to?
  - How do we evaluate fusion?
  - What setup tolerance do we accept?
- What is typical workflow?
- How accurate are we?

What IGRT solutions do we have at UCLA?

- Tomotherapy – MV CT
- Novalis Tx – Exactrac, kV OBI, kV CBCT, MV Portal imaging
- Truebeam – kV OBI, kV CBCT, MV Portal imaging
- ViewRay – MRI (not yet installed)

Tomotherapy MV CT



- Advantages
  - 3D image
  - 3D/3D registration
  - Can correct for patient roll
  - Soft tissue visualization
  - Less artifacts than kV CBCT
- Disadvantages
  - Longer scan acquisition time (2.5 min or more) during which patient can move
  - Dose (1 – 3 cGy) with MV energy photons
  - Lower contrast than kV CT

ExacTrac Stereoscopic kV imaging

- Advantages
  - Stereoscopic kV image (2 tubes and flat panels)
  - 2D/3D registration for 6D target correction
  - Fast acquisition and analysis (Easily used intra-fraction)
  - Low dose (0.25 – 2 mGy per image)
  - Fixed geometry imager for stability
- Disadvantages
  - Planar kV images can't resolve soft tissue well
  - Can be blocked by gantry
  - Limited field of view (~13cm x 13cm)

kV OBI (Varian)

- Advantages
  - Orthogonal kV imaging
  - Larger field of view (imager active area ~30cm x 40cm)
- Disadvantages
  - Planar kV can't resolve soft tissue well
  - Slower than ExacTrac
  - 2D/2D image registration slightly less accurate than 2D/3D

CBCT (Varian)

- Advantages
  - 3D images
  - 3D/3D registration
  - Faster acquisition than Tomo MV CT but slower than kV OBI or ExacTrac
  - Soft tissue visualization
- Disadvantages
  - Subject to image artifacts
  - More dose than kV OBI and ExacTrac, but less than MV CT

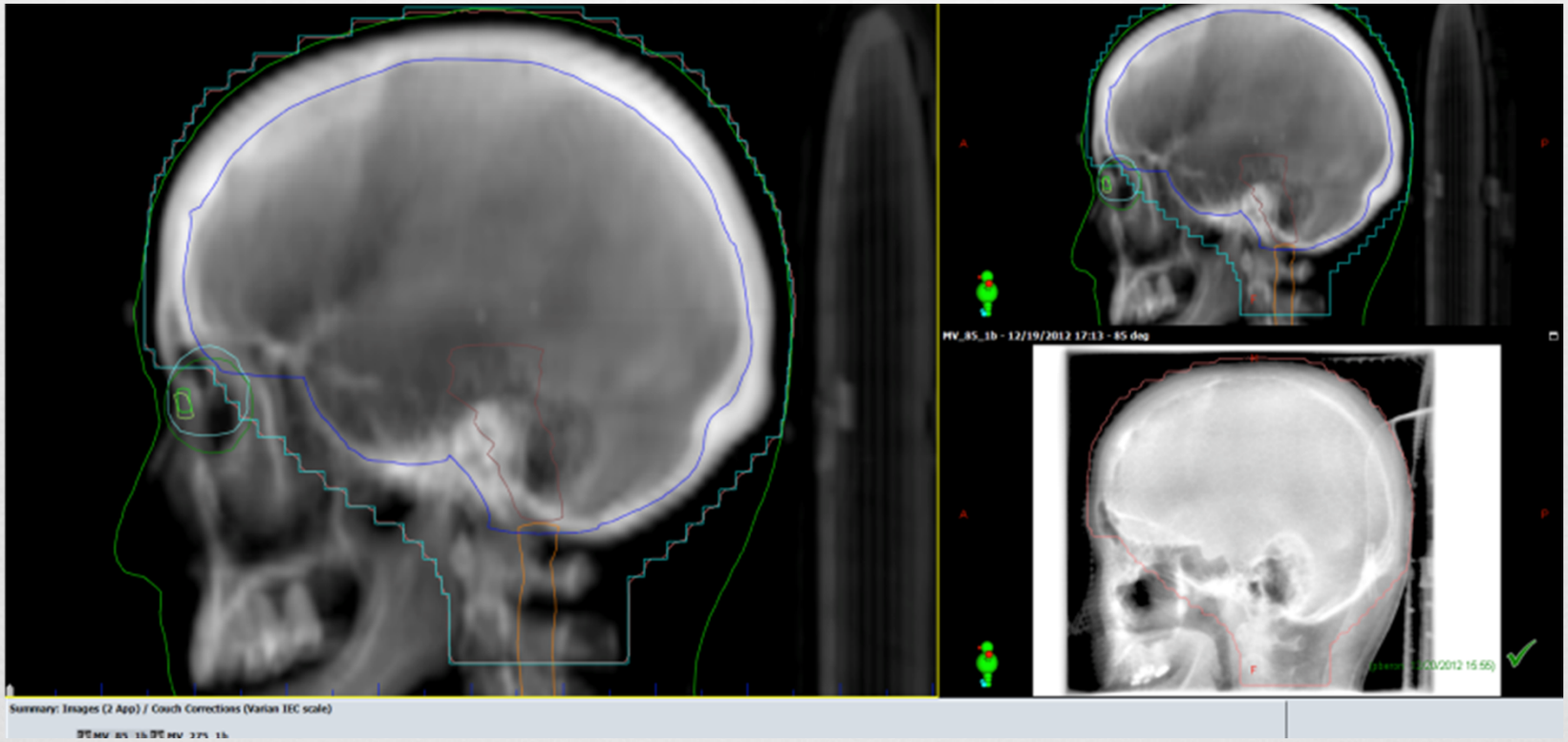
Portal Imaging (Varian)

- Advantages
  - Can directly image anatomy through the field portal and evaluate relationship of field to anatomy
  - Can be combined with a kV image to get orthogonal data for 3D setup (MV-kV imaging)
- Disadvantages
  - Low soft tissue contrast
  - Higher dose than kV imaging

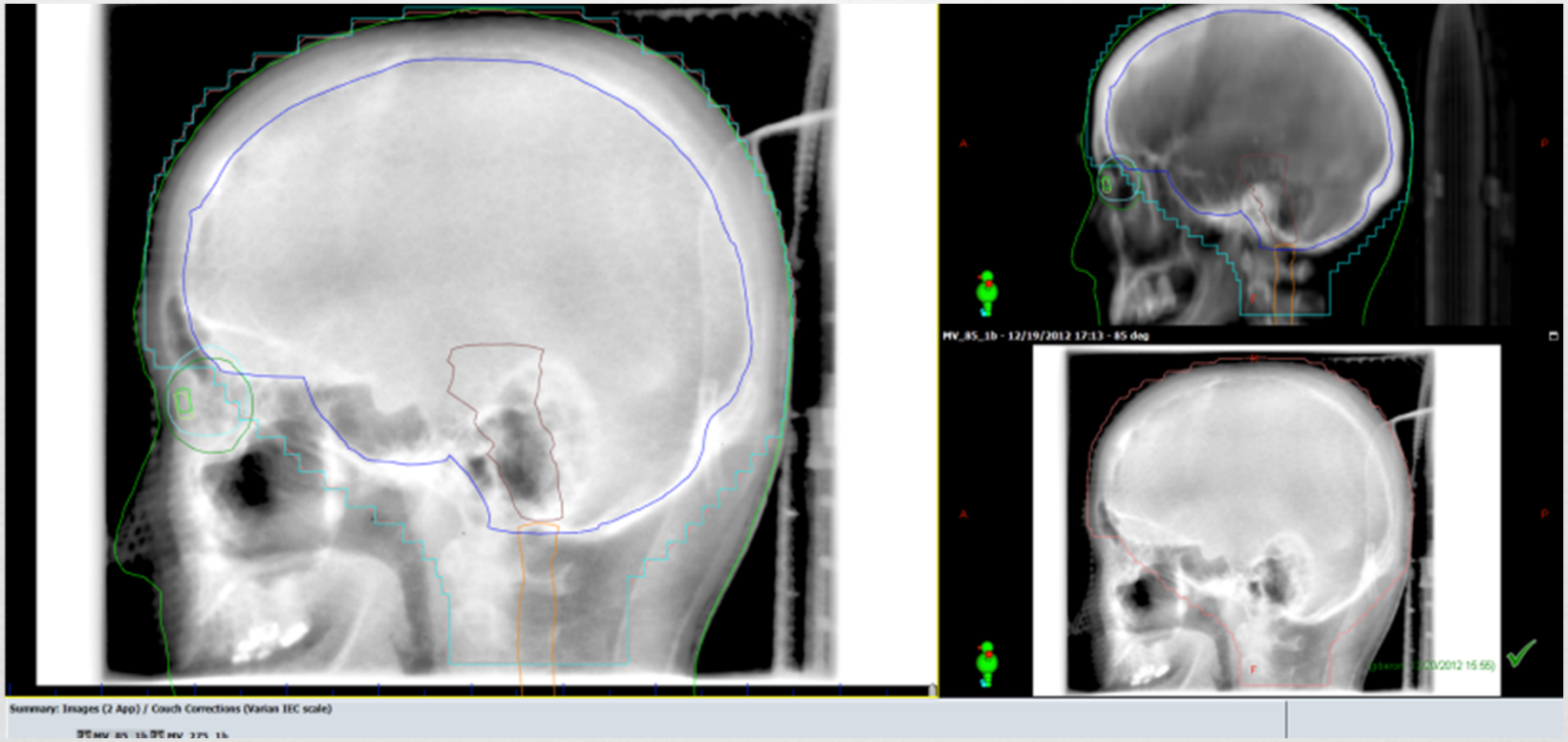
Clinical Examples

- Cranial
- H&N
- Thorax
- Abdomen
- Spine
- Pelvis

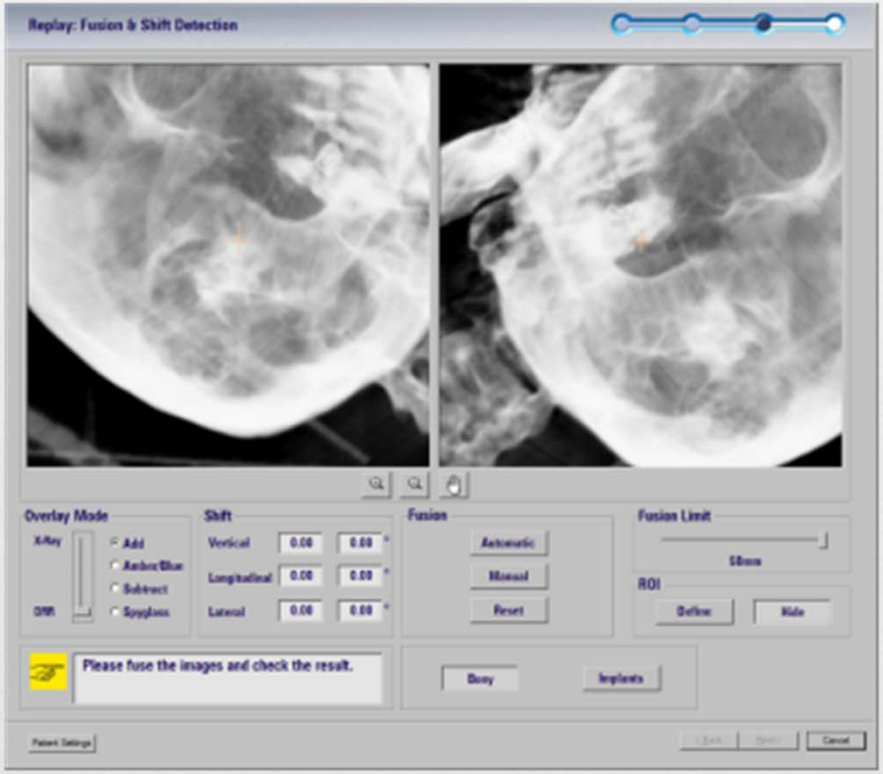
Cranial (Whole Brain)



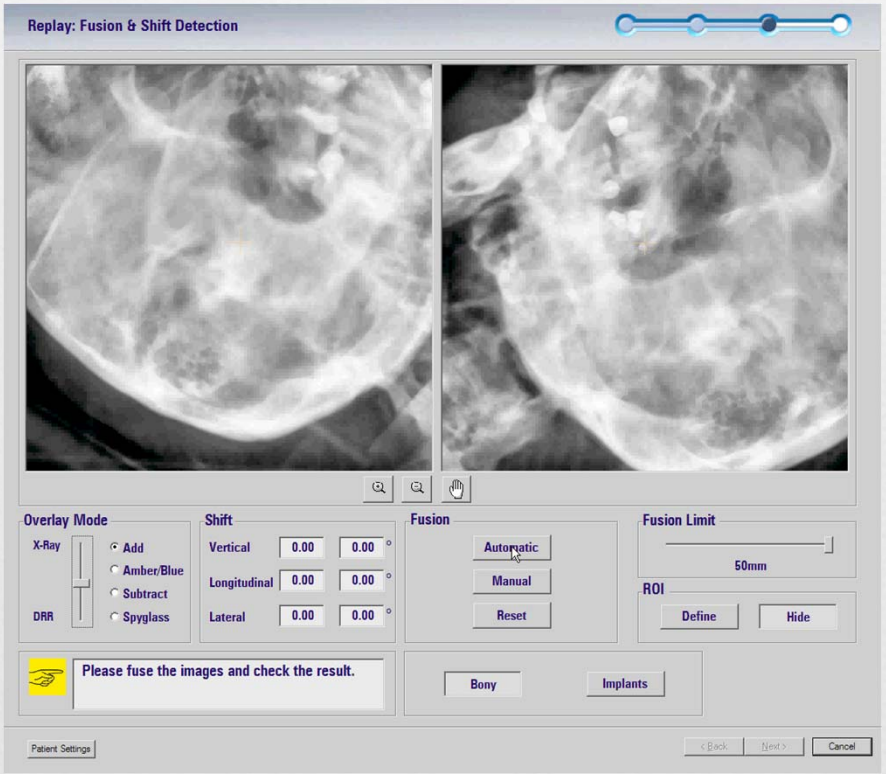
Cranial (Whole Brain)



Cranial SRS (Trigem)

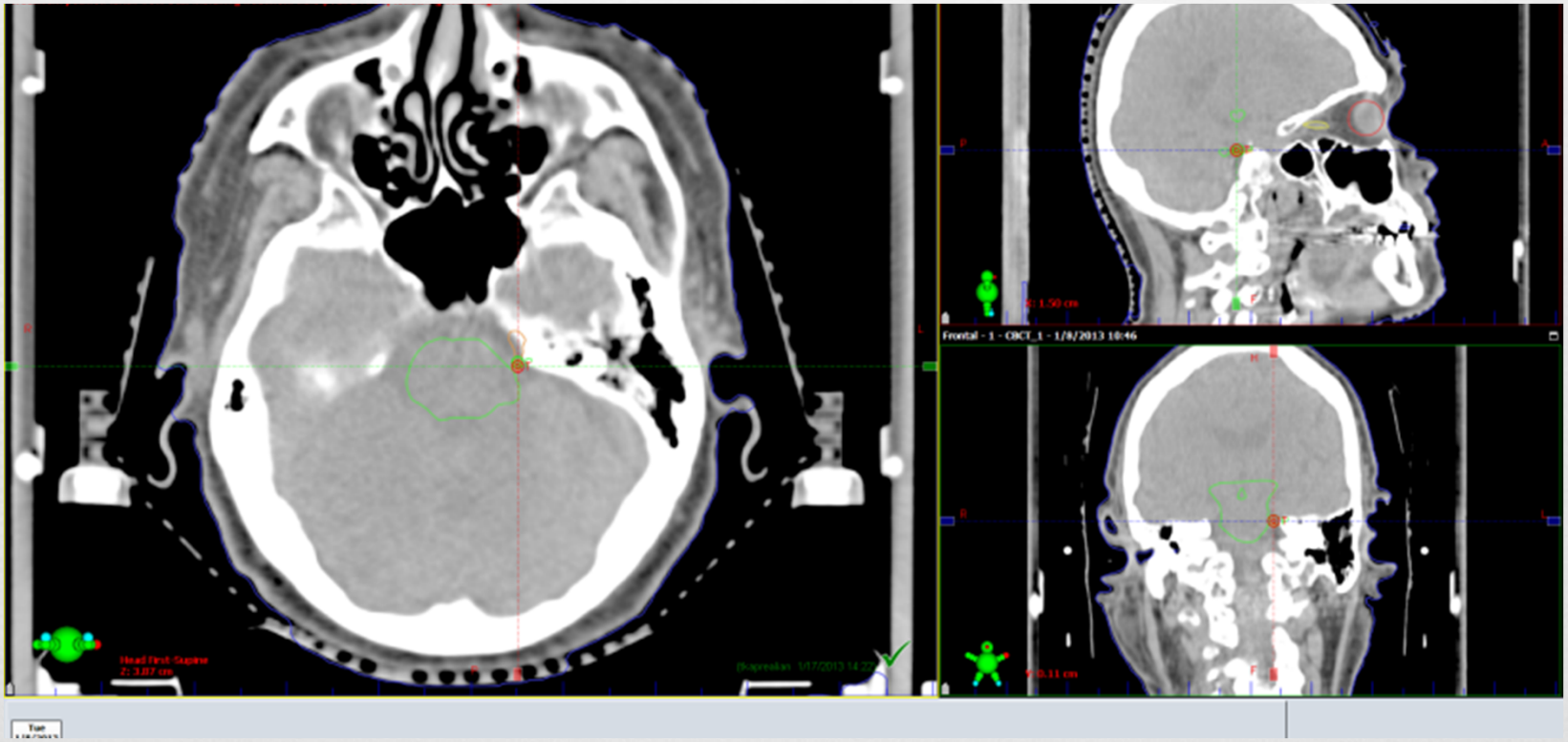


Cranial SRS (Trigem)

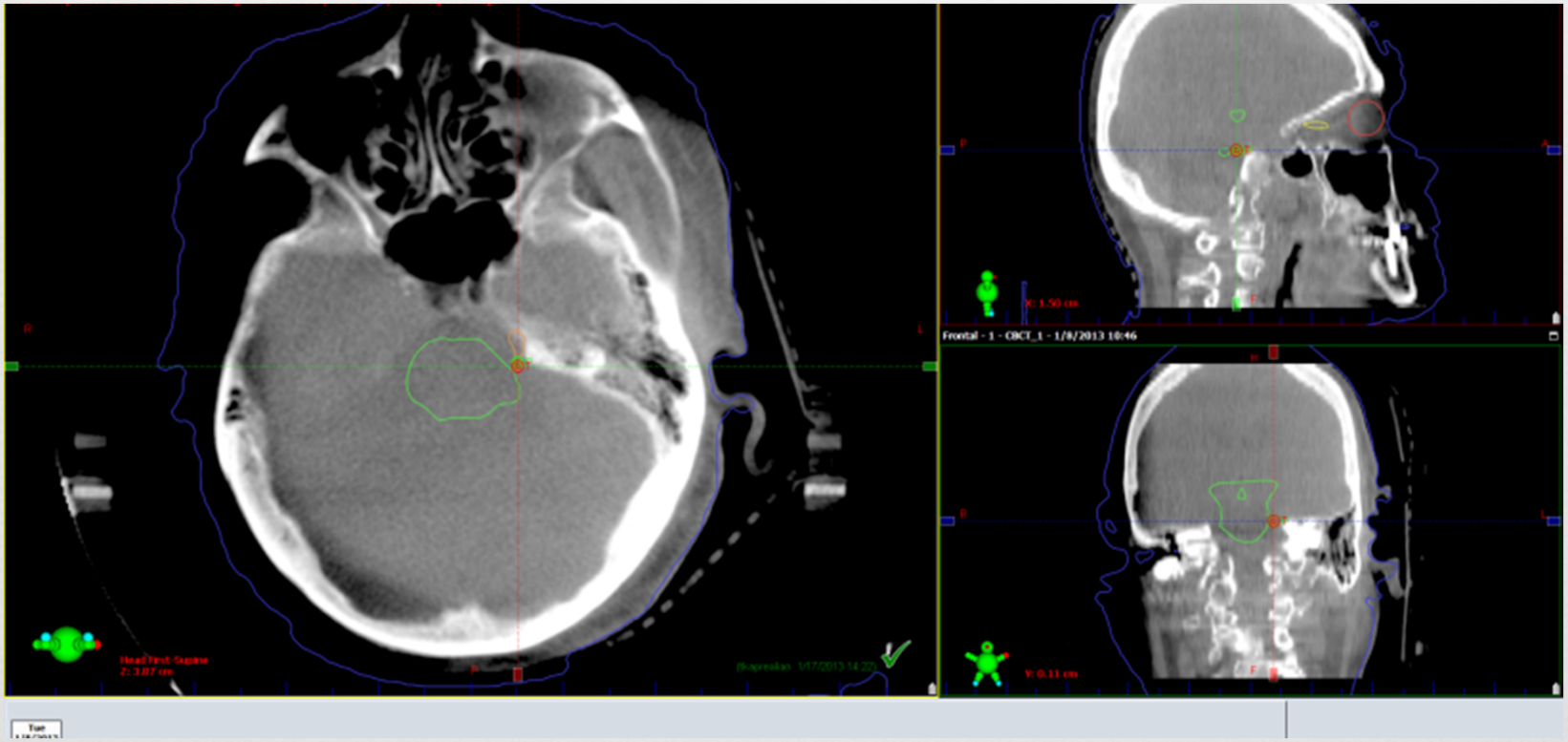


Check orbits and Mastoid. Ignore mandible.

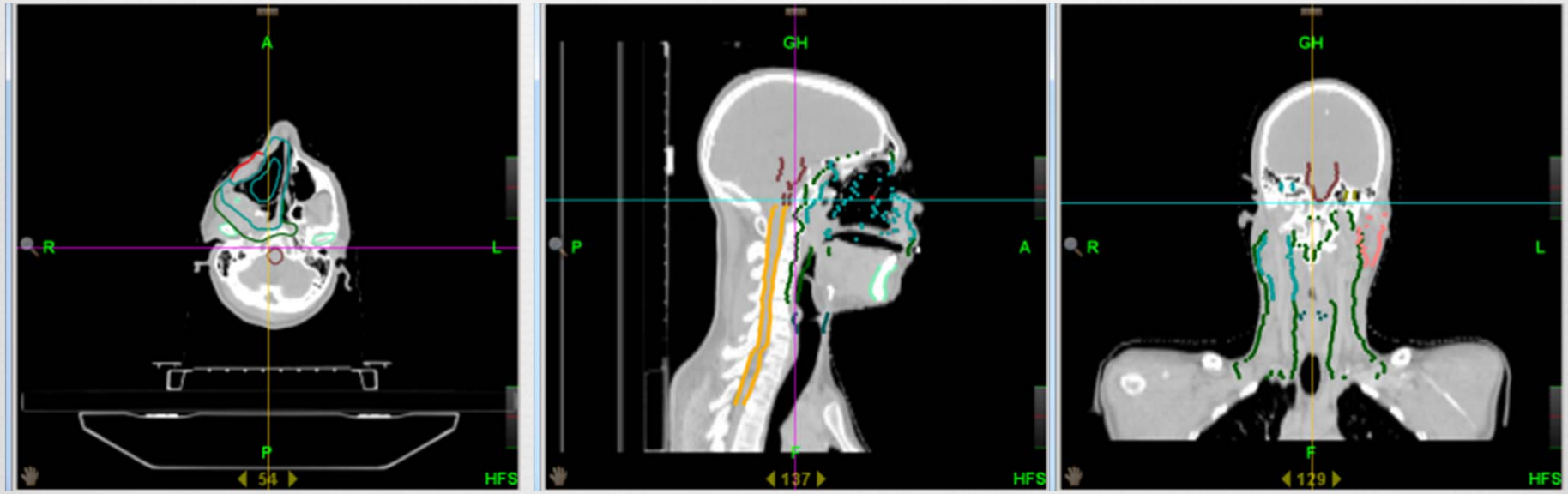
Cranial SRS (Trigem)



Cranial SRS (Trigem)

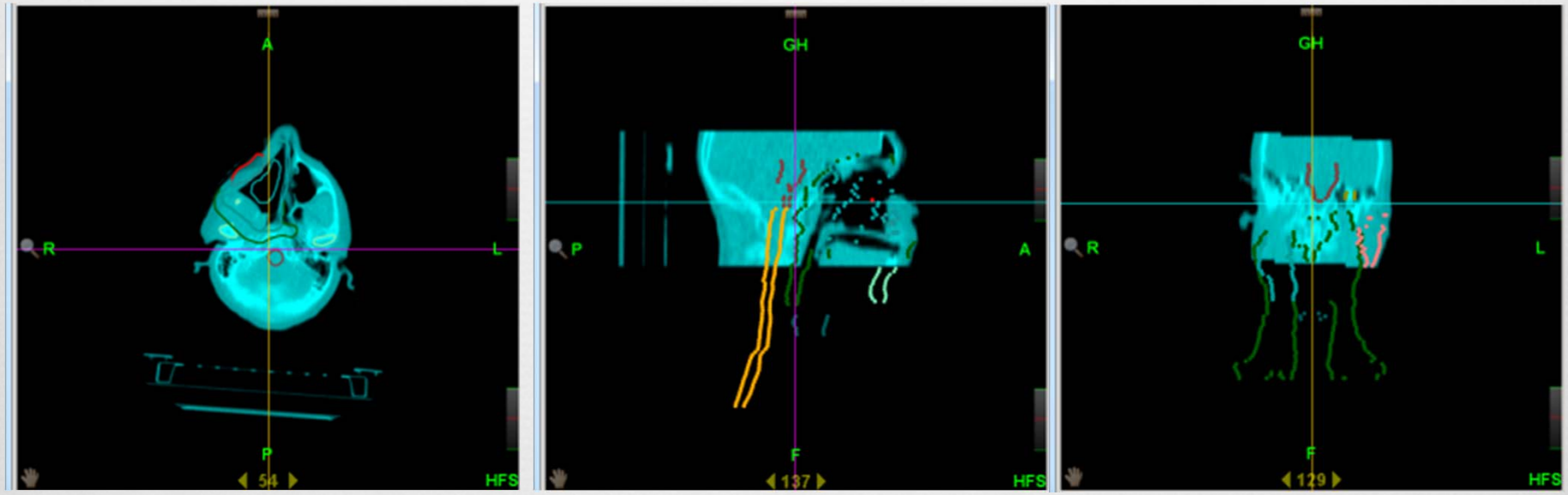


H&N Tomotherapy



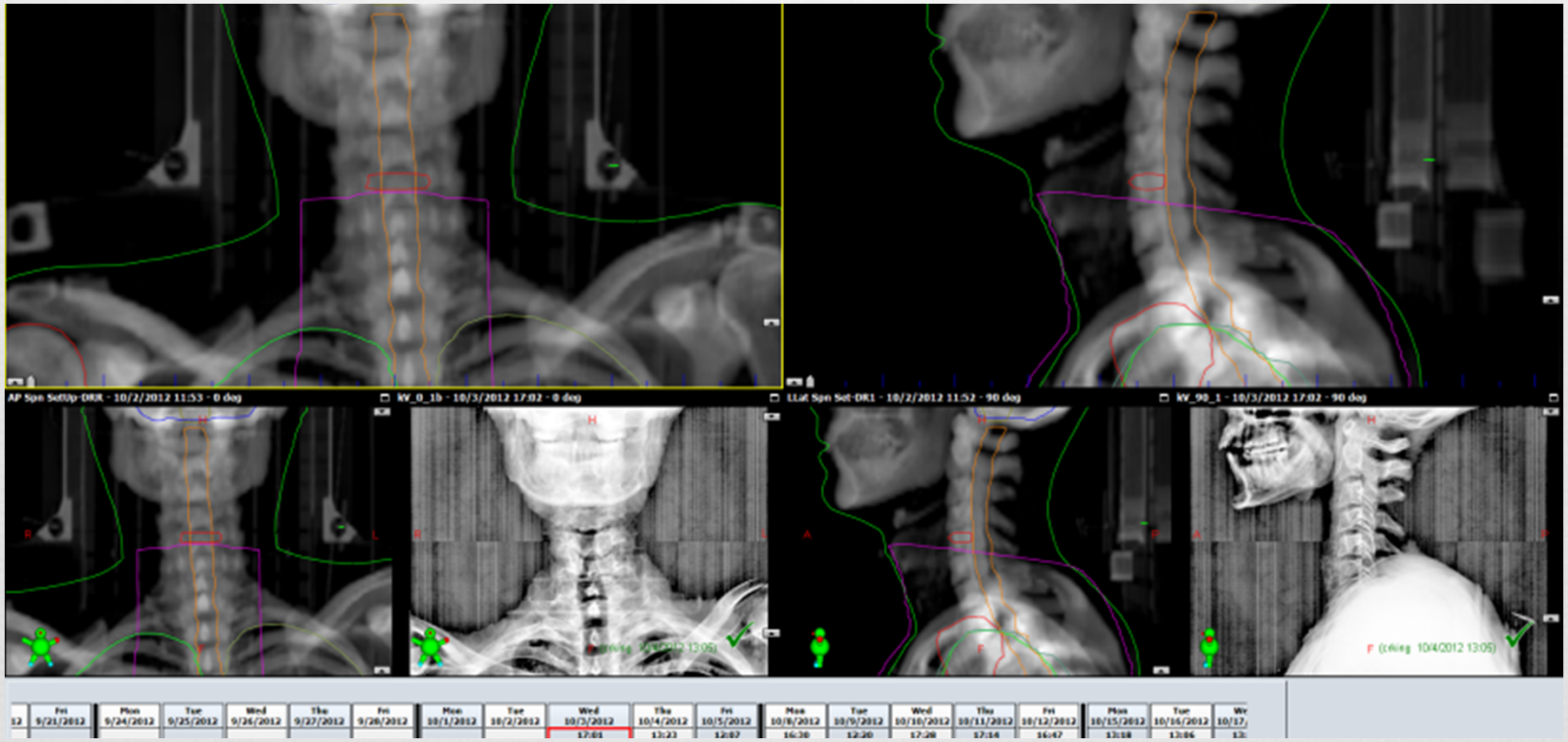
Sim CT

H&N Tomotherapy



MV CT

H&N kVkV Match



DRR

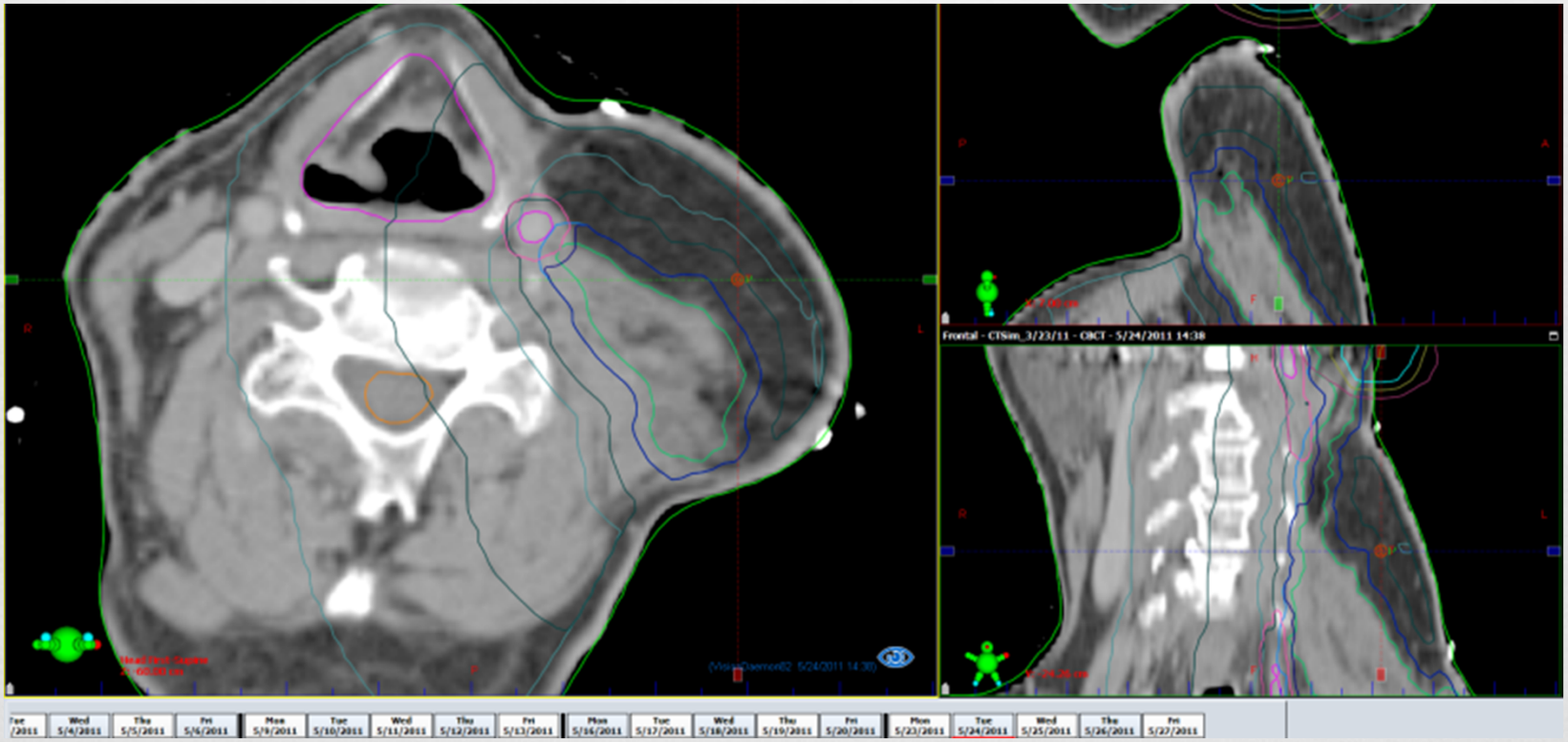
H&N kVkV Match

Check spinous process alignment

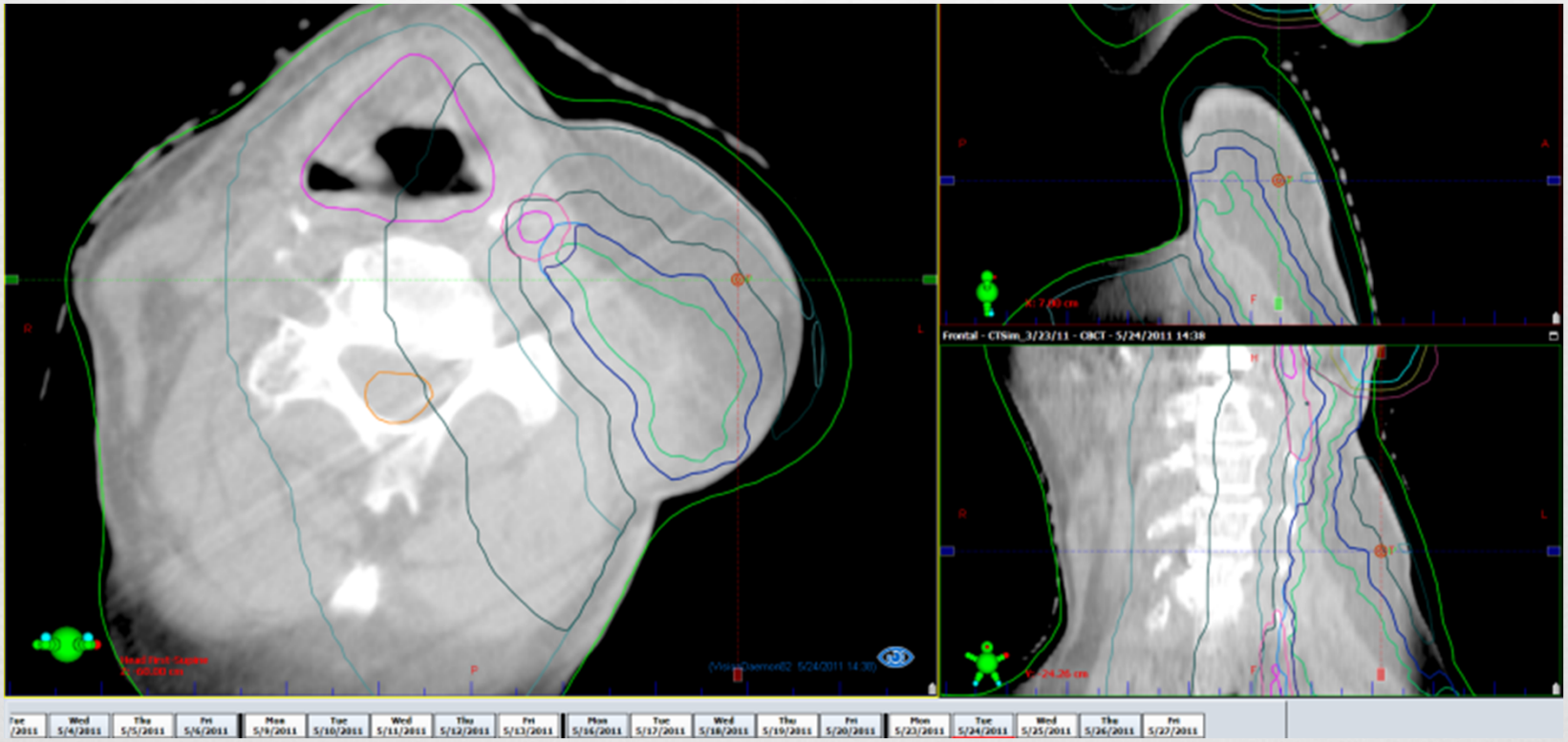
Check C2 alignment

X-Ray

H&N CBCT



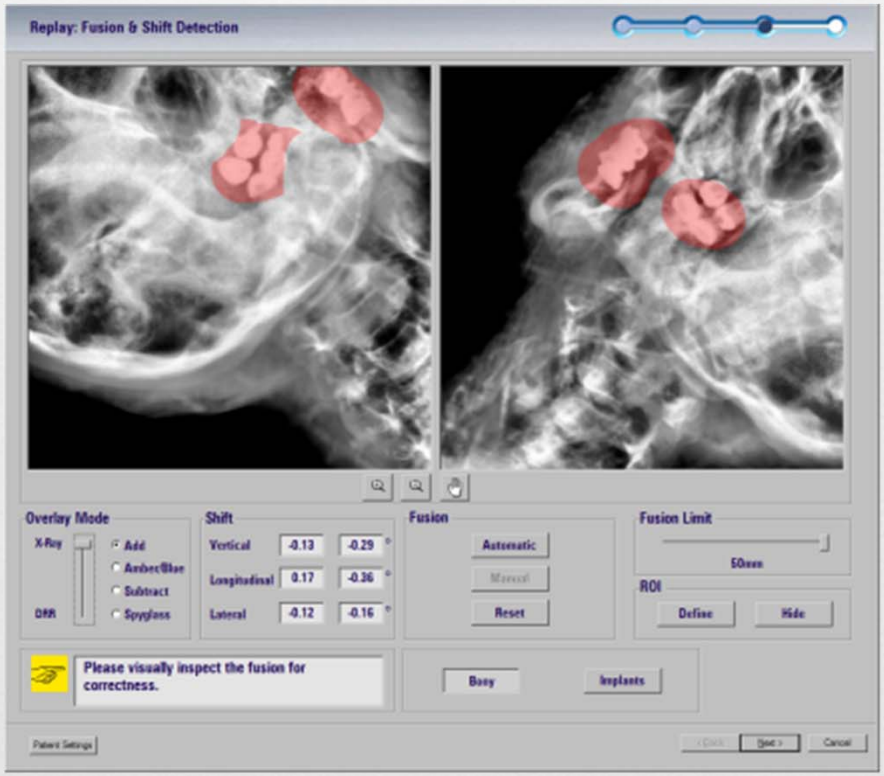
H&N CBCT



H&N ExacTrac

DRR

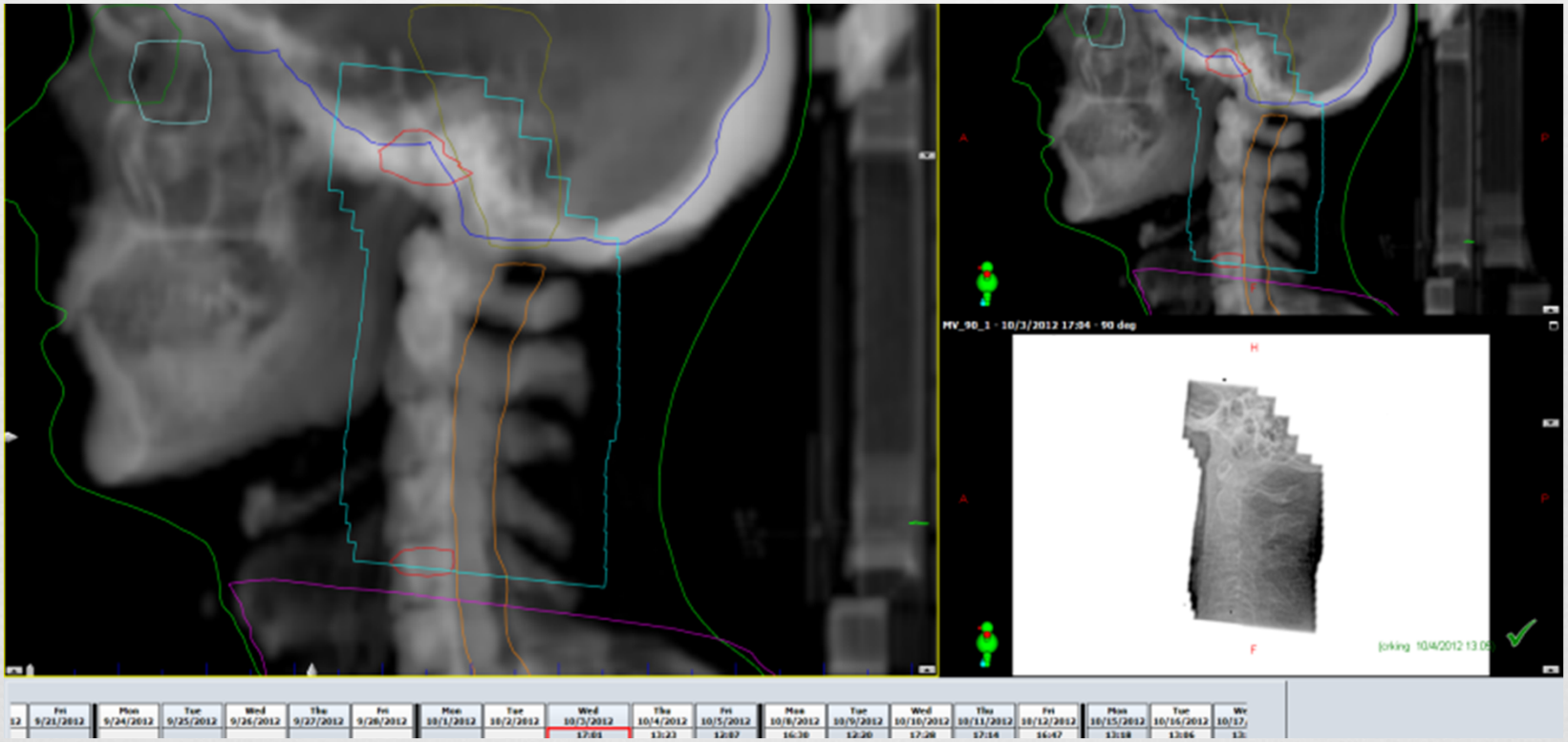
H&N ExacTrac



Check maxillary sinus and c-spine. C2 is obscured on ExacTrac due to camera configuration.

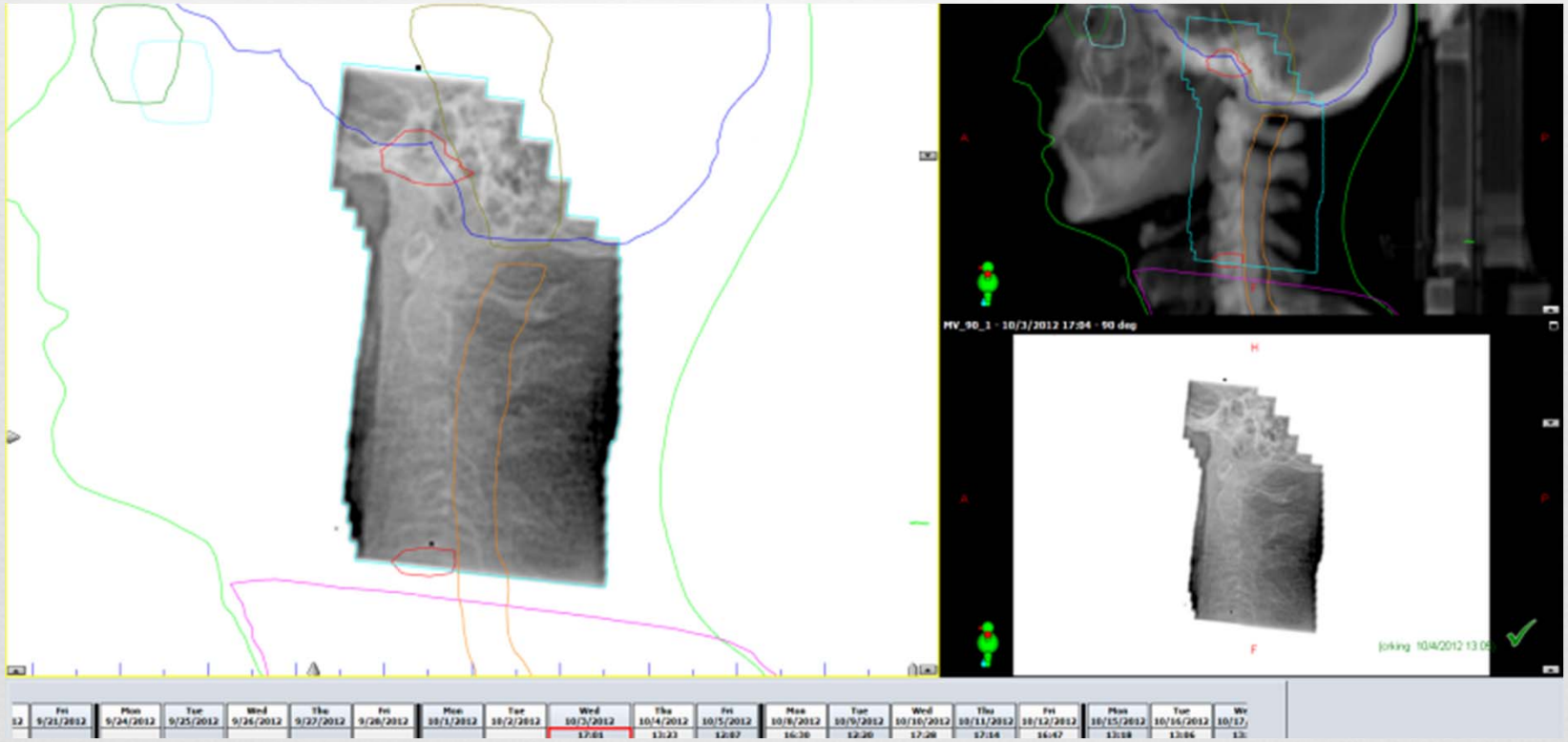
X-Ray

H&N Portal Image



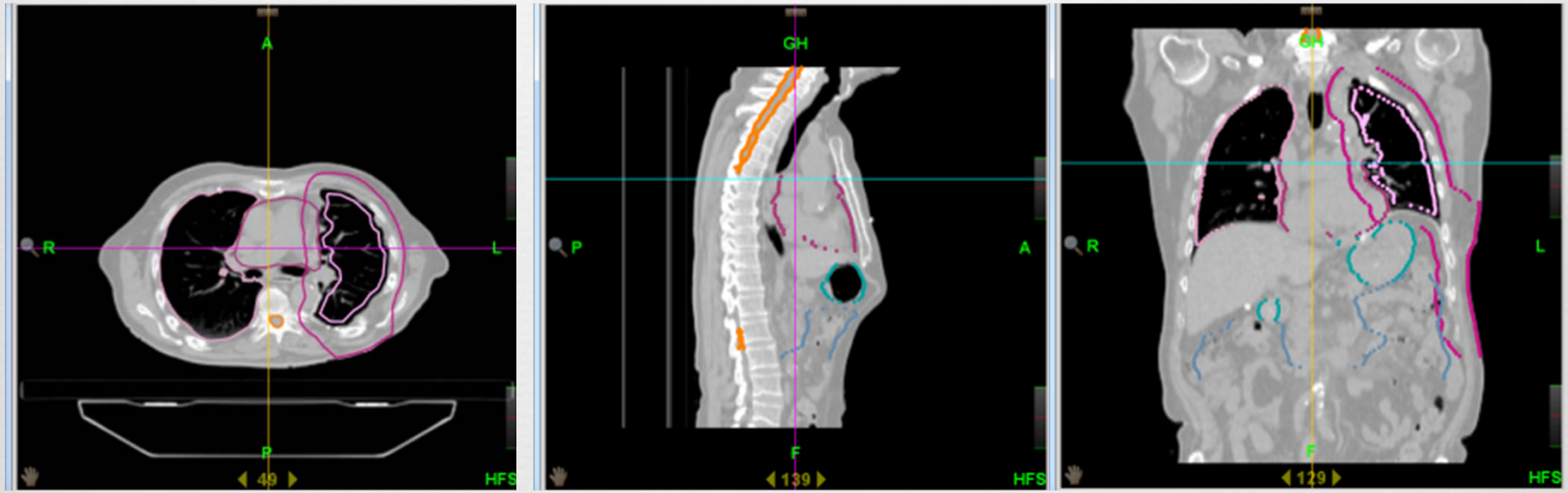
DRR

H&N Portal Image



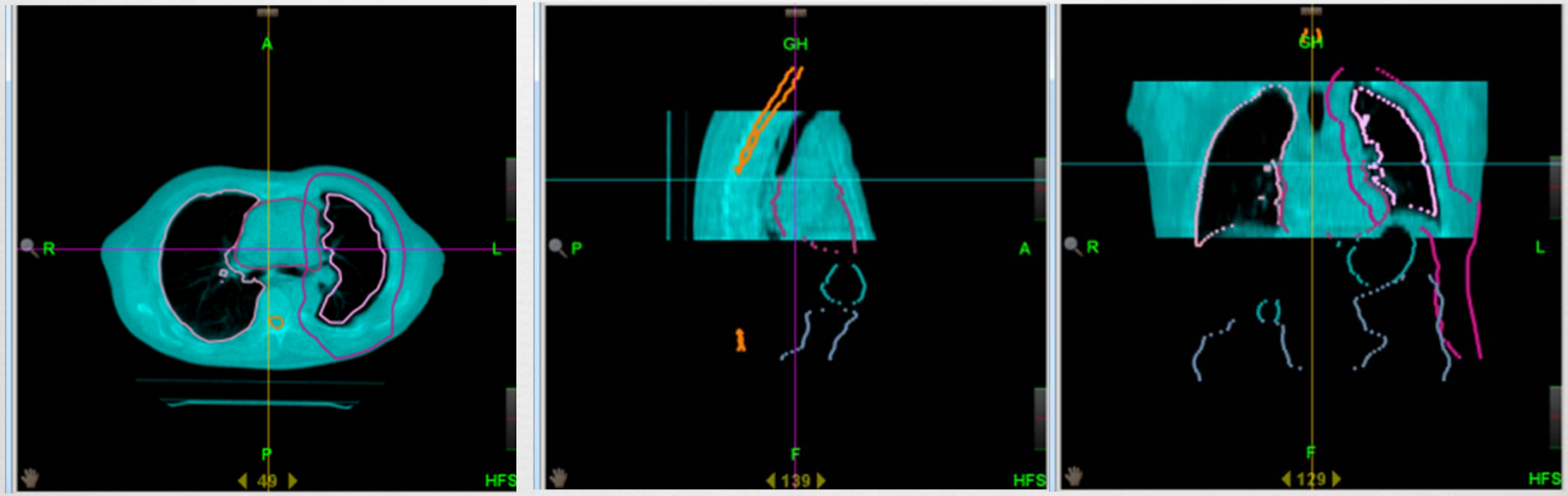
X-Ray

Thorax Tomotherapy



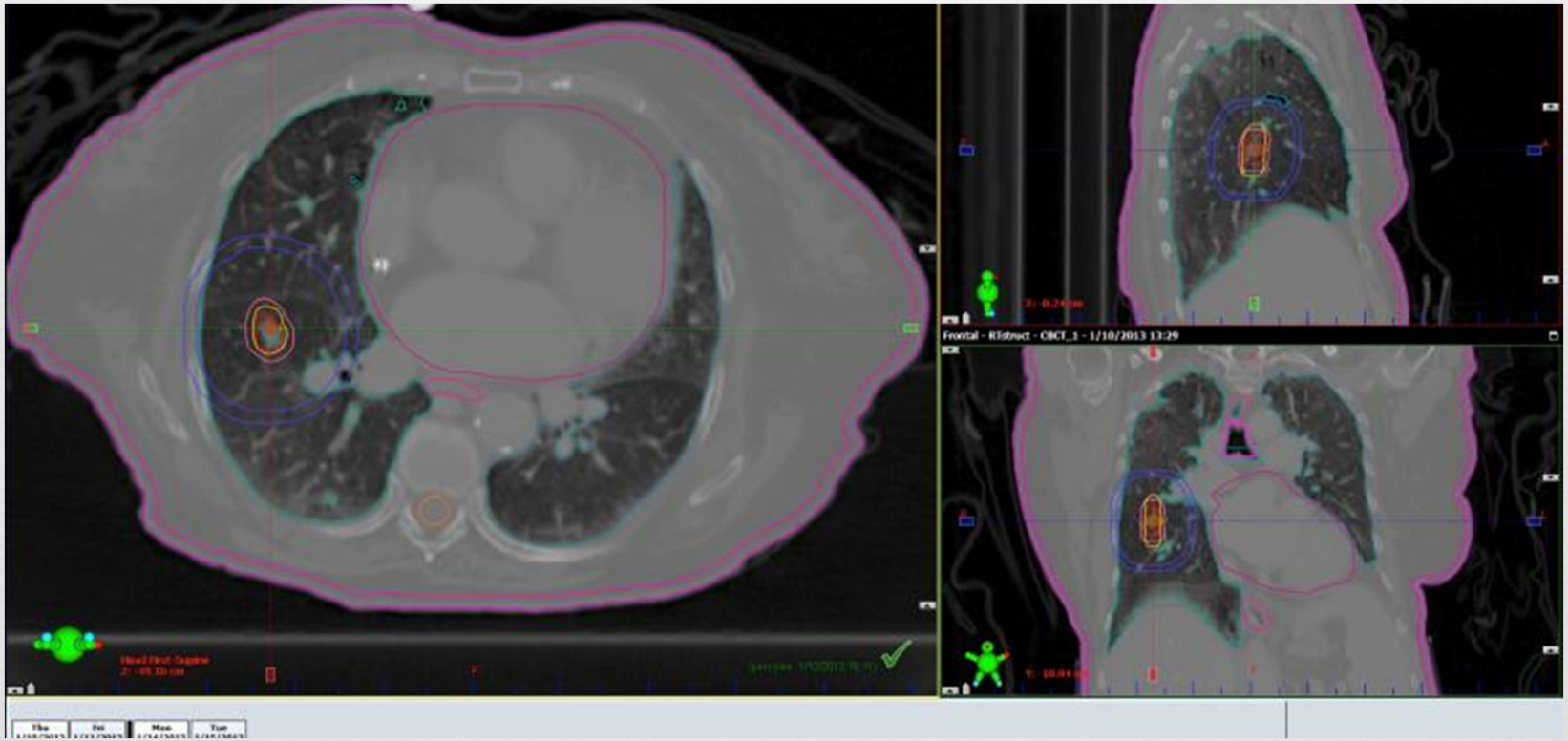
Sim CT

Thorax Tomotherapy



Treat CT

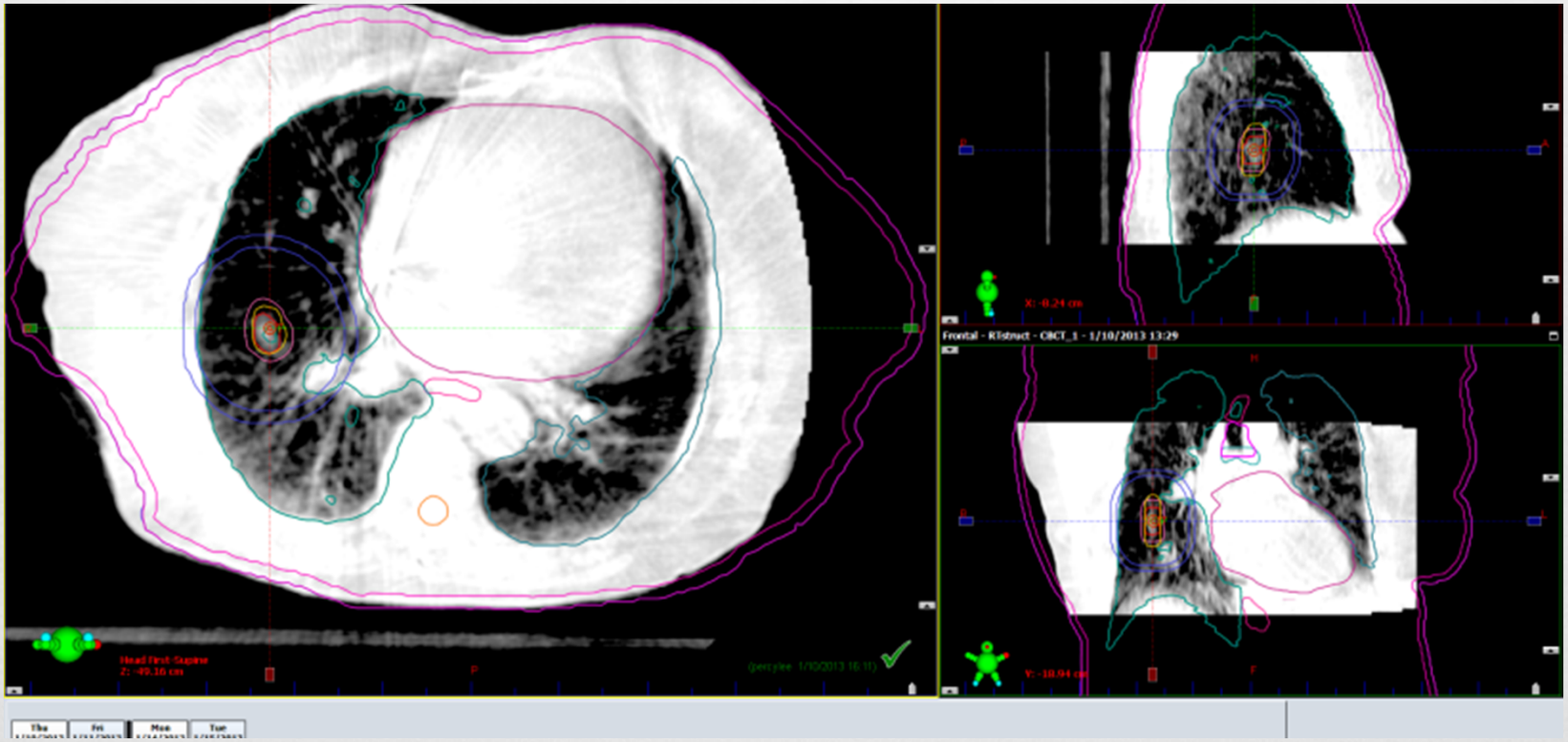
Thorax CBCT



Sim CT

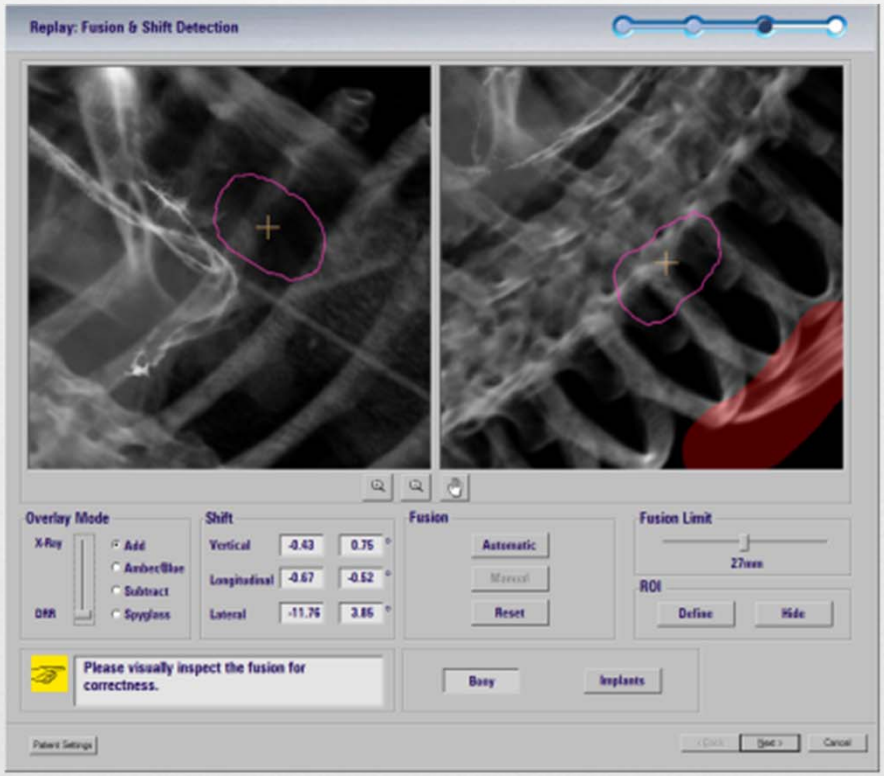
Thorax CBCT

Match normal anatomy then center the tumor wrt the ITV/PTV



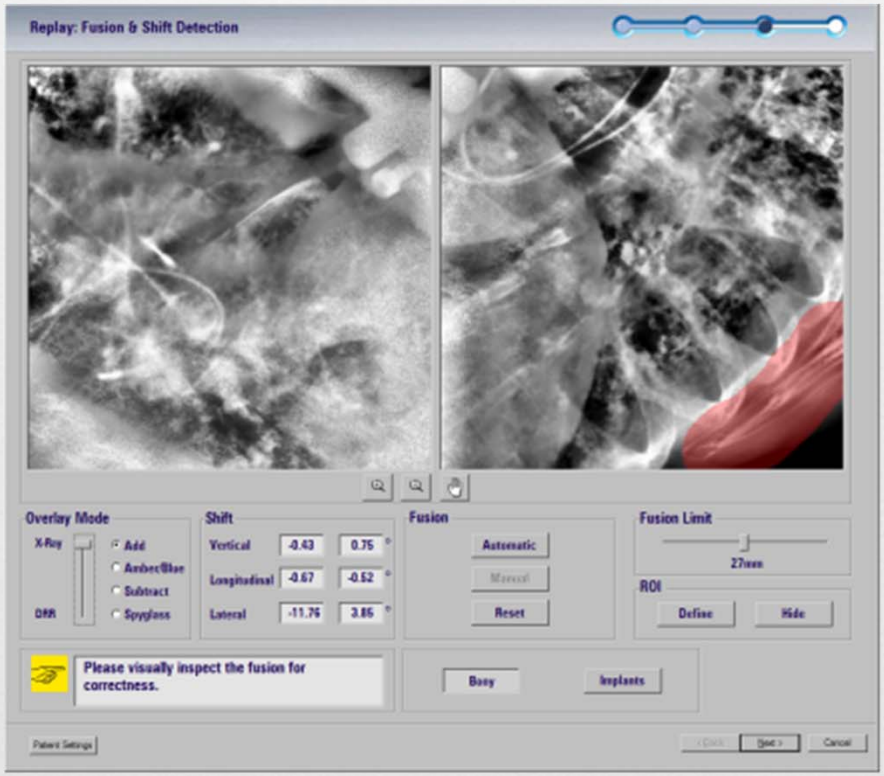
CBCT

Thorax ExacTrac



DRR

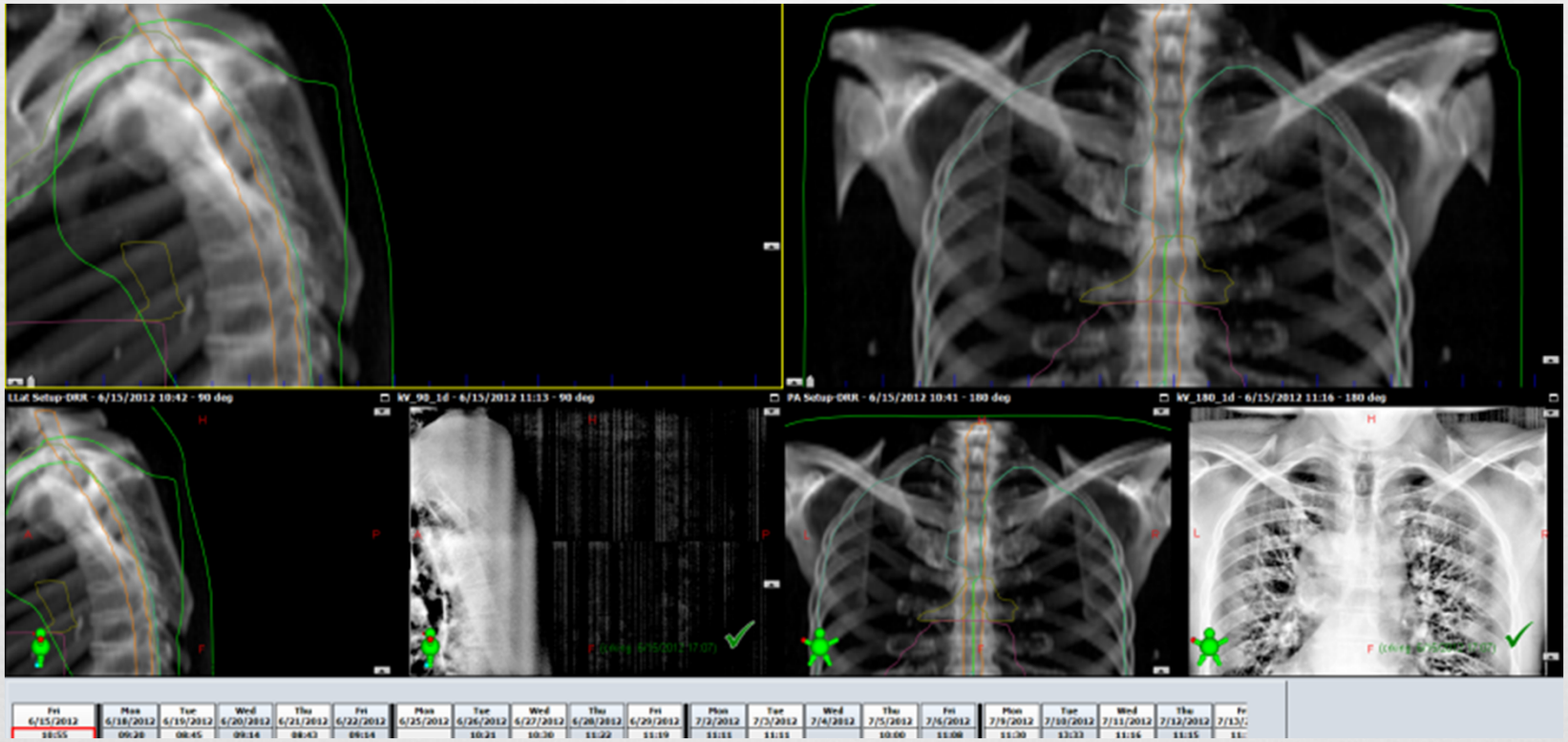
Thorax ExacTrac



kV X-Ray

Don't rely on scapula position.
Variable with arm position.
Ribs can also move.
Use spine if in the FOV.

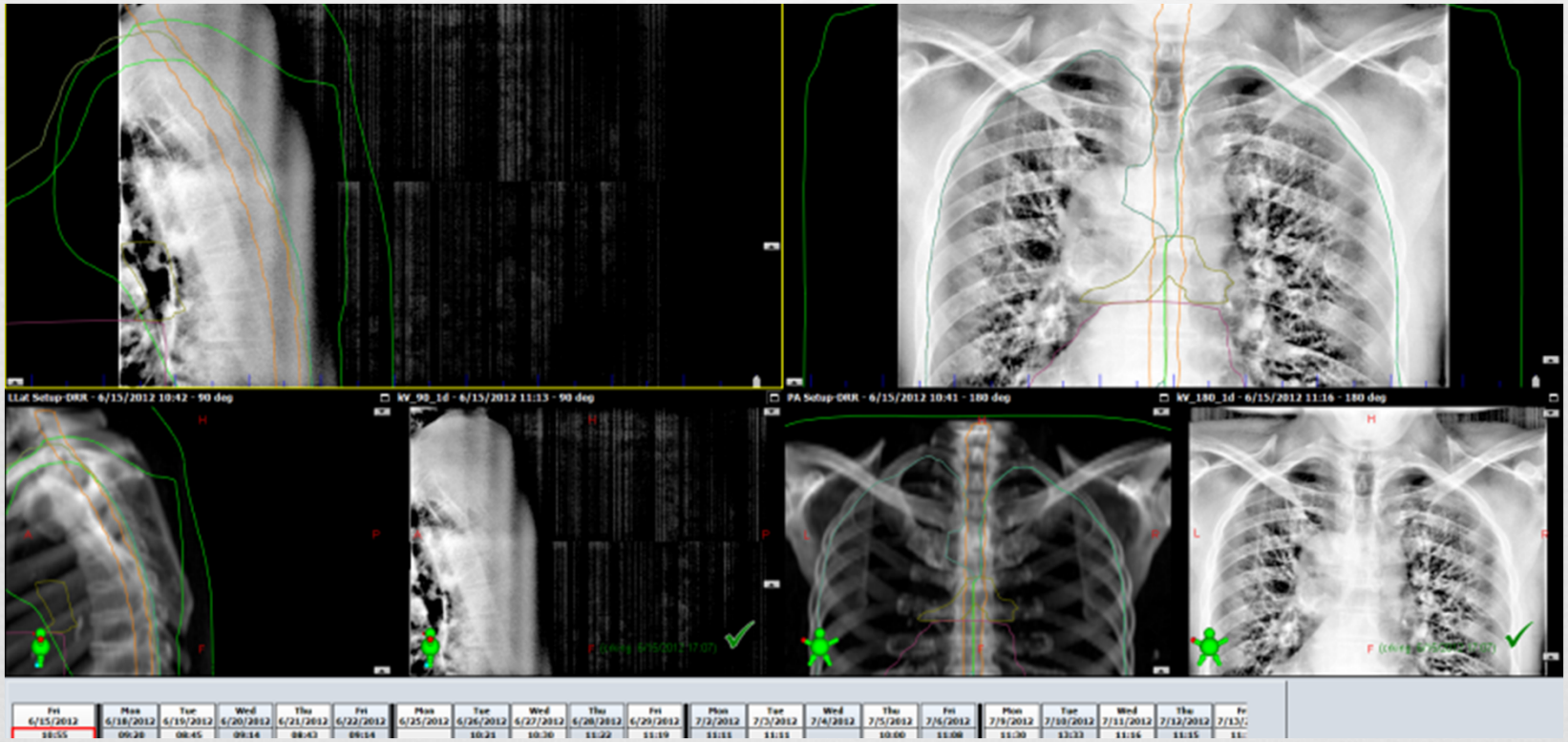
Thorax kV OBI



DRR

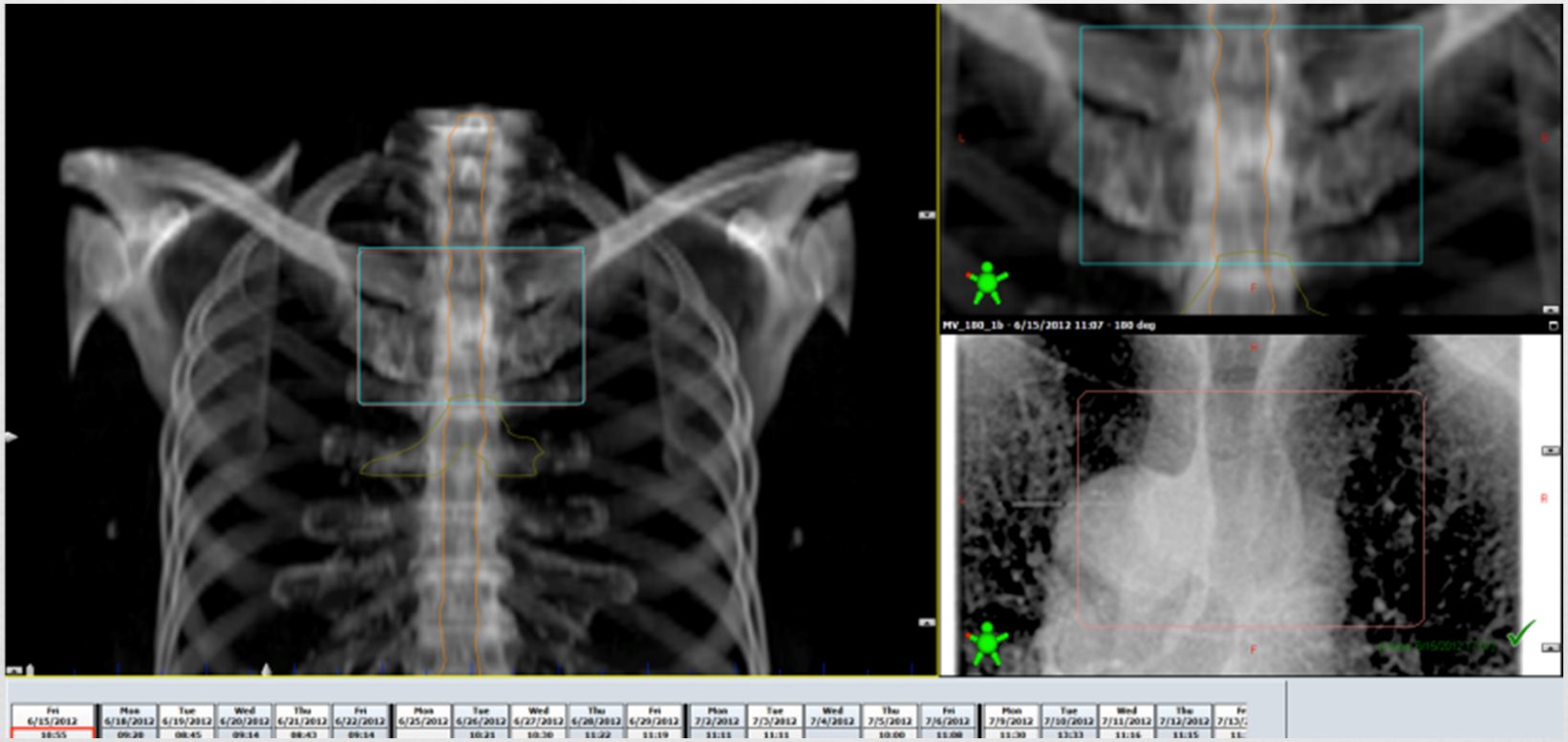
Thorax kV OBI

Match vertebral bodies in lateral view



kV x-ray

Thorax Portal Image

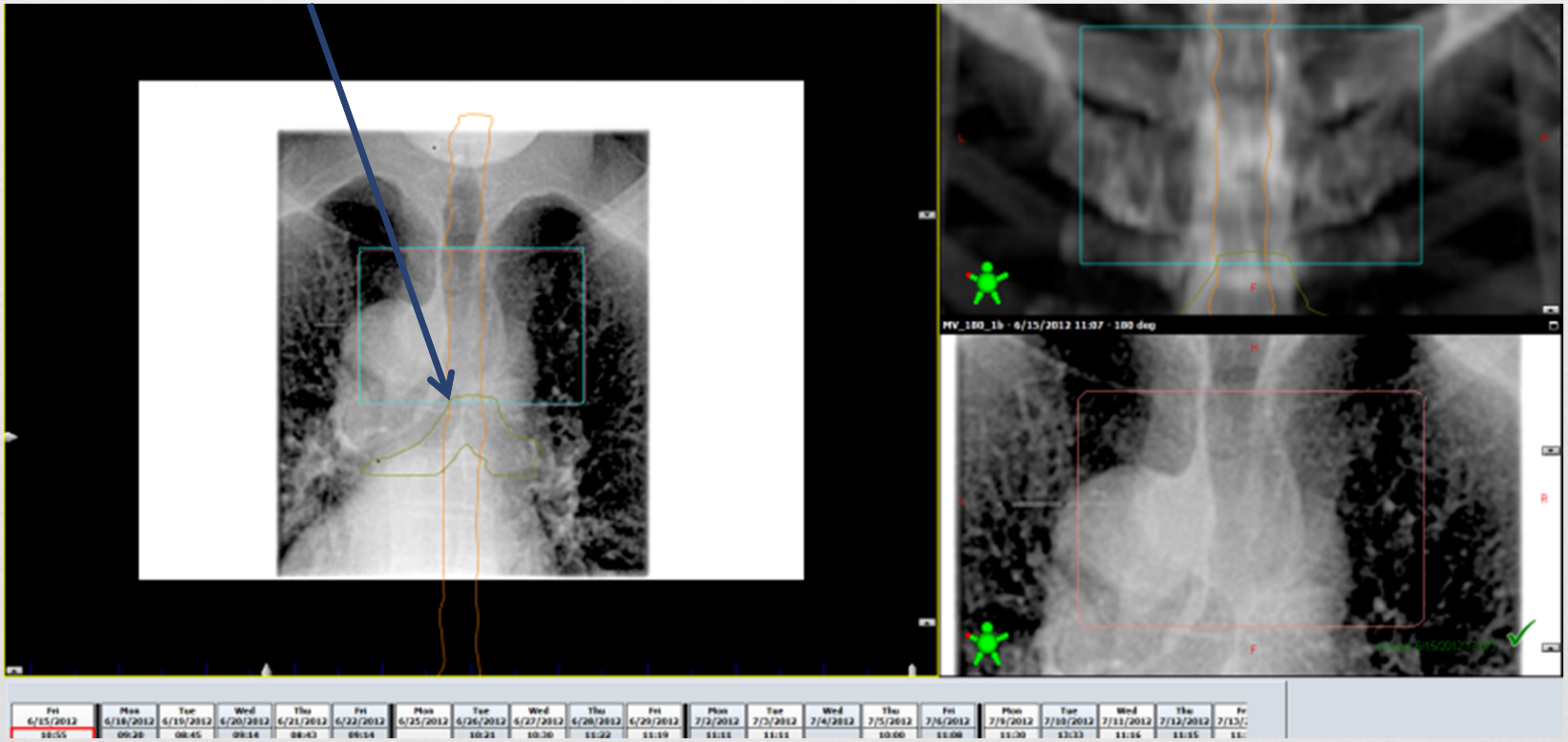


DRR

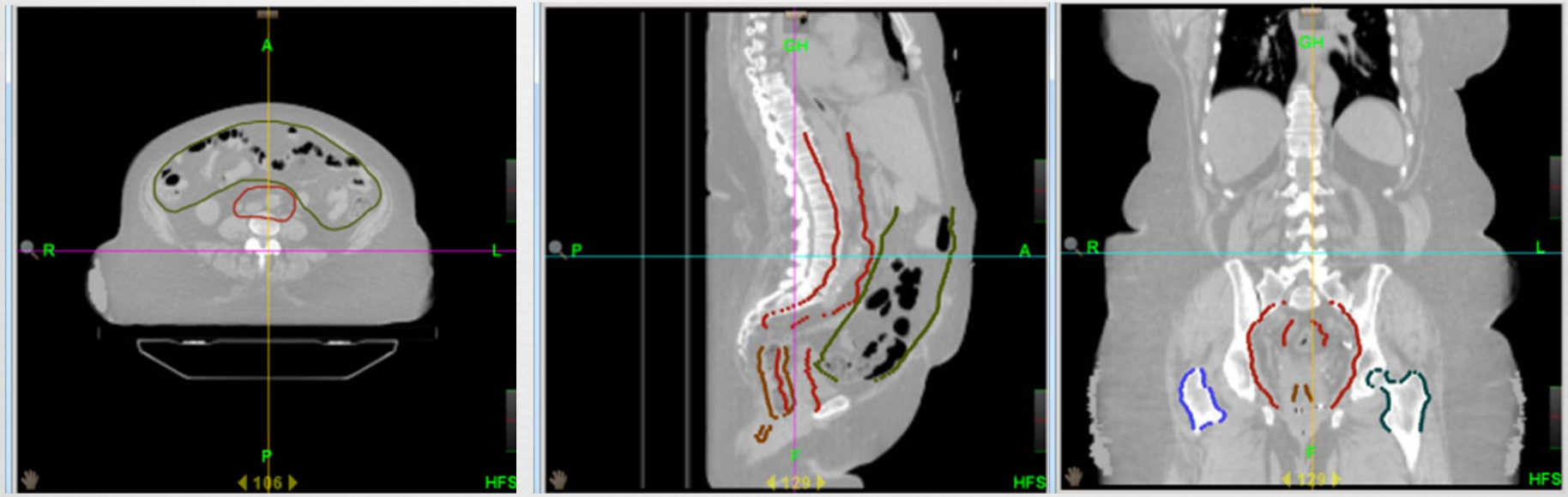
Thorax Portal Image

Carina can usually be seen on MV. Match with contours from planning.

Vertebral bodies can sometimes be seen.

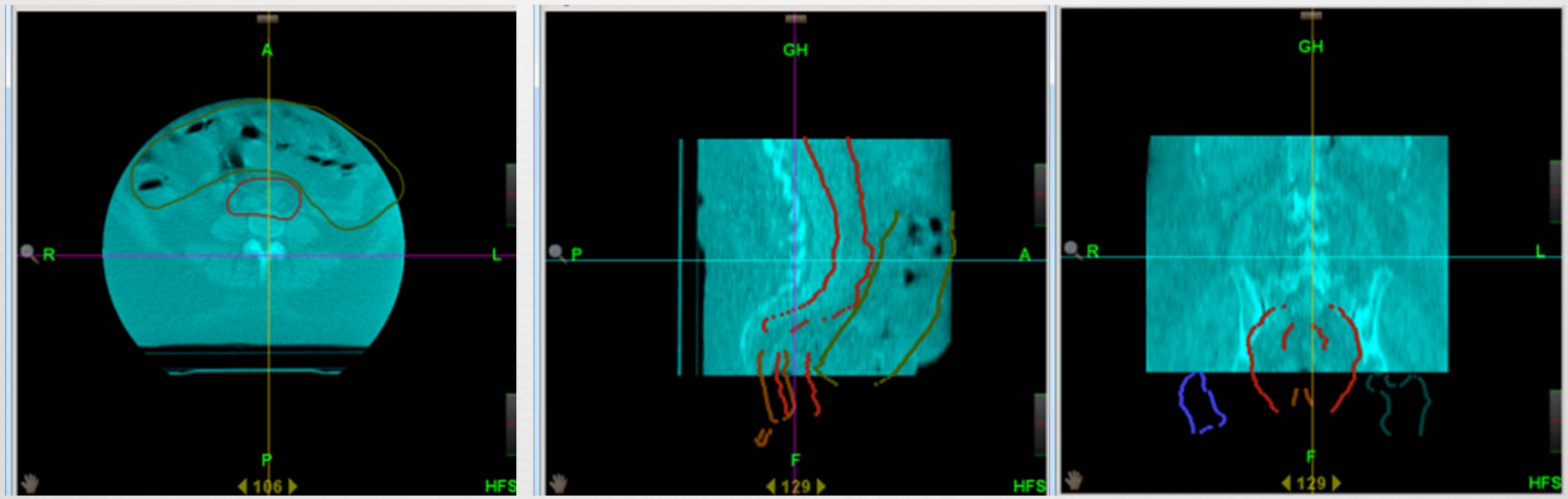


Abdomen Tomotherapy



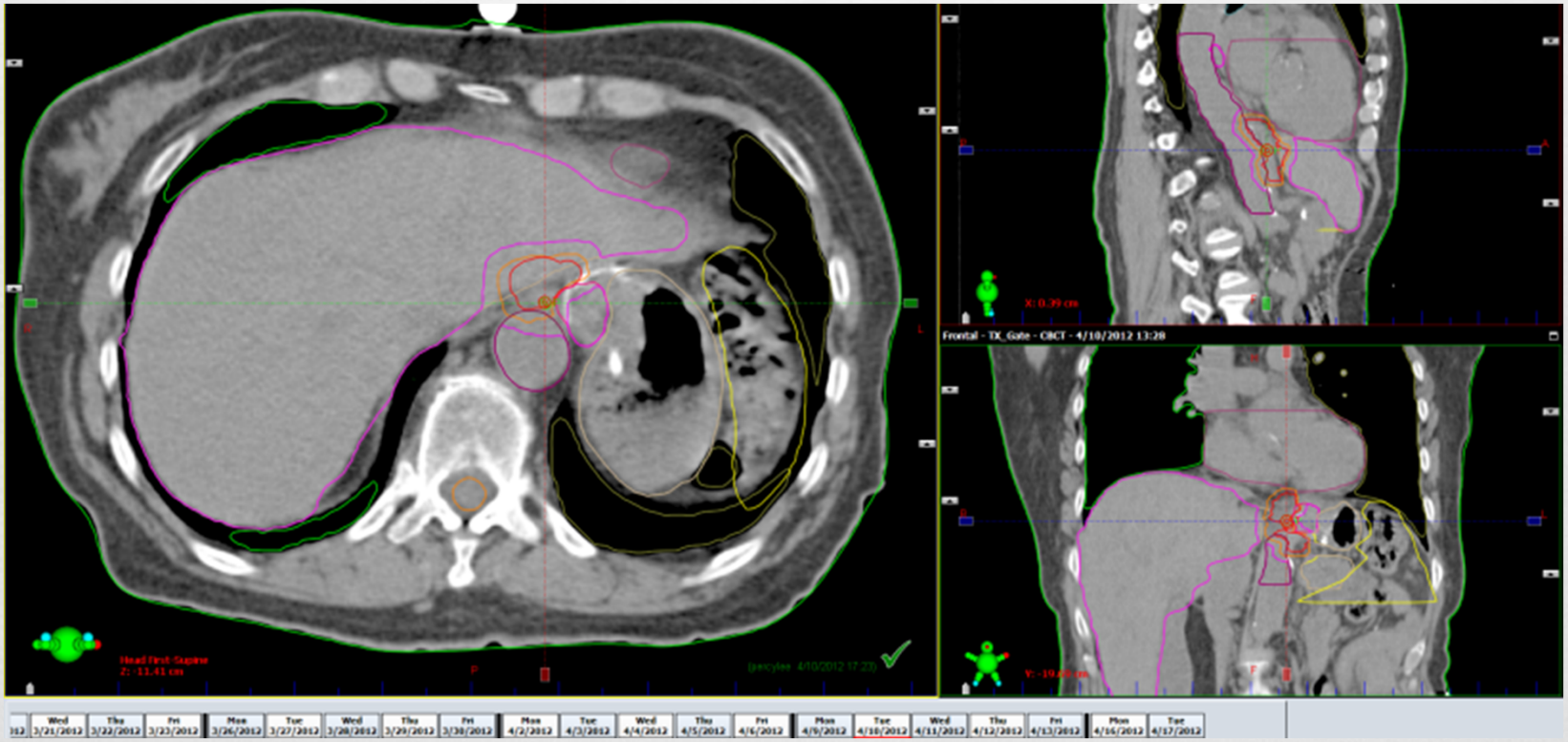
DRR

Abdomen Tomotherapy



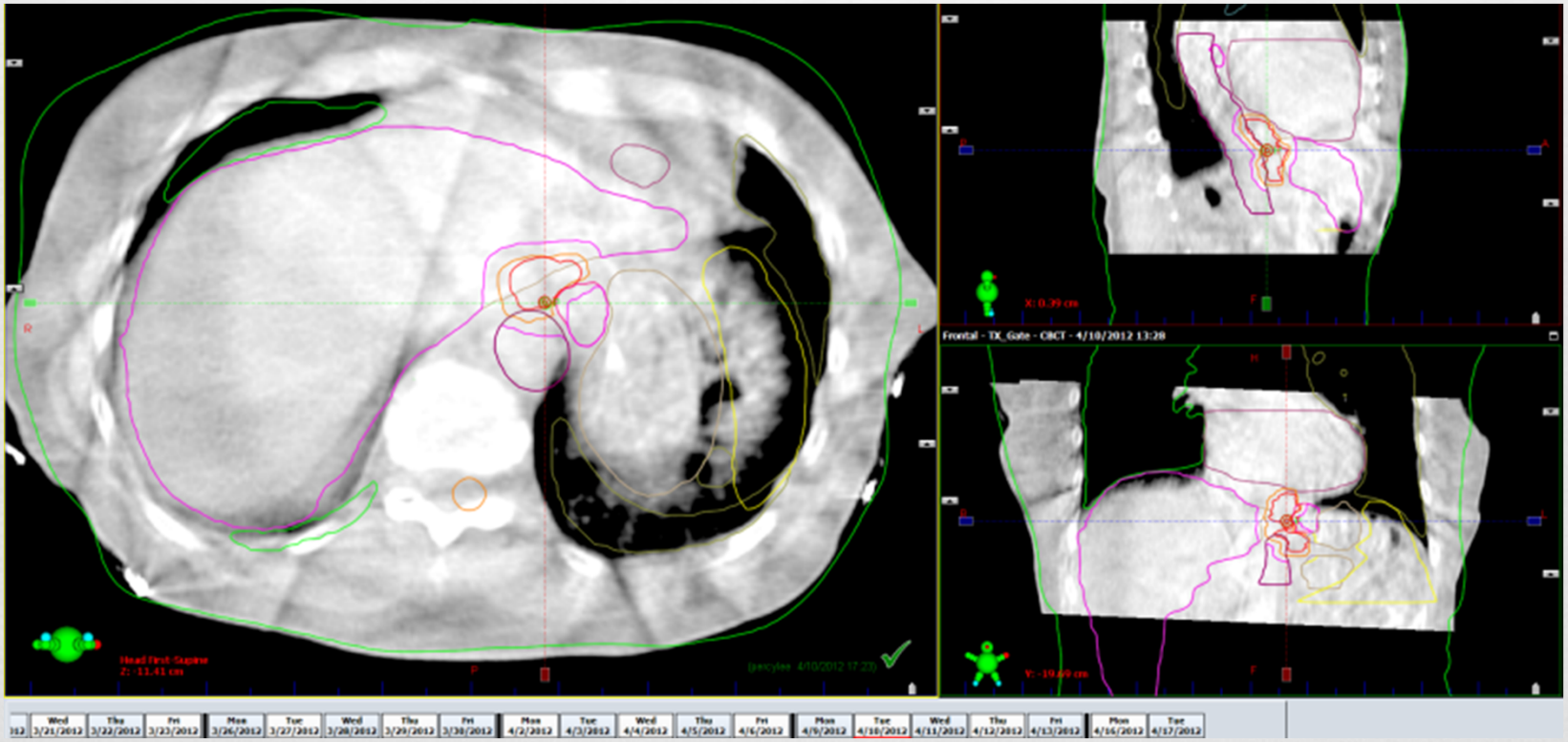
Treat CT

Abdomen CBCT

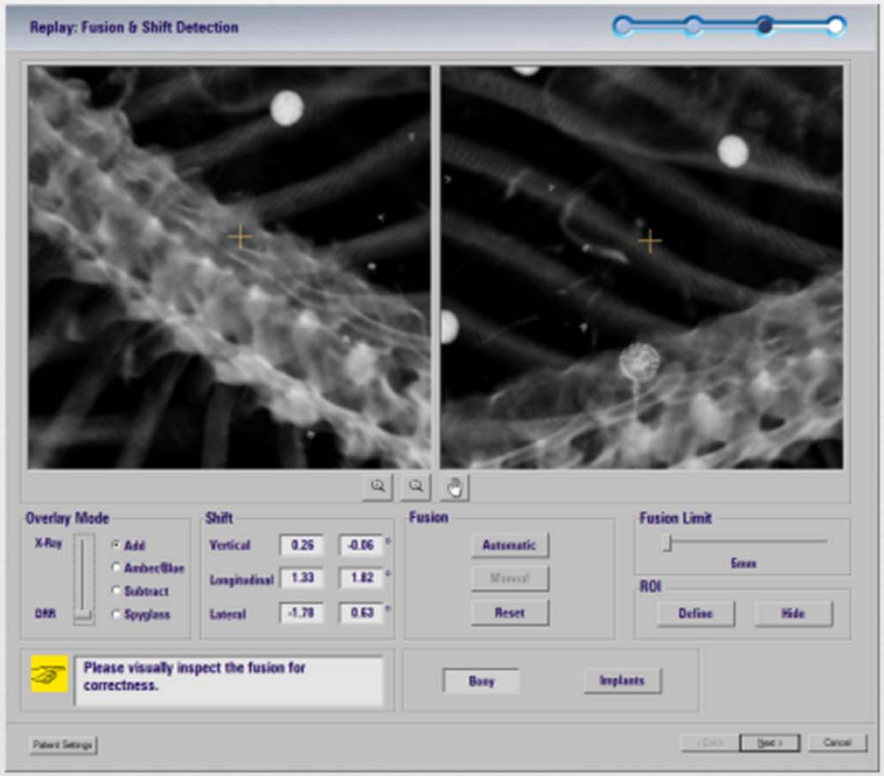


DRR

Abdomen CBCT



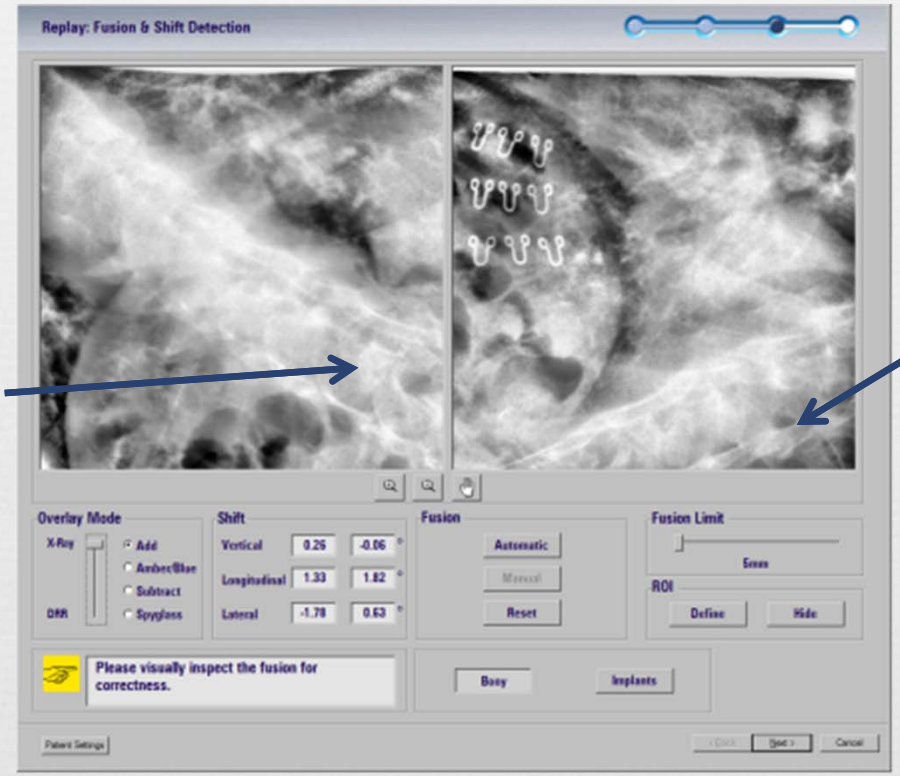
Abdomen/Spine ExacTrac



DRR

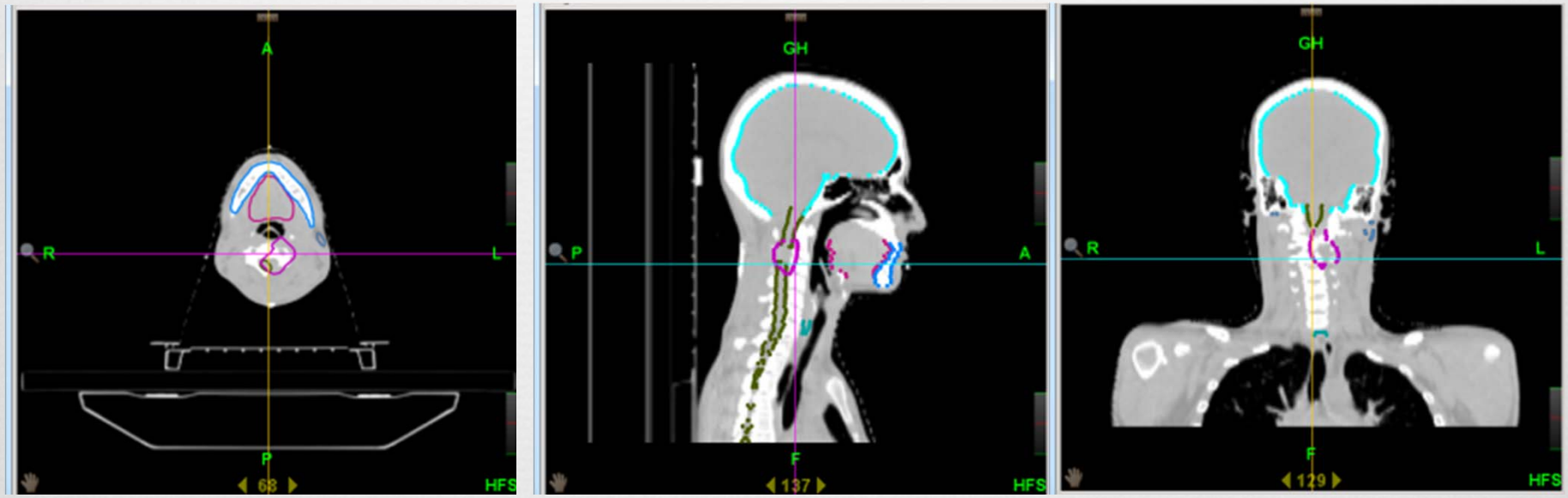
Abdomen/Spine ExacTrac

Find a unique feature on the spine to ensure correct level.



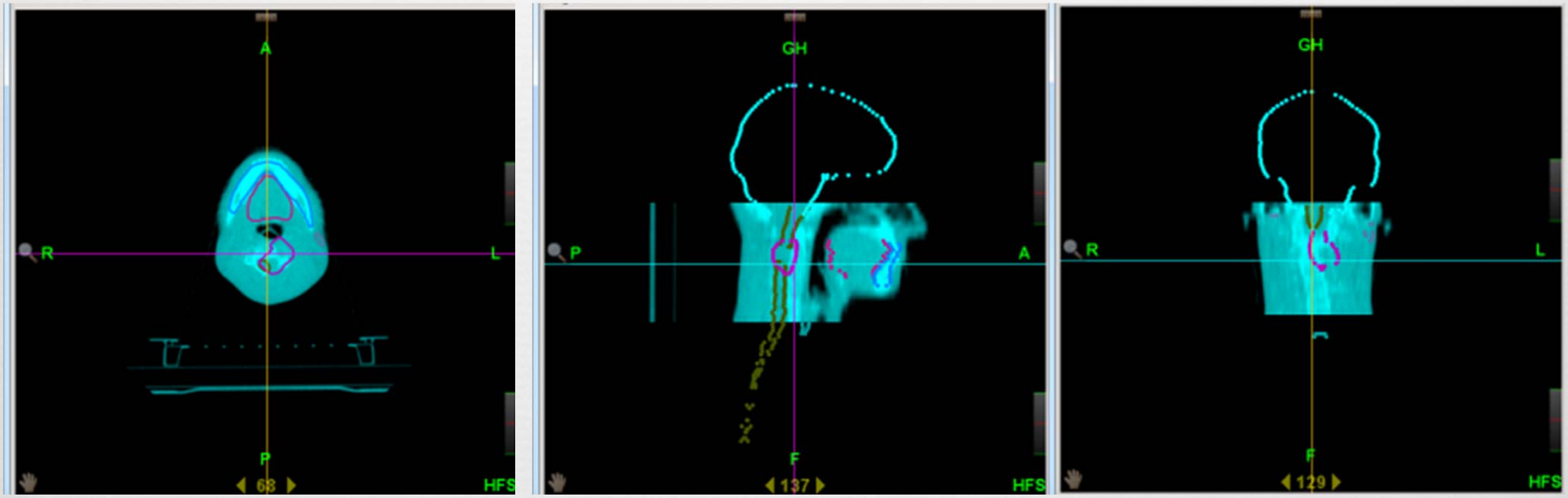
Intervertebral foramen

Spine Tomotherapy



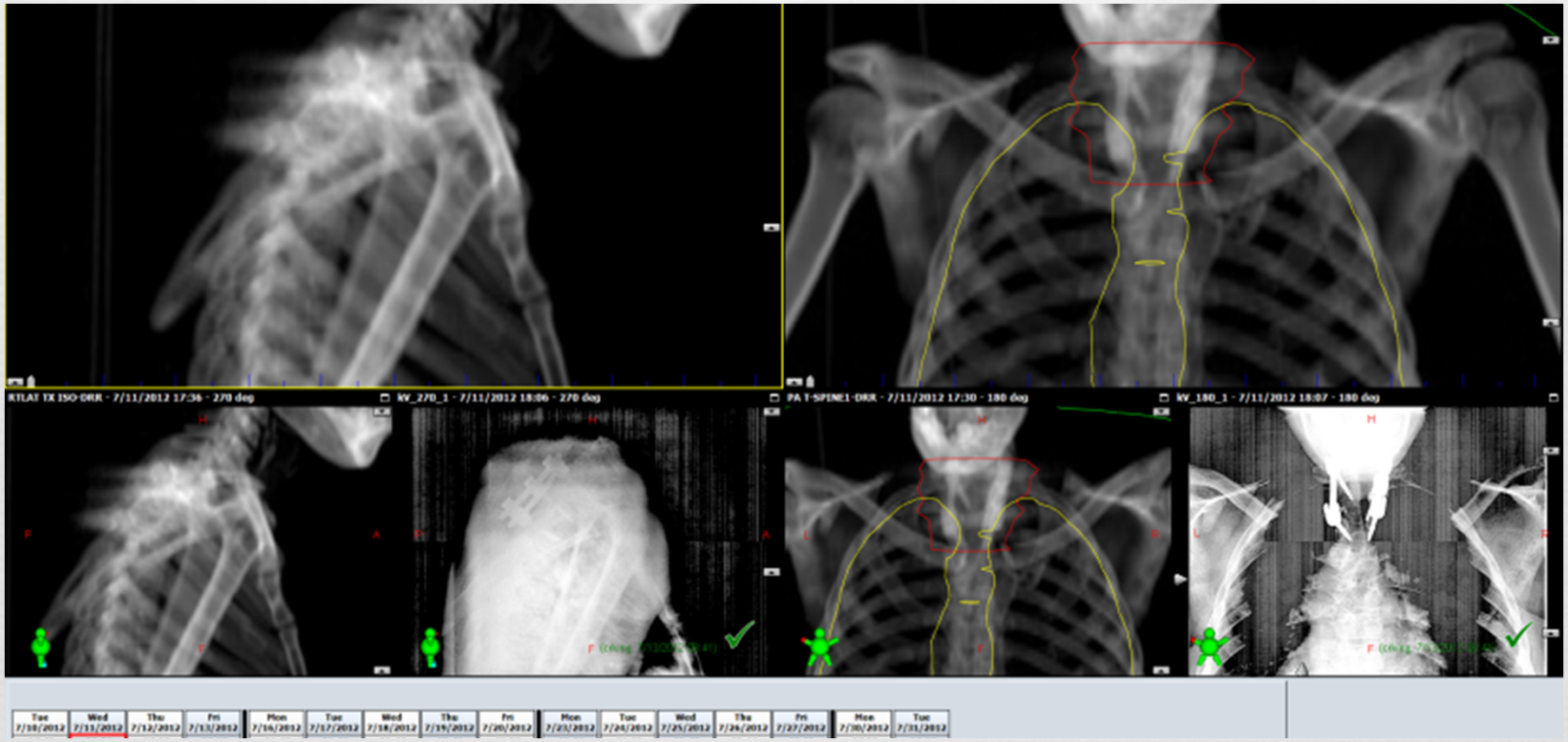
DRR

Spine Tomotherapy



Treat CT

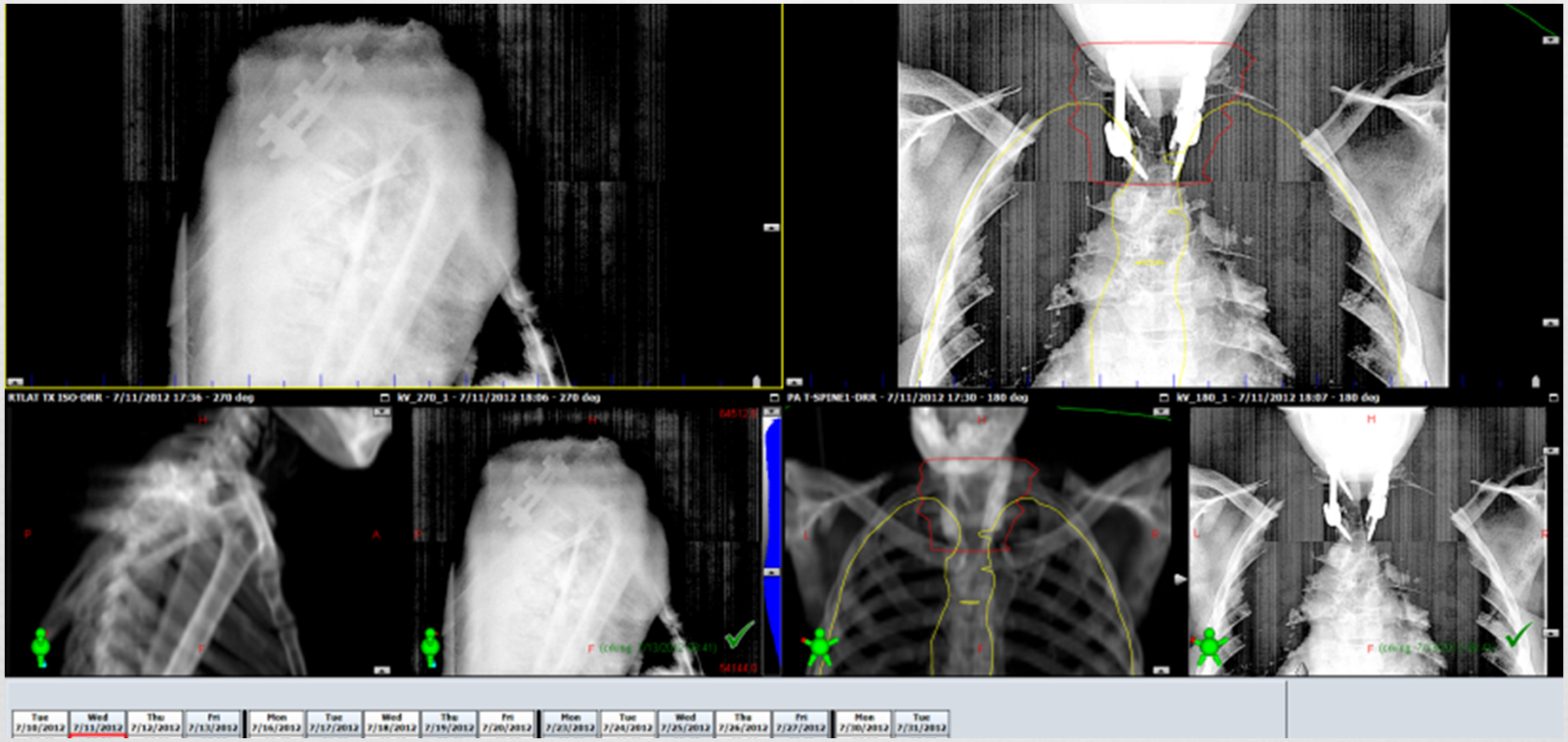
Spine kV OBI



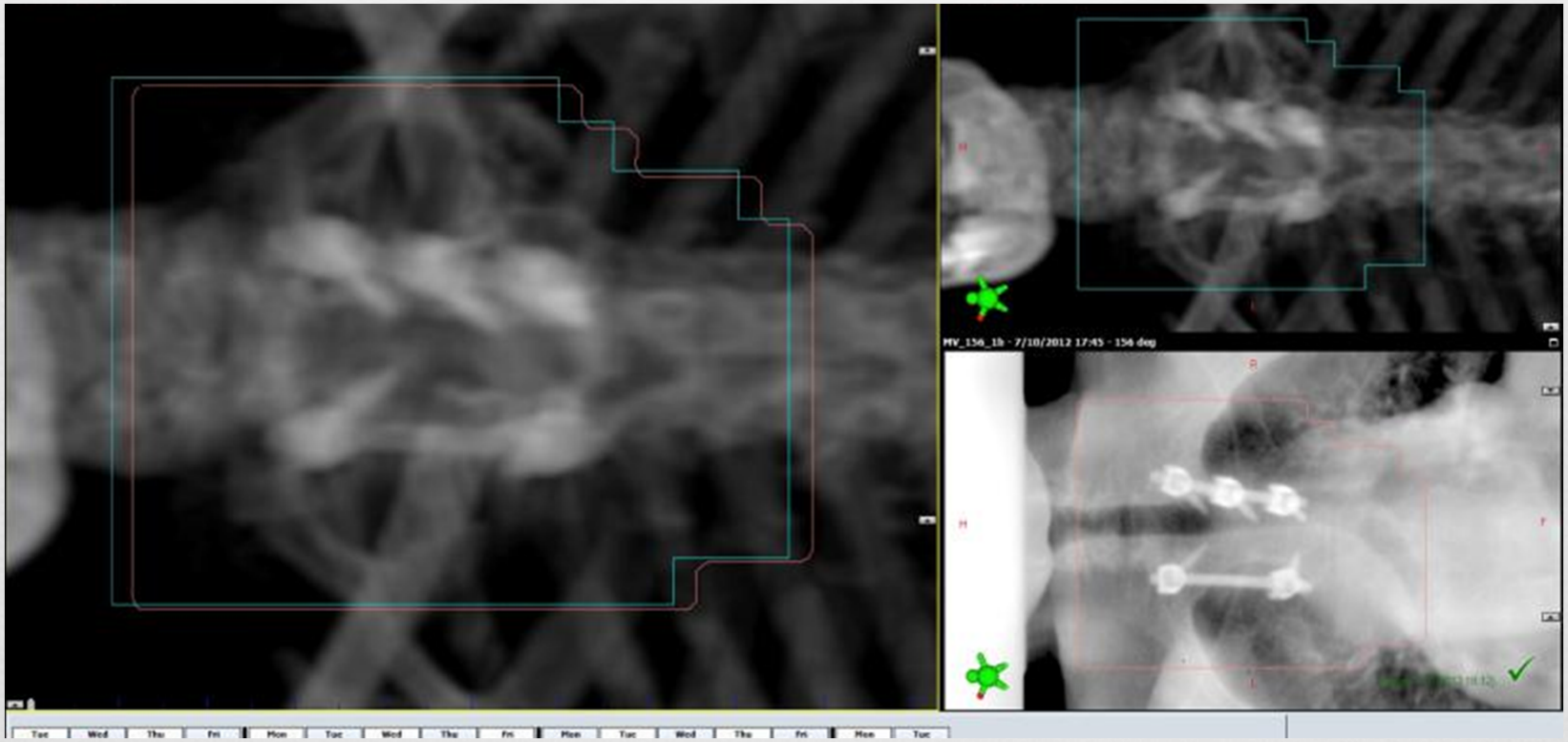
DRR

Spine kV OBI

Prosthetic hardware.

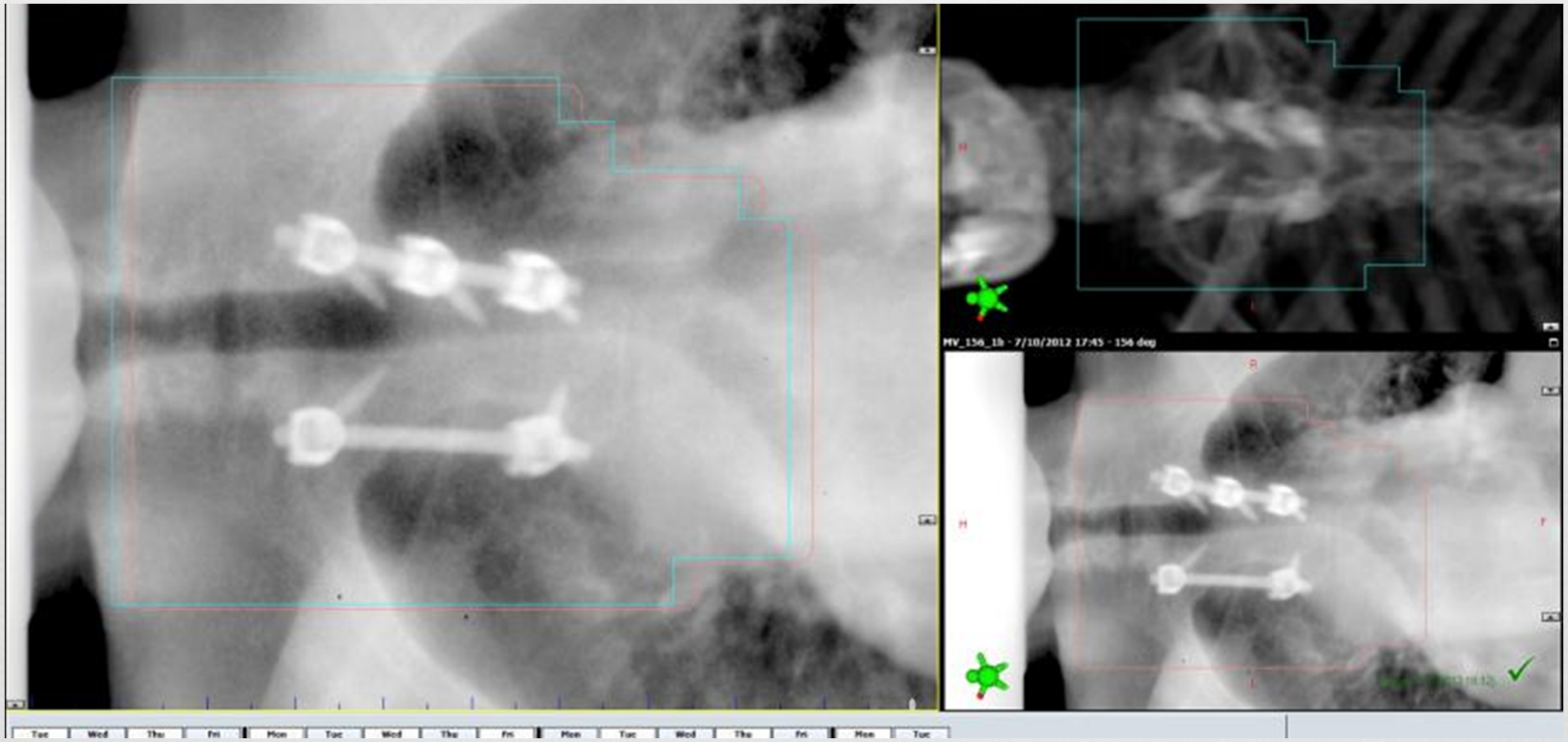


Spine Portal Image



DRR

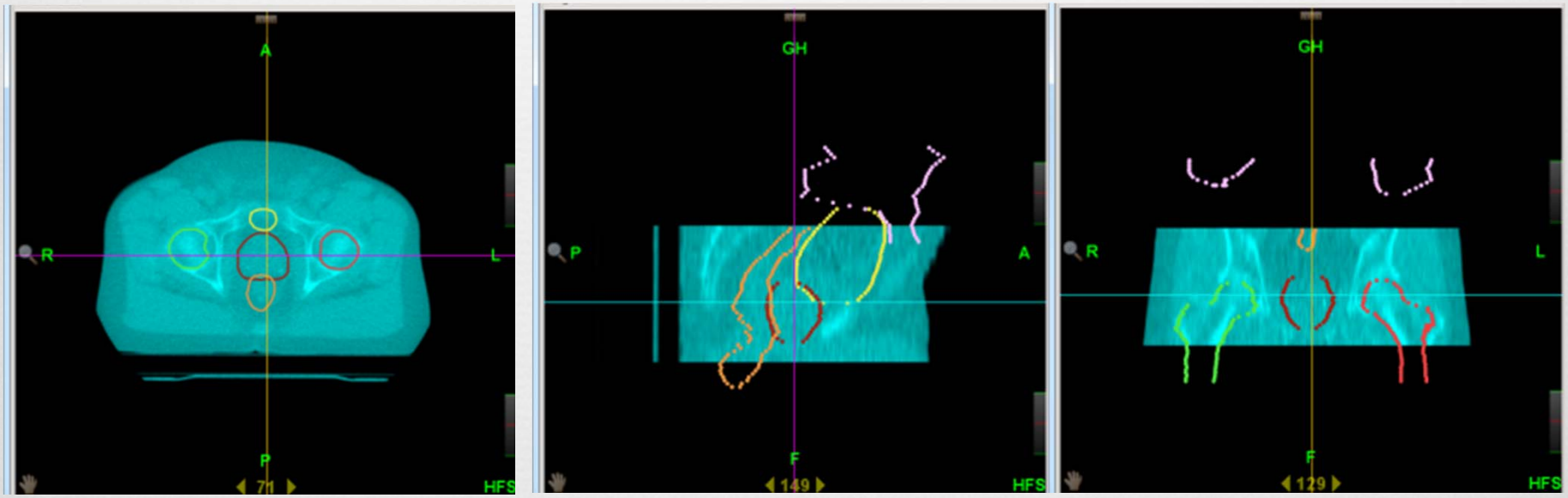
Spine Portal Image



Pelvis Tomotherapy

DRR

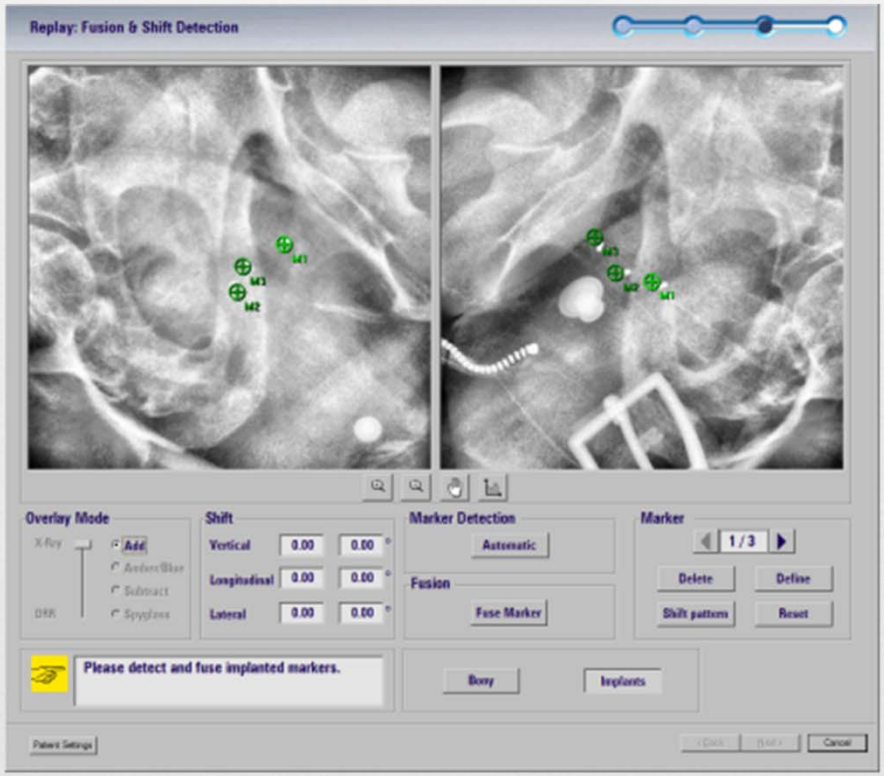
Pelvis Tomotherapy



Treat CT

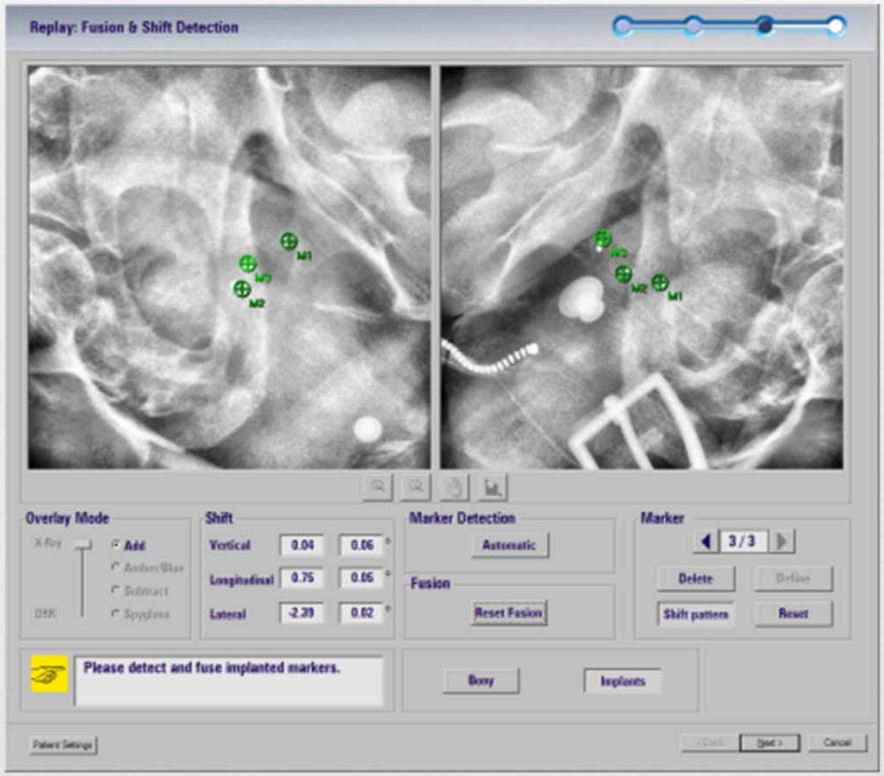
Pelvis ExacTrac Fiducial Match

Expected Marker locations



Pelvis ExacTrac Fiducial Match

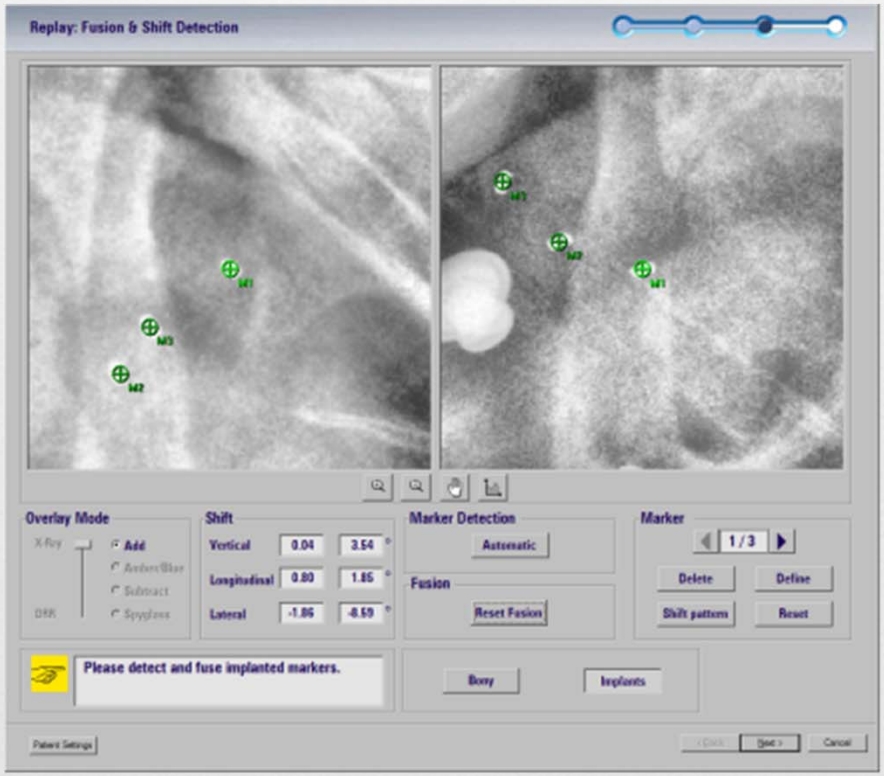
Markers shifted as a group. This assumes fiducial pattern has not deformed.



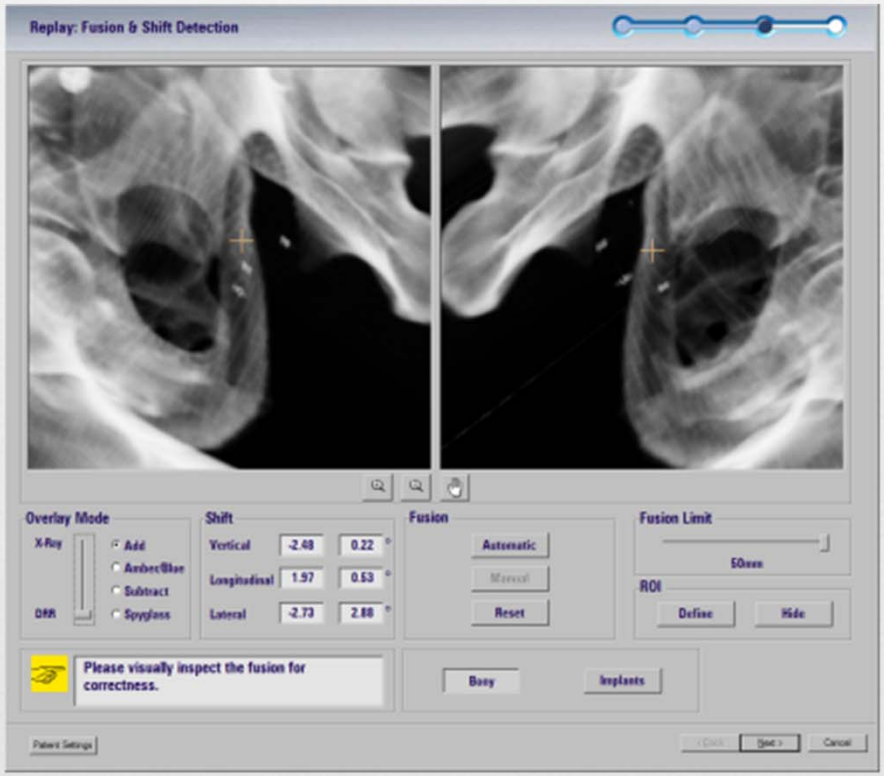
Pelvis ExacTrac Fiducial Match

Individual markers matched with their corresponding fiducials.

If the pattern changes too much from expected the system will complain and only allow a center of mass match.



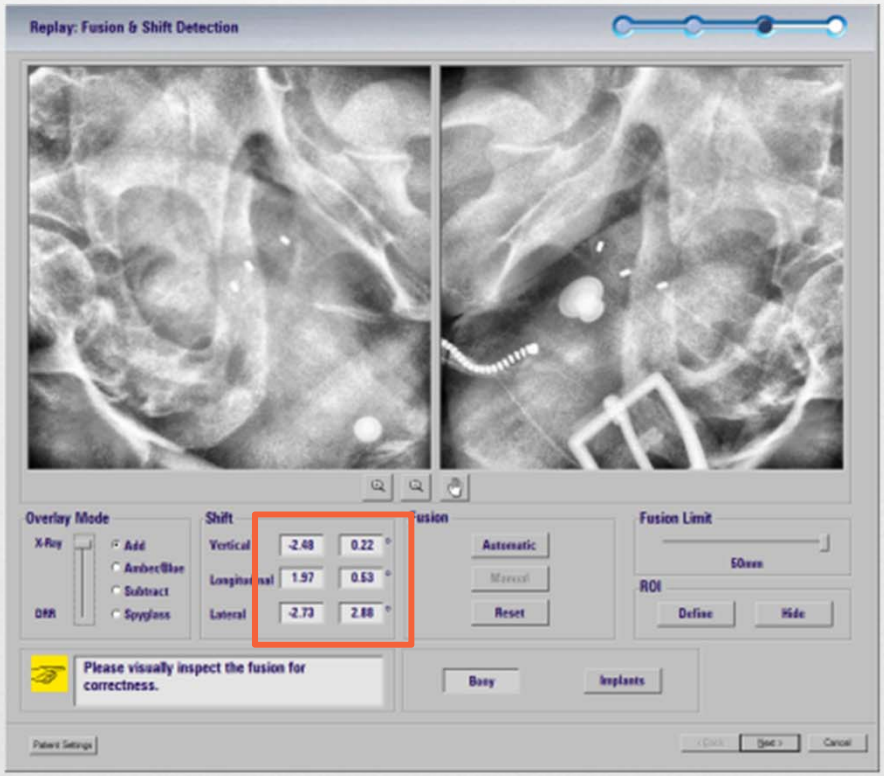
Pelvis ExacTrac Bone Match



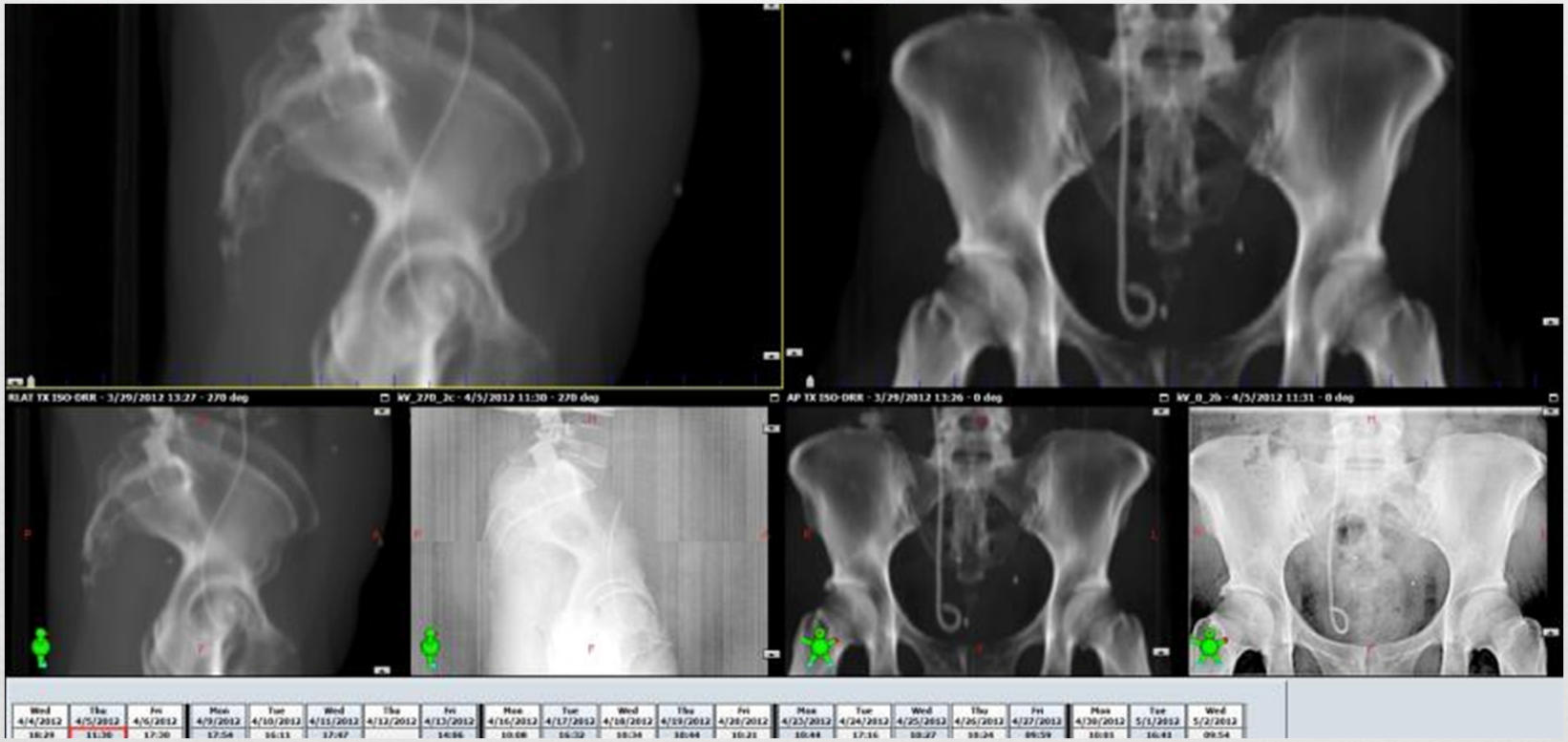
DRR

Pelvis ExacTrac Bone Match

~ 1mm difference from fiducial match in this case. Can be more if target moves relative to skeletal anatomy

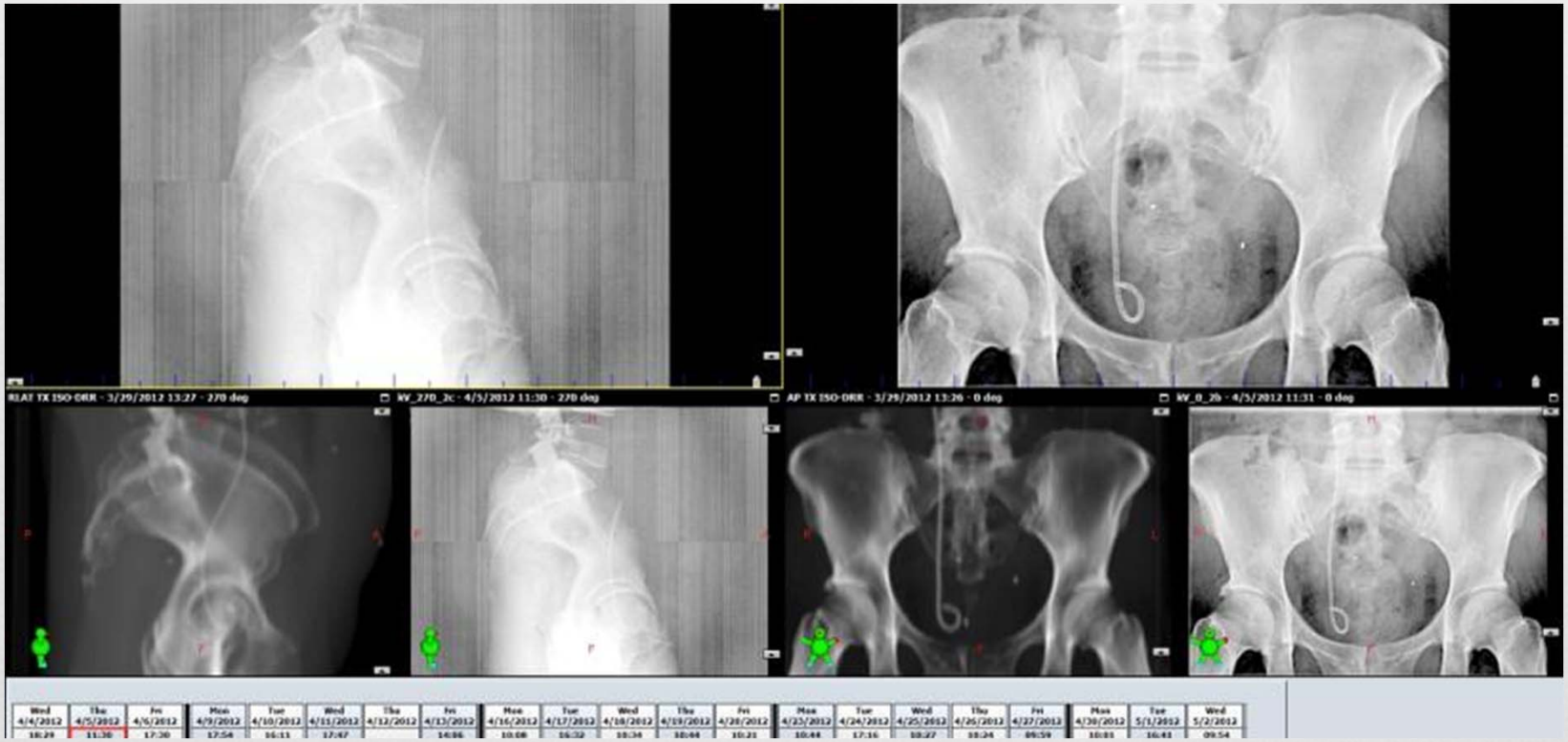


Pelvis kV OBI

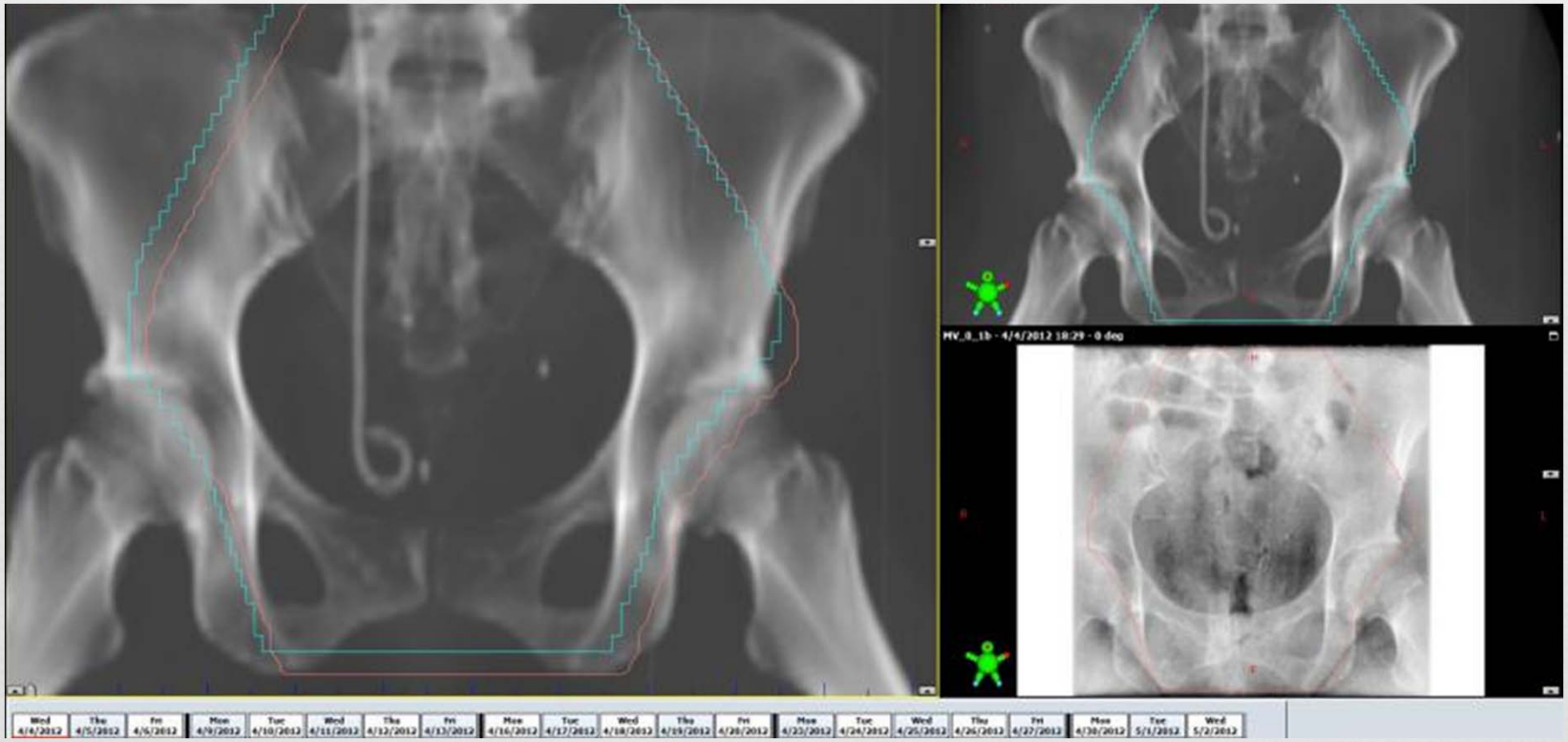


DRR

Pelvis kV OBI



Pelvis Portal Image



DRR

Pelvis Portal Image

What Imaging is Most Appropriate

- Tomotherapy: MV CT only available
- Cranial (match to skull)
  - Whole Brain: **Portal imaging**. Large field with wide margin. Want to see field relative to target.
  - SRT: **ExacTrac or kV match**. Tight margins needs accurate setup. 3D or 6D correction.
  - SRS: **ExacTrac**. Tight margins need accurate setup. Intrafraction imaging for movement correction. (Note: we add CBCT for Trigeminal Neuralgia as an independent double check of positioning only)

What Imaging is Most Appropriate

- H&N (match C2 or primary tumor location)
  - **kV match** is fast to acquire and gives large field of view.
  - Periodic CBCT can be added to track anatomic changes.
- Thorax (match tumor or nearby soft tissue)
  - Large field fractionated: **kV match** is fast to acquire with large FOV.
  - IMRT and SBRT: **CBCT** and align to target.

What Imaging is Most Appropriate

- Abdomen (match spine or tumor/soft tissue)
  - Large field fractionated: **kV match** is fast to acquire with large FOV. Align to spine.
  - IMRT and SBRT: Align to tumor or nearby soft tissue landmarks using **CBCT.**
- Spine (match spine)
  - **ExacTrac** or **kV match** is fast to acquire and gives large field of view.
  - SRS/SBRT: **ExacTrac**. Tight margins need accurate setup. Intrafraction imaging for movement correction. Possible 6D correction.

What Imaging is Most Appropriate

- Pelvis (match fiducials, soft tissue or skeleton)
  - Fractionated Prostate: **ExacTrac or kV Match** using fiducial alignment.
  - SBRT Prostate: **ExacTrac** with fiducial alignment. ExacTrac allows intrafraction movement correction. CBCT added for rectum and bladder volume check.
  - Fractionated Pelvis (non-prostate): **ExacTrac or kV Match** using skeletal alignment.
  - SBRT Pelvis (non-prostate): **CBCT** unless target is in bone (then use ExacTrac).

Alignment Tolerance

- Most fractionated cases are given a 2mm image guidance tolerance level.
  - If anatomic offset ≤2mm on imaging, then shift does NOT need to be performed.
  - If anatomic offset >2mm on imaging, then shift patient.
- With ExacTrac, any time a correction is performed a new set of verification images is also performed.
- Most SRS cases are given a 1mm image guidance tolerance.
- TGN, Sphenopalatine ganglion & Thalamotomy SRS are treated with 0.5mm tolerance on ExacTrac.

Snap Verification on ExacTrac

Sometimes the gantry obscures one of the ExacTrac imagers.

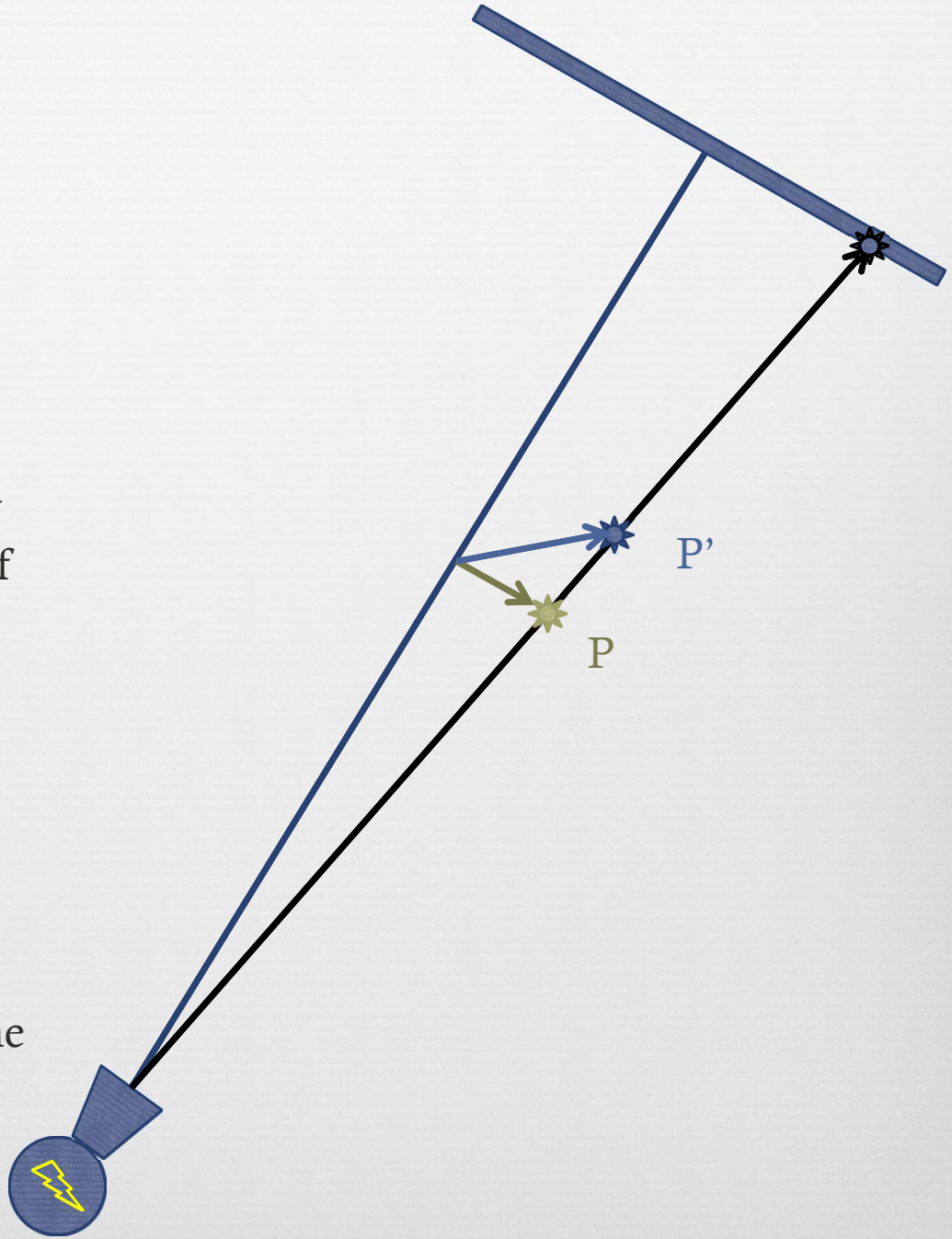
To avoid spending time repositioning the gantry a single image can be obtained, and 3D target movement can be **estimated** based on this single image.

Snap Verification on ExacTrac

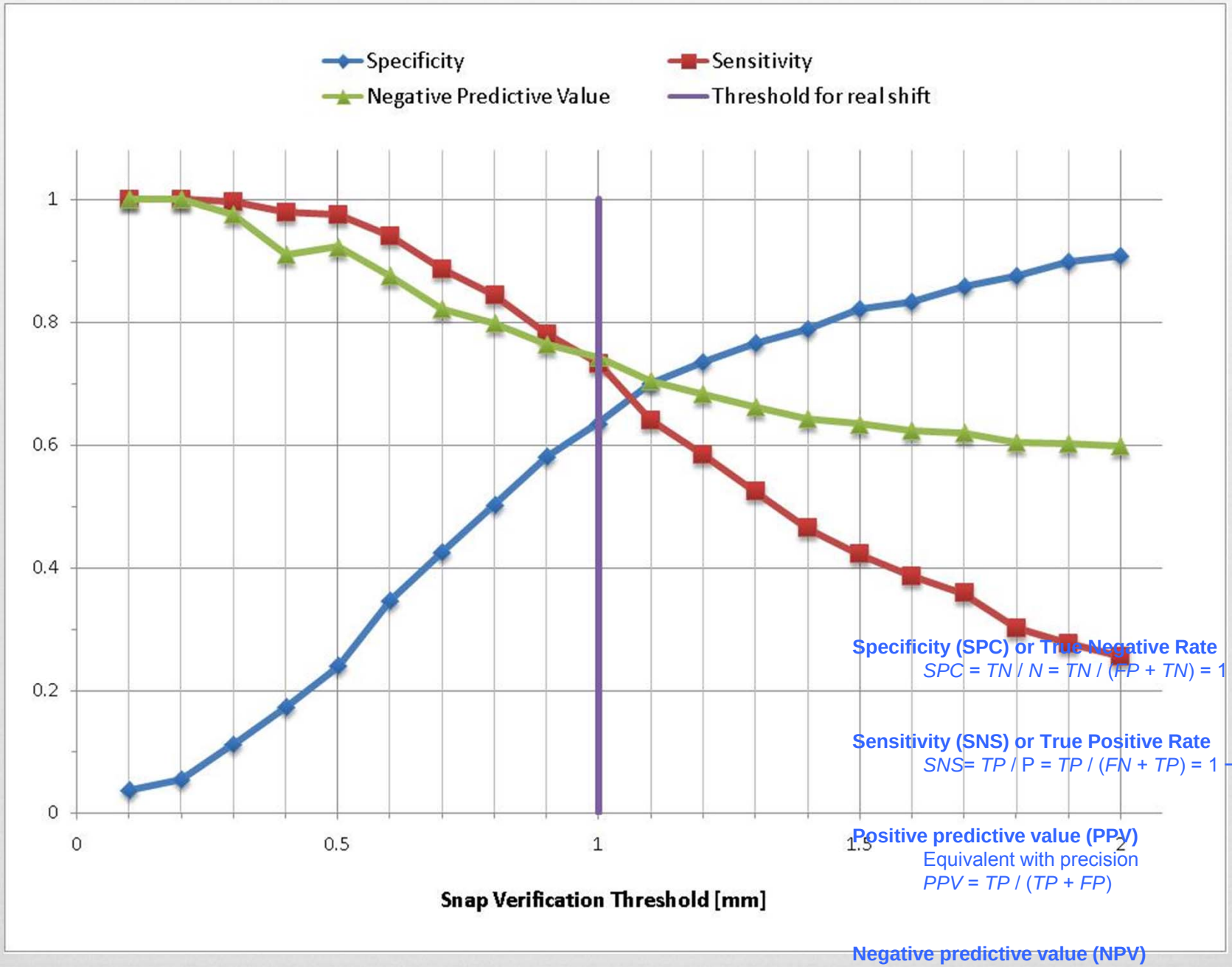
A single image can only reliably detect translations in the plane of the image (2D).

Out of plane movement can be missed.

Snap predicts whether 3D shift exceeds a given value based on the amount of 2D shift detected.



Julian Beever



Specificity (SPC) or True Negative Rate
SPC = TN / N = TN / (FP + TN) = 1 − FPR

Sensitivity (SNS) or True Positive Rate
SNS= TP / P = TP / (FN + TP) = 1 − FNR

Positive predictive value (PPV)
Equivalent with precision
PPV = TP / (TP + FP)

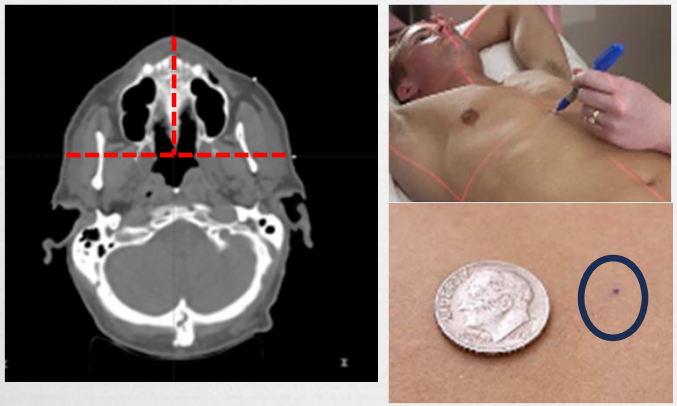
Negative predictive value (NPV)
NPV = TN / (TN + FN)

Workflow

- Fiducial setup and kV OBI
- IR marker setup and ExacTrac
- Tomotherapy

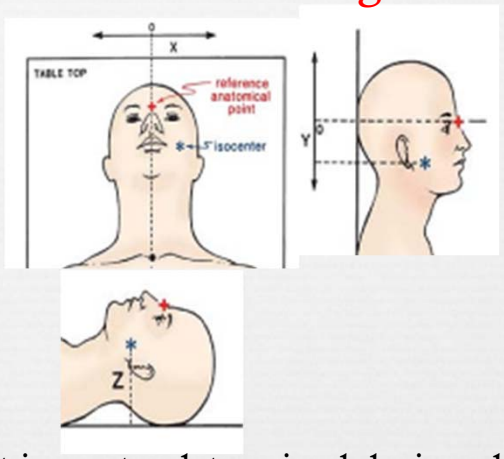
Patient coordinate and isocenter setup: Fiducials

Sim



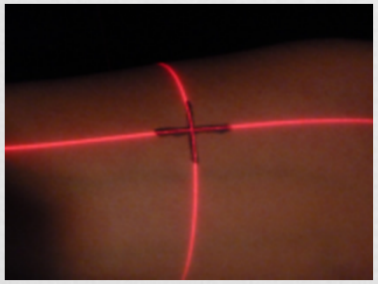
3 external pointers which determines an internal reference point (named “user origin” in Eclipse)

Planning

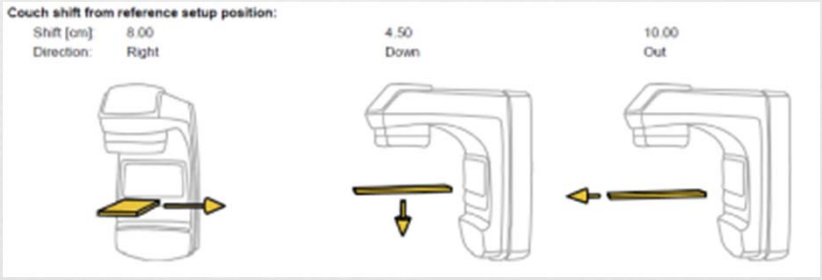


Treatment isocenter determined during planning phase. The planned shift between reference point and treatment isocenter can be calculated.

Treatment setup



Patient initial setup done by alignment of lasers with external markers



Manual shifts of treatment couch according to the offsets determined in planning step shown above

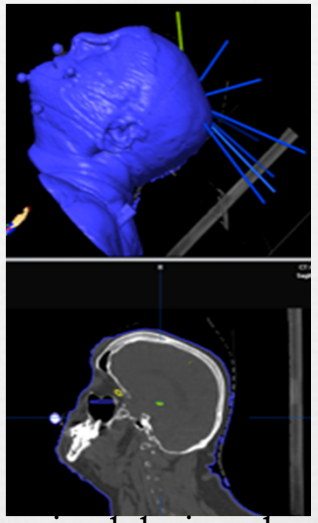
IGRT

Patient coordinate and isocenter setup: ExacTrac

Sim

IR markers create a coordinate reference frame for locating an isocenter

Planning



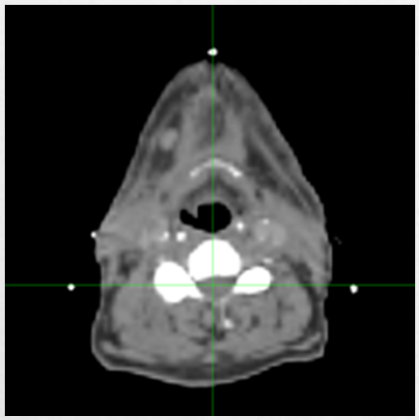
Treatment isocenter determined during planning phase. The relationship between marker positions and treatment isocenter can be calculated.

Treatment setup

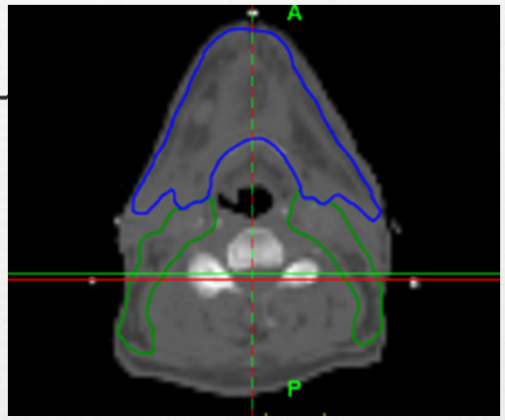
Patient initial setup done by alignment of IR markers that places target at isocenter.

Stereo kV IGRT

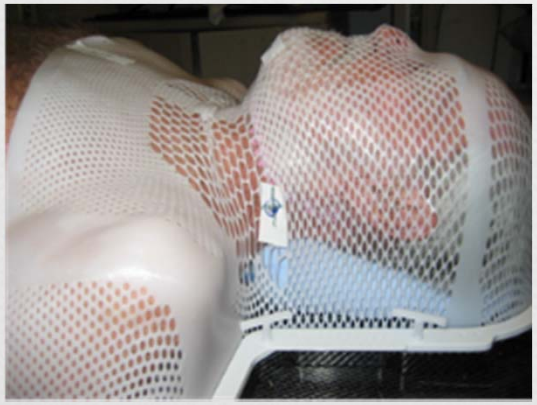
Patient coordinate and isocenter setup: Tomotherapy



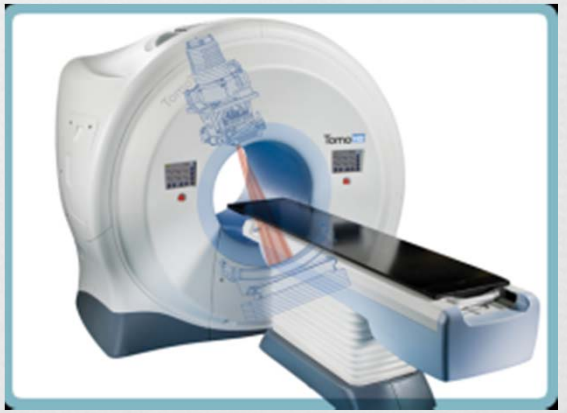
3 BBs placed during simulation
Patient skin marked



During planning, set red lasers to align with BBs

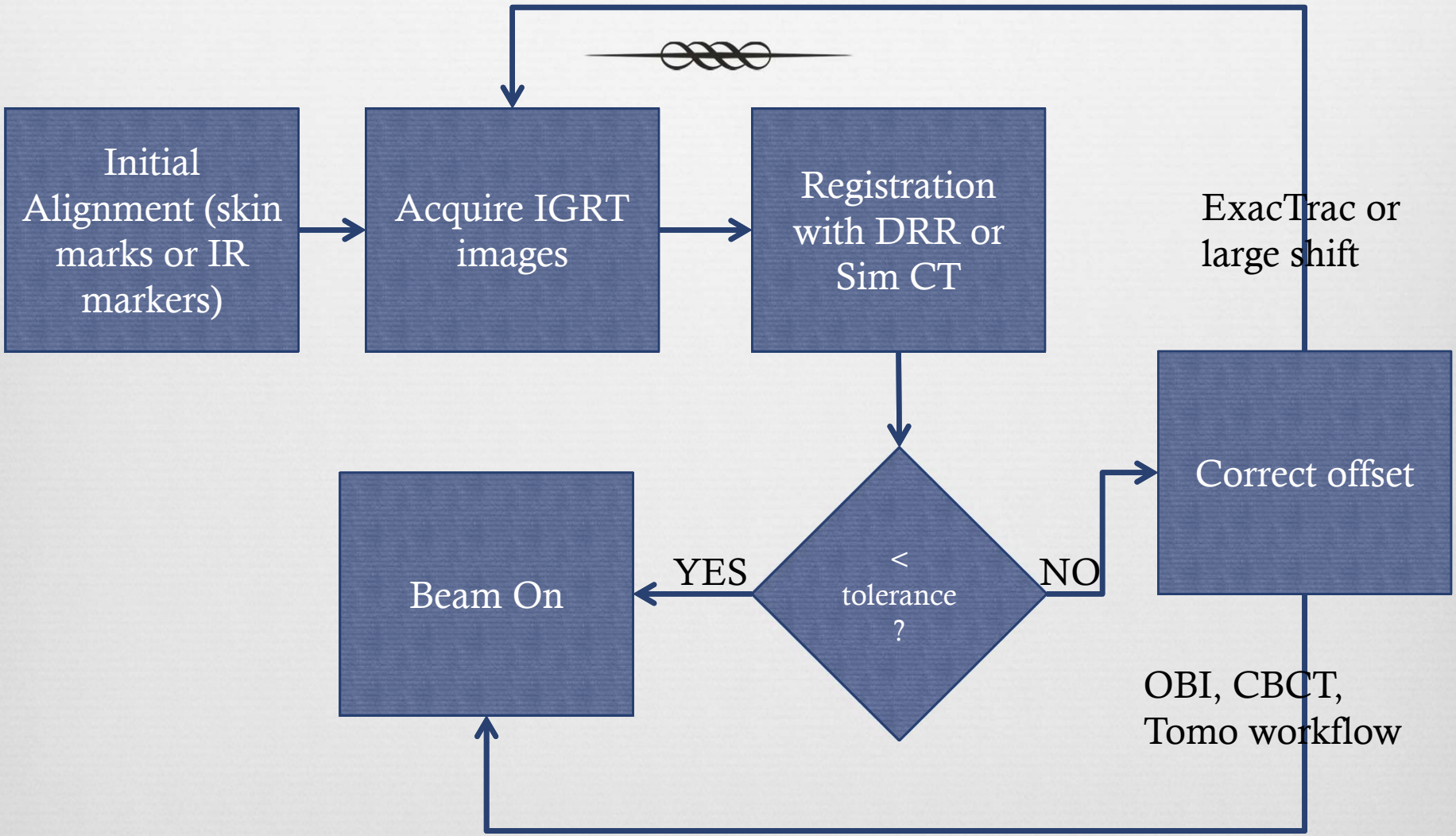


During initial setup, red lasers aligned with patient skin/mask markers



Patient position adjustment based on MVCT

IGRT Process



ExacTrac Example

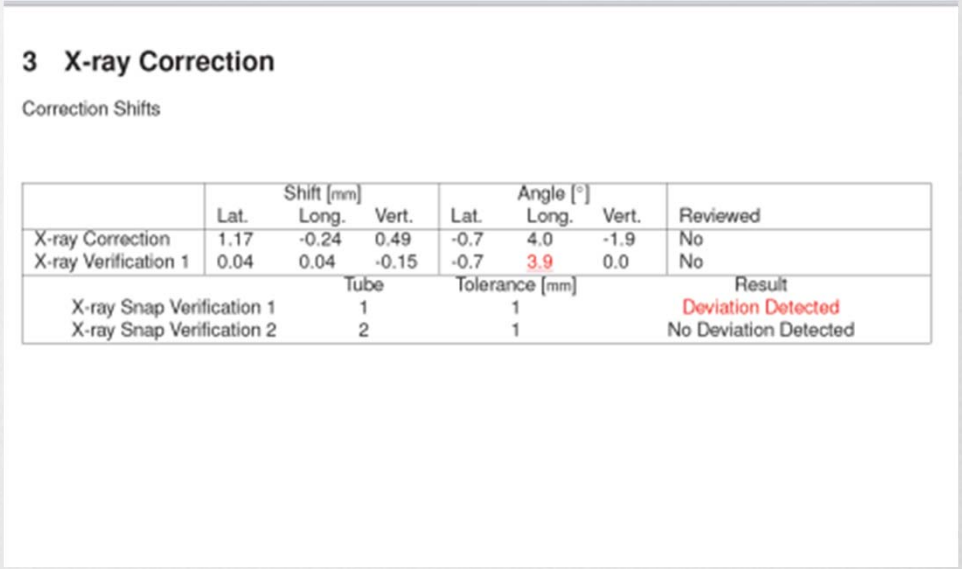
In this example ‘X-ray Correction’ was performed after initial IR marker setup.

The patient was shifted and then ‘X-ray Verification 1’ was acquired.

Snap Verification was obtained half way through treatment using tube 1 and a tolerance value of 1 mm.

The system predicted that a shift had occurred so therapists did snap verification with tube 2.

System predicted No shift based on this image.



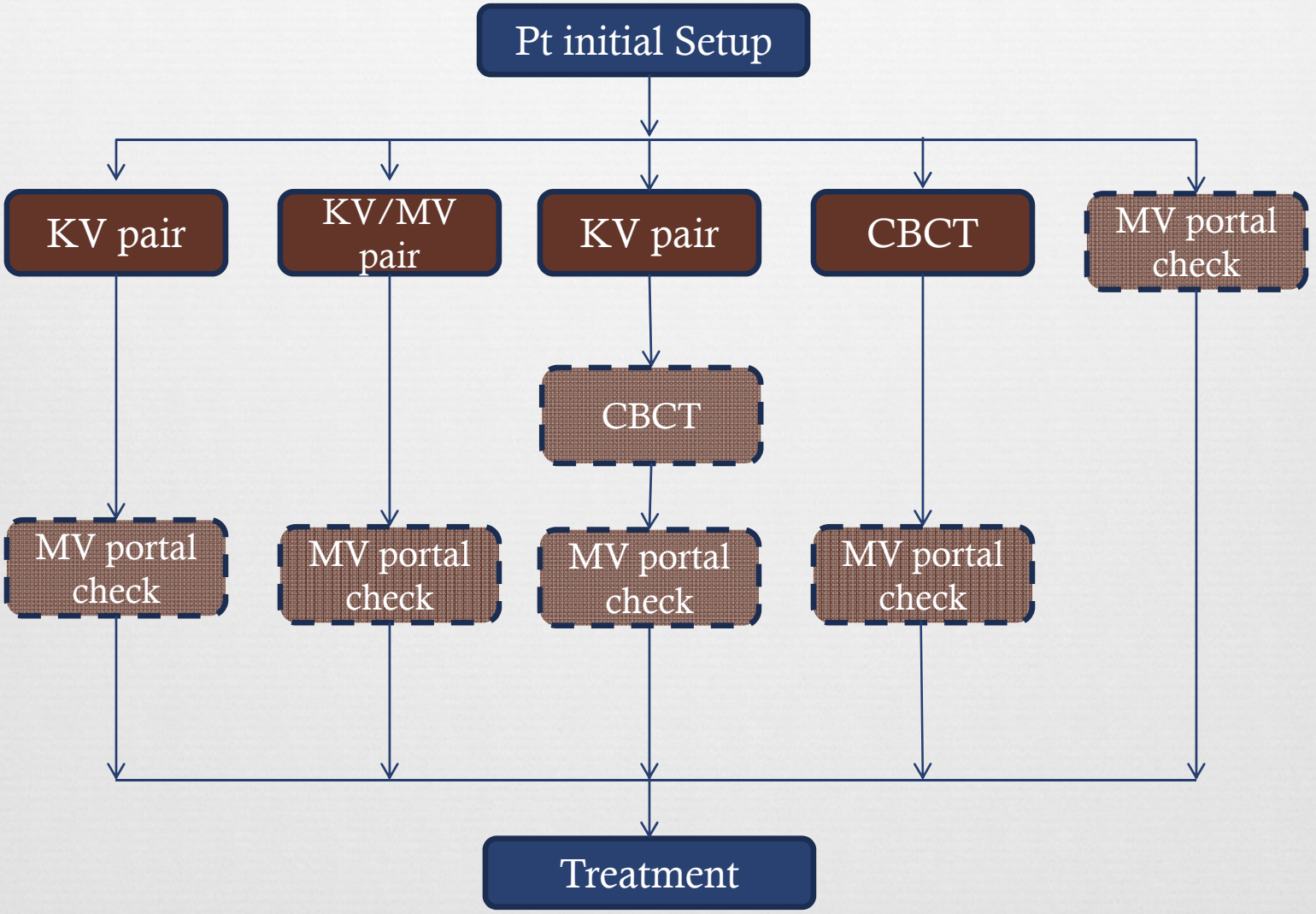
3 X-ray Correction

Correction Shifts

	Shift [mm]			Angle [°]			
	Lat.	Long.	Vert.	Lat.	Long.	Vert.	Reviewed
X-ray Correction	1.17	-0.24	0.49	-0.7	4.0	-1.9	No
X-ray Verification 1	0.04	0.04	-0.15	-0.7	3.9	0.0	No

	Tube	Tolerance [mm]	Result
X-ray Snap Verification 1	1	1	Deviation Detected
X-ray Snap Verification 2	2	1	No Deviation Detected

IGRT Workflow



Accuracy

- Image guidance accuracy is affected by:
  - Sim CT slice thickness
  - treatment image acquisition resolution
  - image quality
  - anatomy you align to (how well can you see it)
  - anatomic distortion
  - patient movement during acquisition
  - calibration and alignment of IGRT system to treatment machine

Accuracy

- Overall treatment accuracy also depends on
  - accurate target contour,
  - accurate image registration (PET, MR, etc.),
  - mechanical accuracy of the machine.
- While image registration accuracy on perfectly static anatomy ~0.3 mm, the overall best accuracy of treatment delivery is ~1.5mm on most modern gantry mounted linacs.

Accuracy

- Patients can move several mm or more following setup (before and during treatment). So treat as soon as possible following IGRT acquisition.
- Due to patient anatomic changes relative to sim, patient movement between treatments and within treatments, uncertainty in image fusion and mechanical accuracy of linacs the extra-cranial treatment accuracy is probably not better than 2mm and may be much worse in some cases.

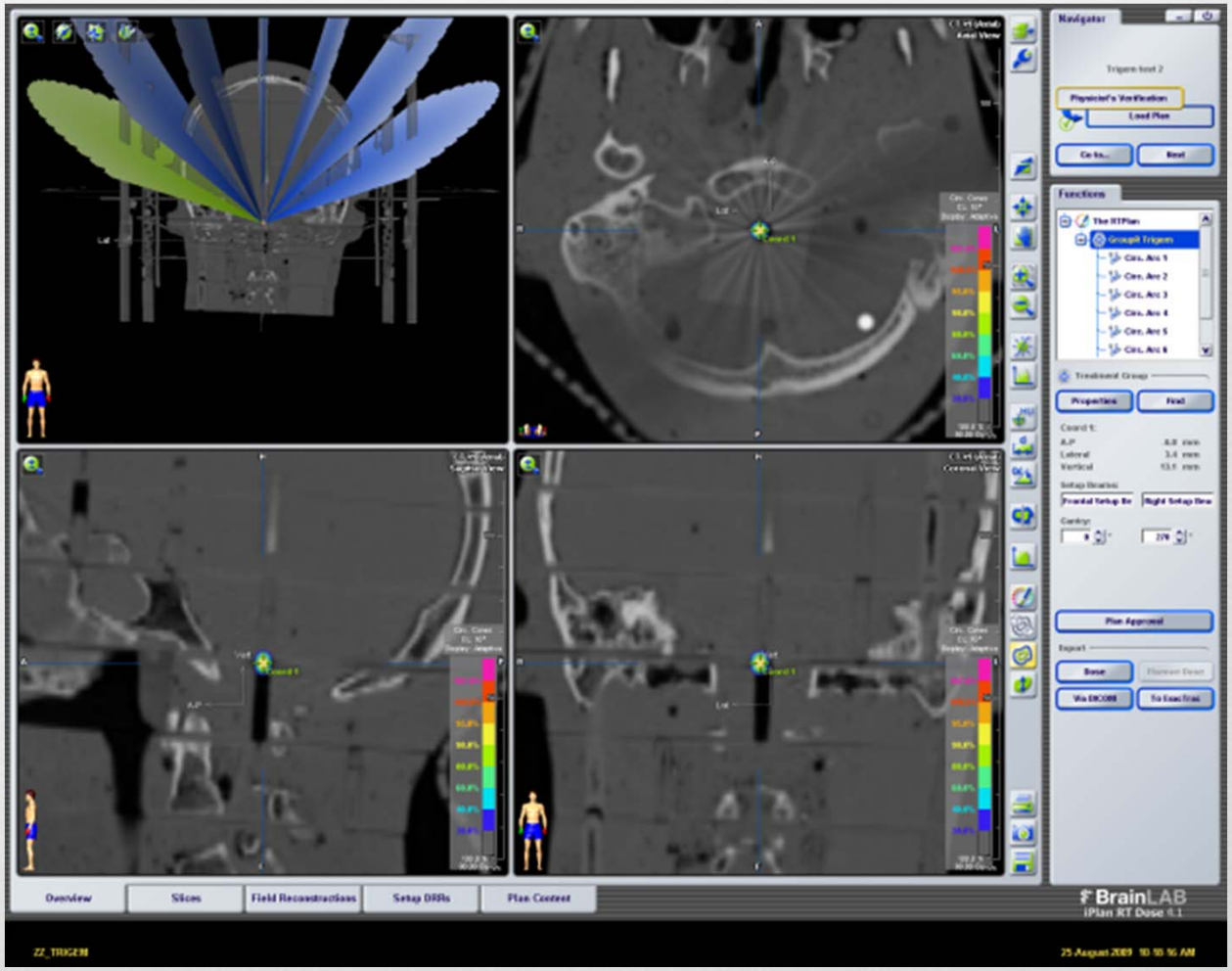
How accurate are you? End-to-End Test

At least annually we perform an end-to-end test on Novalis Tx.

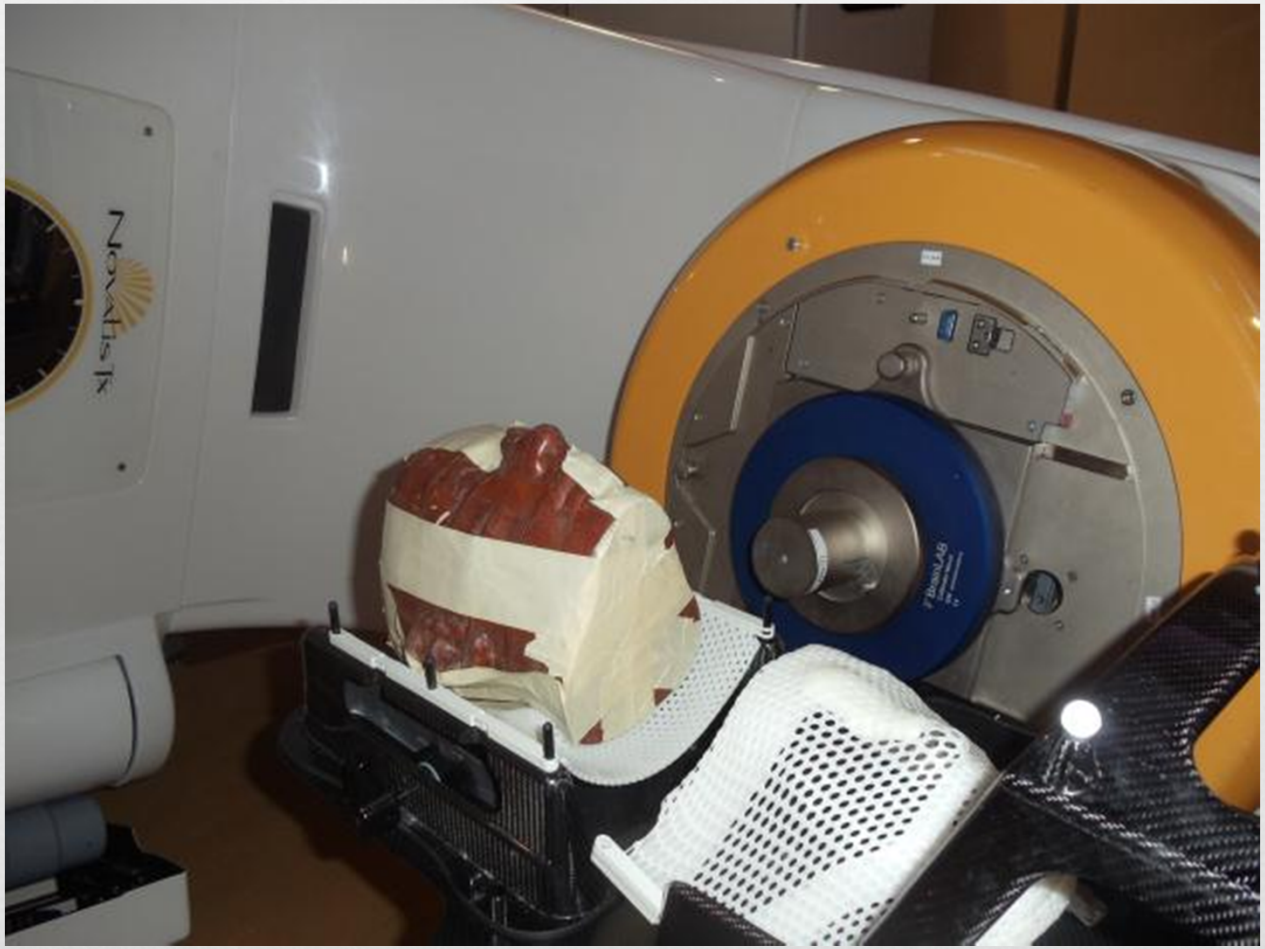
Scan a skull phantom with embedded target next to film.

Create clinically relevant plan (e.g. TGN plan). Deliver plan to phantom using same IGRT method as used for patients.

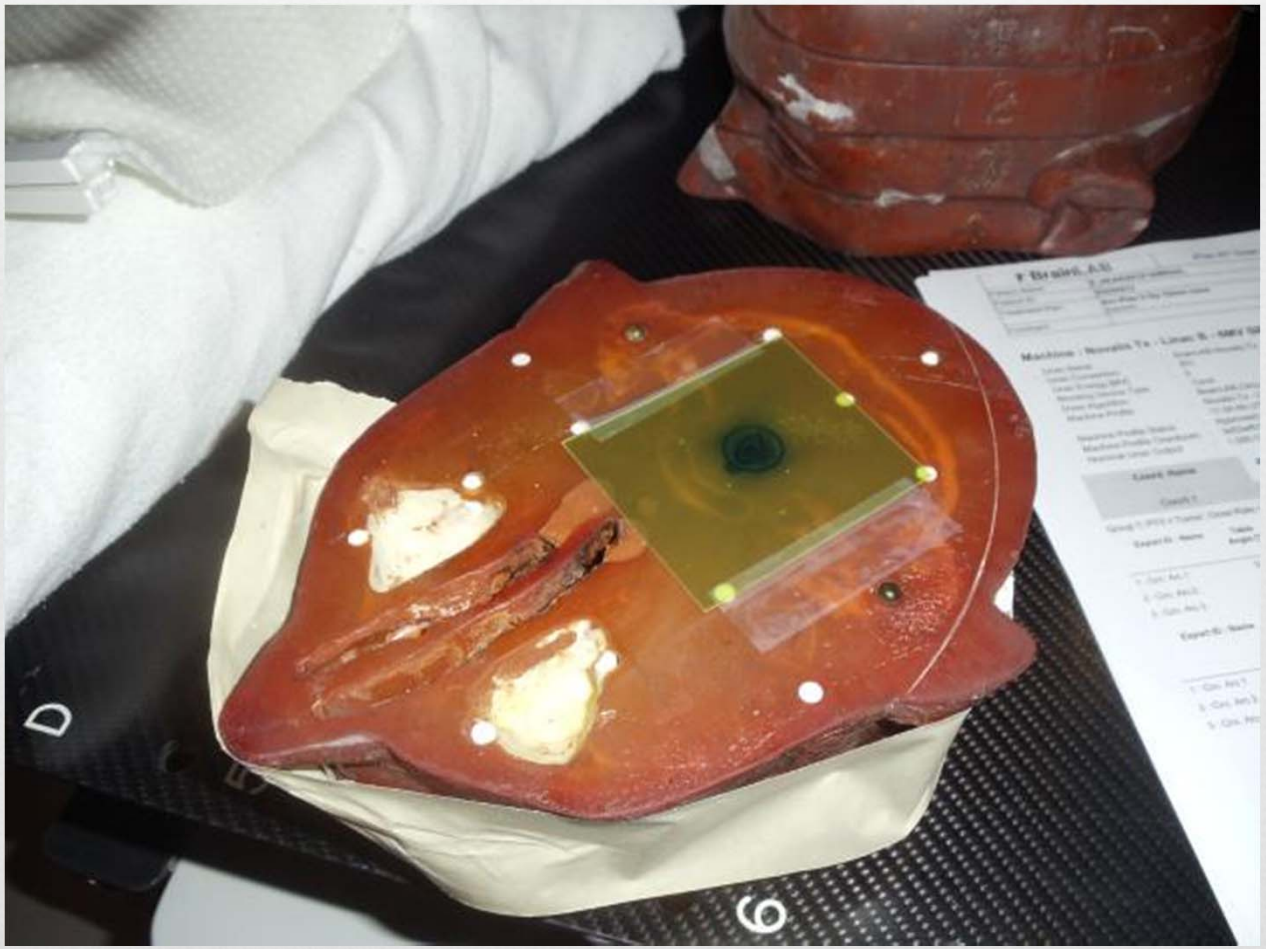
Measure distance from target to dose distribution on film.



End-to-End Test



End-to-End Test



How accurate are we?

Ink mark shows actual target location.

Field location ~0.5mm offset from target in this plane.

Typically ≤ 0.8mm.

The Future

Quiz

- You want to treat a liver met patient with SBRT. The patient does NOT have implanted fiducials. What machine would you chose to treat on and what IGRT method would you use on that machine?
- What IGRT tolerance for translations will you accept?