Use of Image Registration and Fusion Algorithms and Techniques in Radiotherapy

Preliminary Recommendations from TG 132*

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*Report is currently under review by AAPM

Disclosure

- Kristy Brock: RaySearch Licensing
- Sasa Mutic: ViewRay Shareholder, Modus licensing agreement, Varian research and licensing, Radialogica Shareholder, Treat Safely Partner
- Todd McNutt: Philips Collaboration, Elekta Licensing
- Hua Li: Philips Research
- Marc Kessler: Varian research and co-development agreements

Learning Objectives

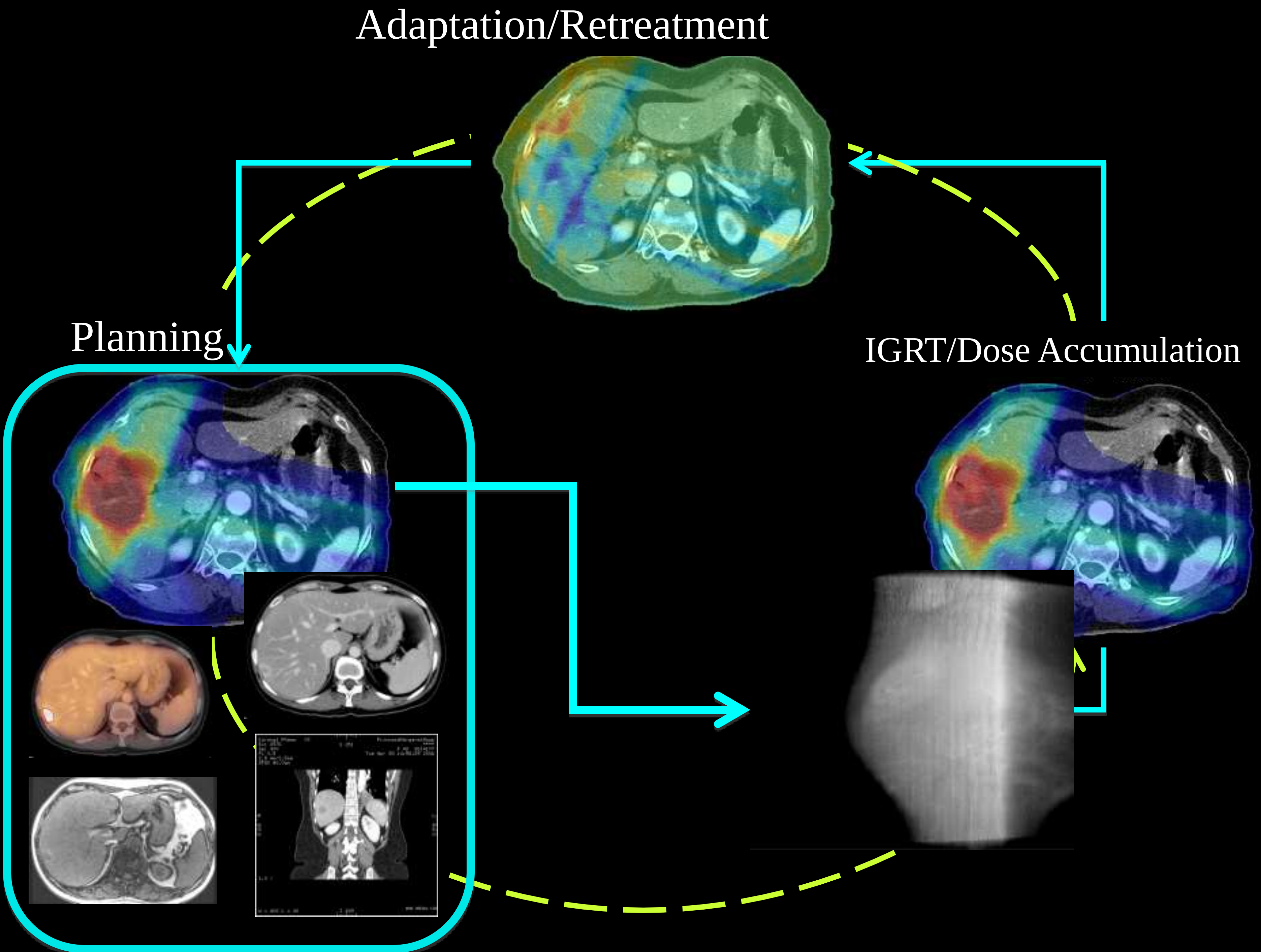
1. Understand the importance of acceptance testing, including end-to-end tests, phantom tests, and clinical data tests.
2. Describe the methods for validation and quality assurance of image registration techniques.
3. Describe techniques for patient specific validation.

Task Group Charge

1. Review the existing techniques and algorithms for image registration and fusion
2. Discuss issues related to effective clinical implementation of these techniques and algorithms in a variety of treatment planning and delivery situations
3. Discuss the methods to assess the accuracy of image registration and fusion
4. Discuss issues related to acceptance testing and quality assurance for image registration and fusion

Outline

- Importance of commissioning for image registration
- Methods for commissioning and clinical validation
- Example clinical workflow
- Q&A


Adaptation/Retreatment
Planning
IGRT/Dose Accumulation

Importance of Commissioning

- Implementation effects accuracy[1,2]
  - Cannot infer accuracy based on other studies

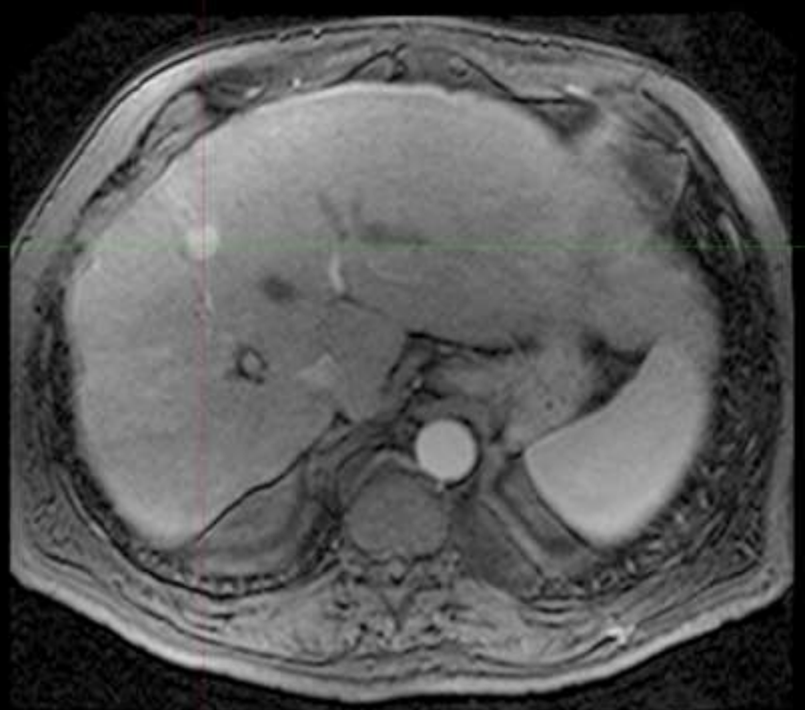
Potential Risks of Uncertainties

- Deformable registration is not 'always better' than rigid
  - More degrees of freedom = more potential for error

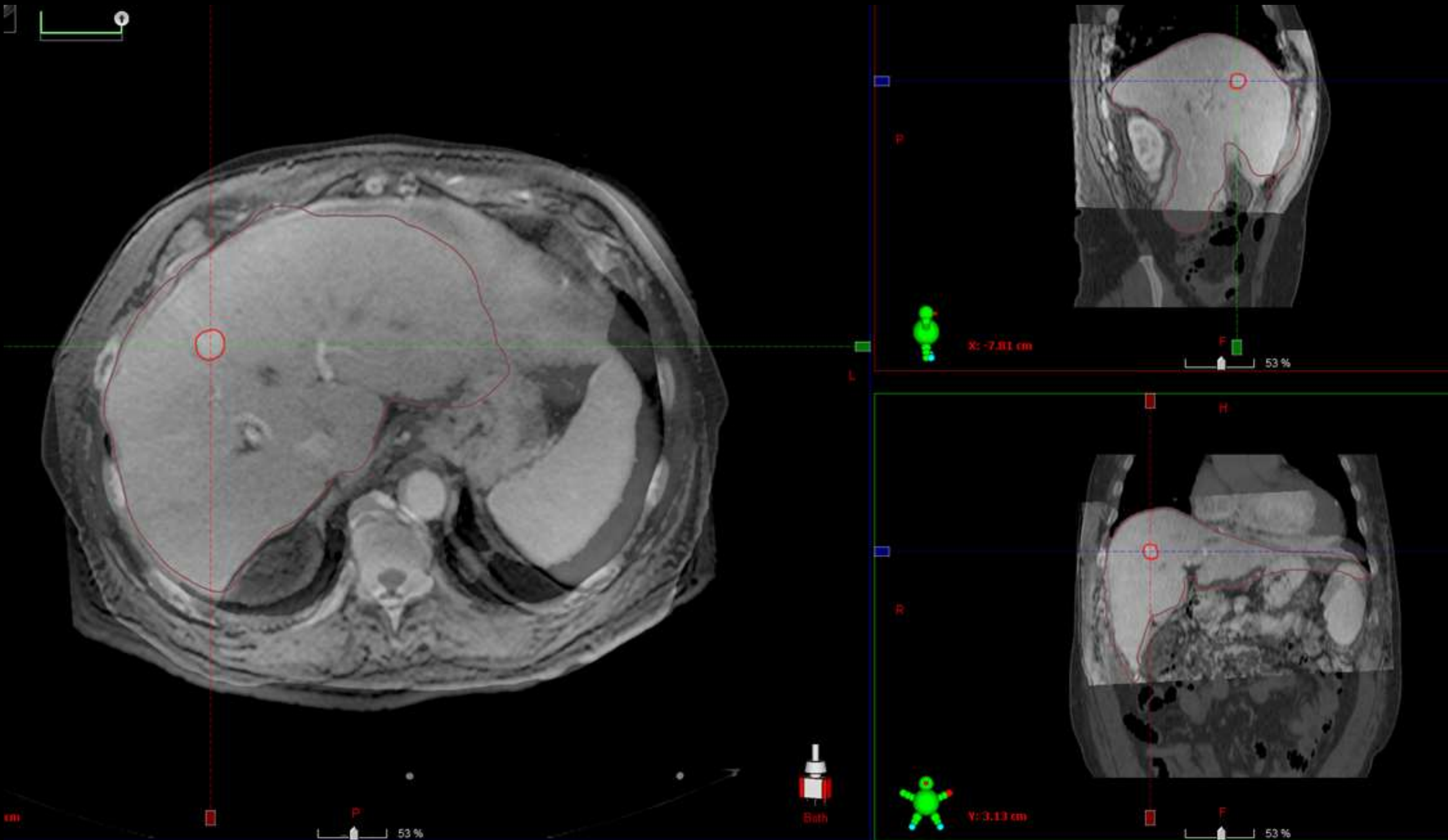
1. Kashani, Med Phs, 2008; 2. Brock IJROBP, 2009

Example: Multi-modality imaging for Planning

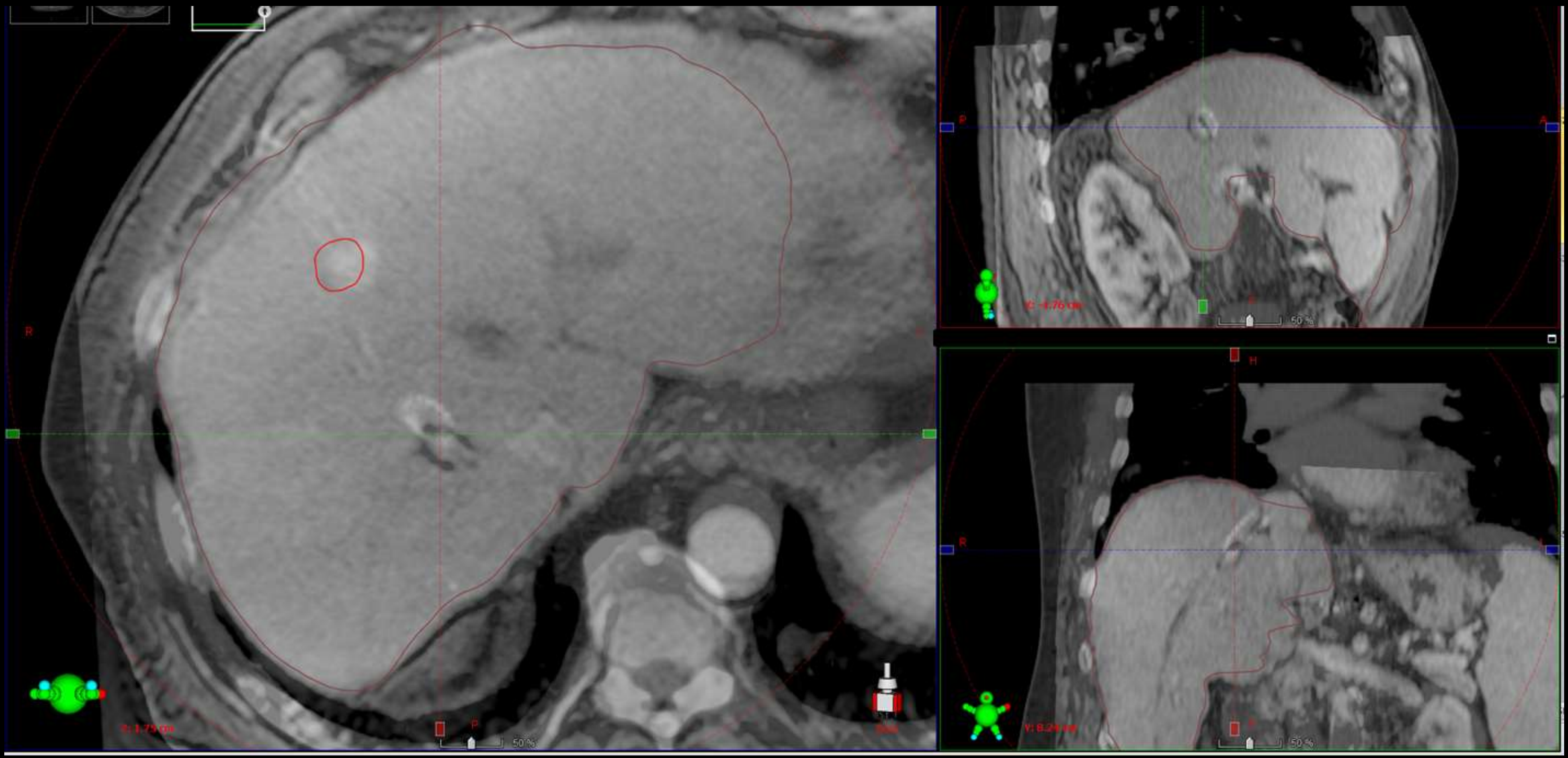
Liver: CT (No Contrast = No visible GTV)



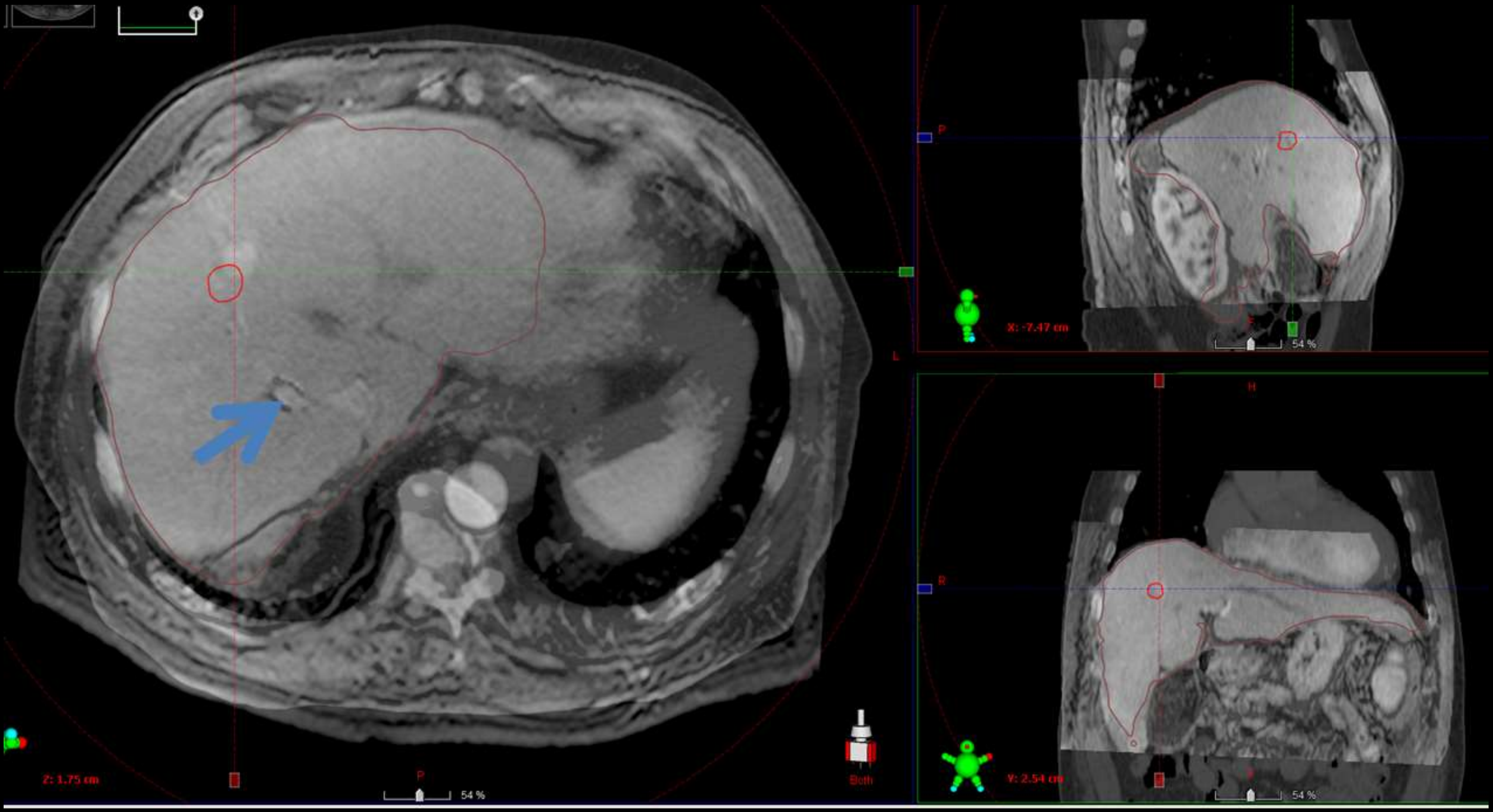
Liver: MR (Visible GTV)



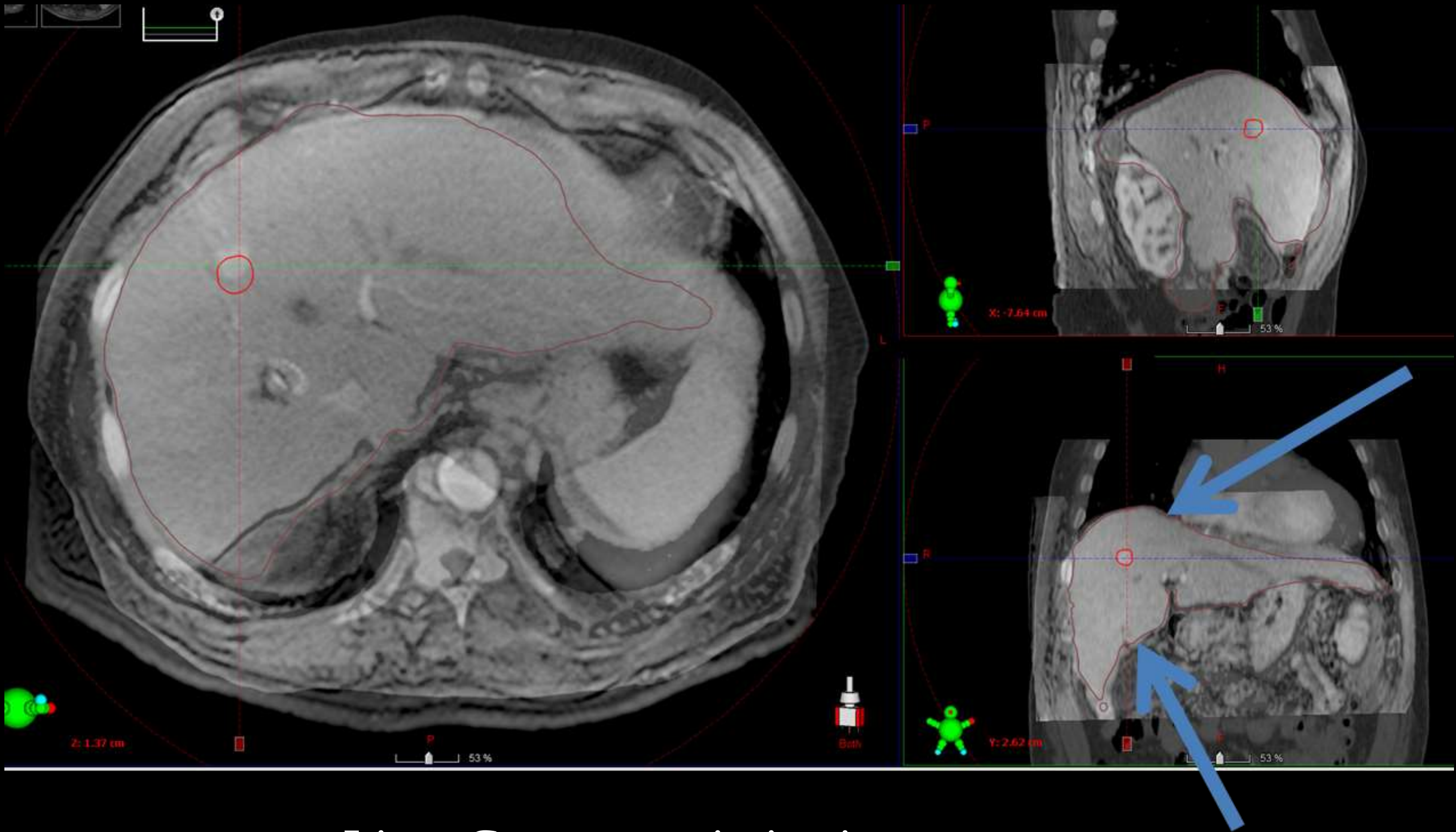
Clinical Registration
X: 26.1mm Y: 119.8mm Z: -12.6mm
X: 1.9deg Y: -2.9deg Z: -4.6deg



Auto, liver last step
X: 25.6mm Y: 120.8mm Z: -26.1mm
X: -1.5deg Y: 2.5deg Z: -3.4deg

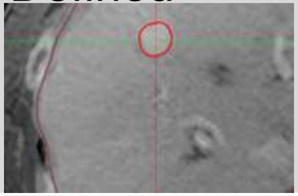
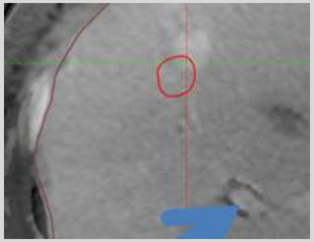


Nearby Structure Map
X: 14.5mm Y: 122.3mm Z: -26.1mm
X: -1.5deg Y: 2.5deg Z: 4.1deg

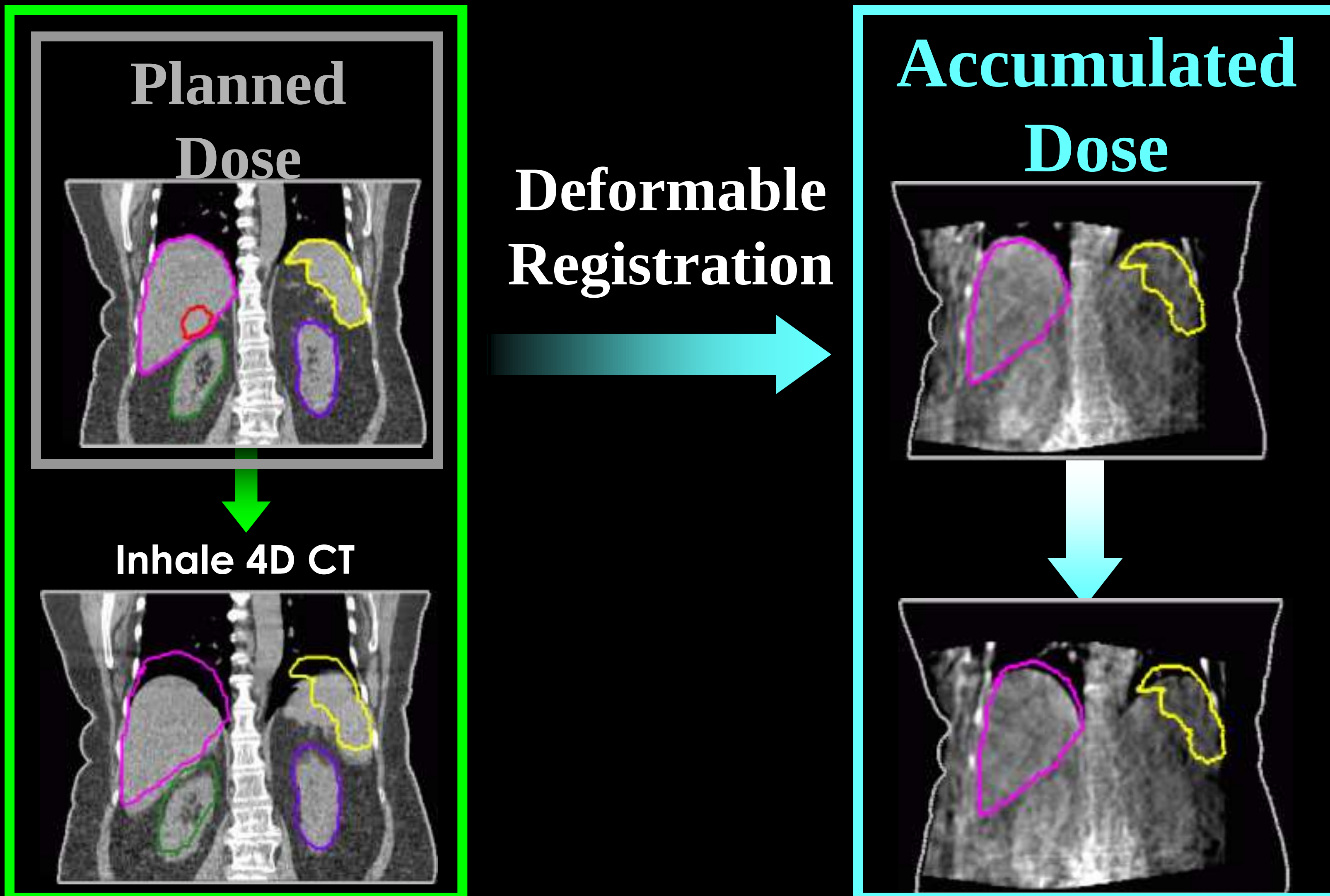


Liver Contour optimization
X: 13.0mm Y: 125.3mm Z: -19.0mm
X: 0.4deg Y: -1.3deg Z: 2.3deg

Overall Comparison [mm, Degrees]

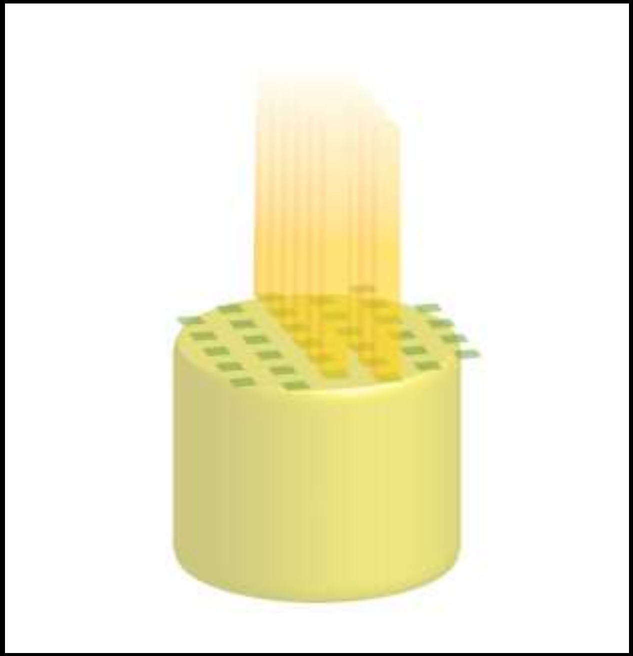
Registration	dX	dY	dZ	X_{ROT}	Y_{ROT}	Z_{ROT}	Overlap
Clinical	26.1	119.8	12.6	1.9	-2.9	-4.6	Defined 
Auto	25.6	120.8	-26.1	-1.5	2.5	-3.4	
Vessel	14.5	122.3	26.1	-1.5	2.5	4.1	
Boundary	13.0	125.3	19.0	0.4	-1.3	2.3	

Example: Dose Accumulation

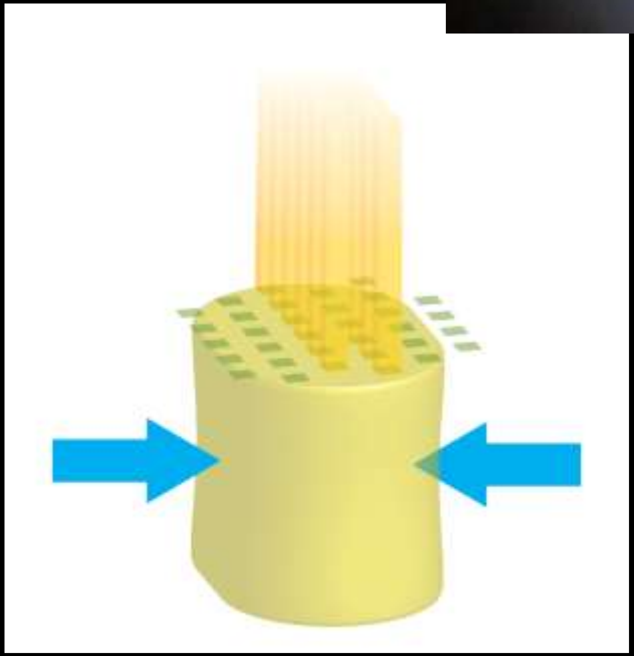


New method to validate Deformable Image Registration

Deformable 3D Presage dosimeters



Control
(No Deformation)



Deformed
(27% Lateral Compression)

Slides Courtesy of Mark Oldham and Shiva Das

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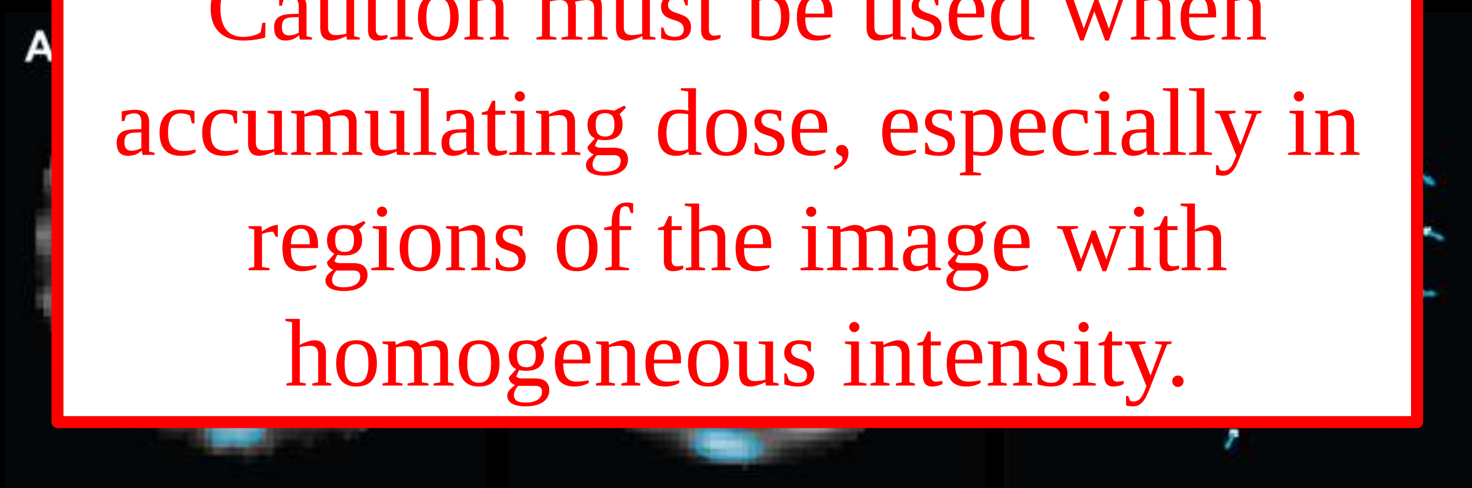
Dosimeter & Deformable Registration-based Dose Accumulation: Dose Distributions

Field Shape Differences

DVF-based



Caution must be used when accumulating dose, especially in regions of the image with homogeneous intensity.

Slides Courtesy of Mark Oldham and Shiva Das

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Validation and QA

How do we Prove it is Reliable?

Commissioning is Important!

- LINAC
  - Know how it works

Why is this particularly challenging for deformable registration?

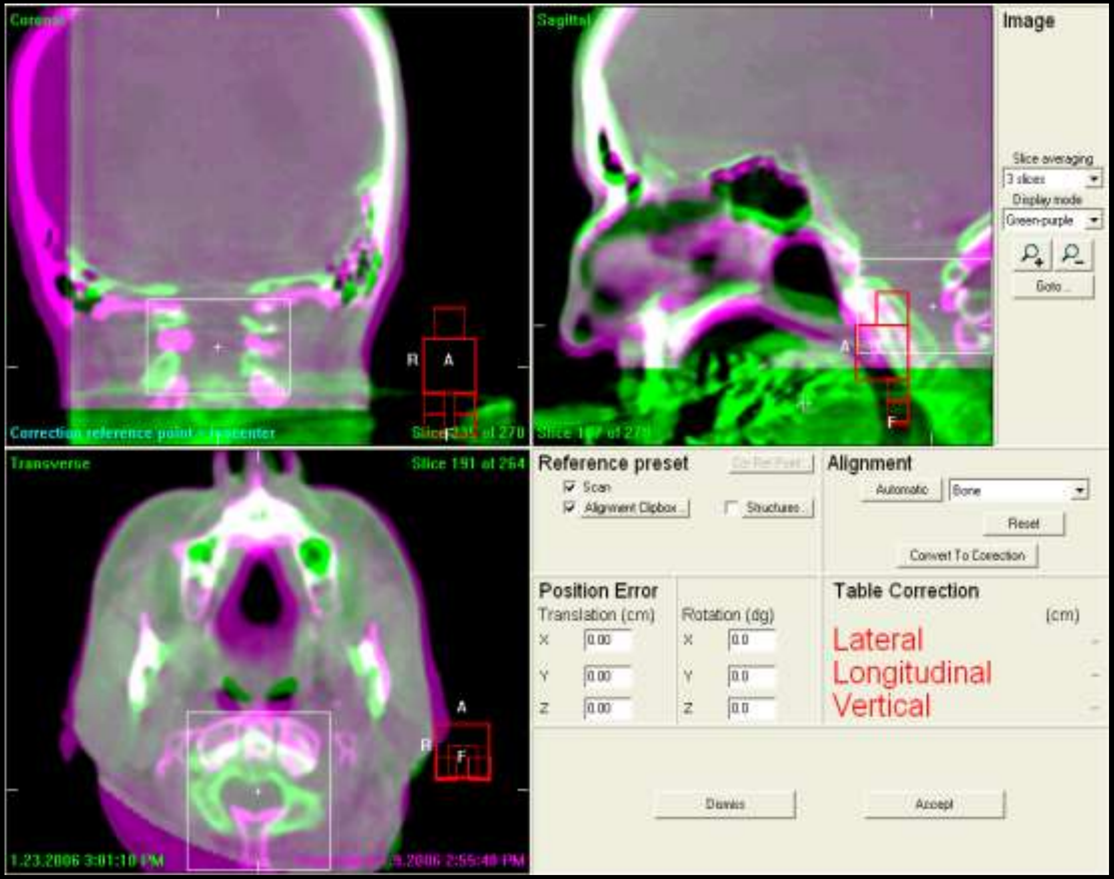
• Algorithms typically don't rely on fundamental physics related to the human anatomy/physiology

- Deformable Registration Algorithm
  - **Find out how it works!**
  - **Accept and Commission the software**
  - **Perform an end-to-end test in your clinic**

Visual Verification

Excellent tool for established techniques

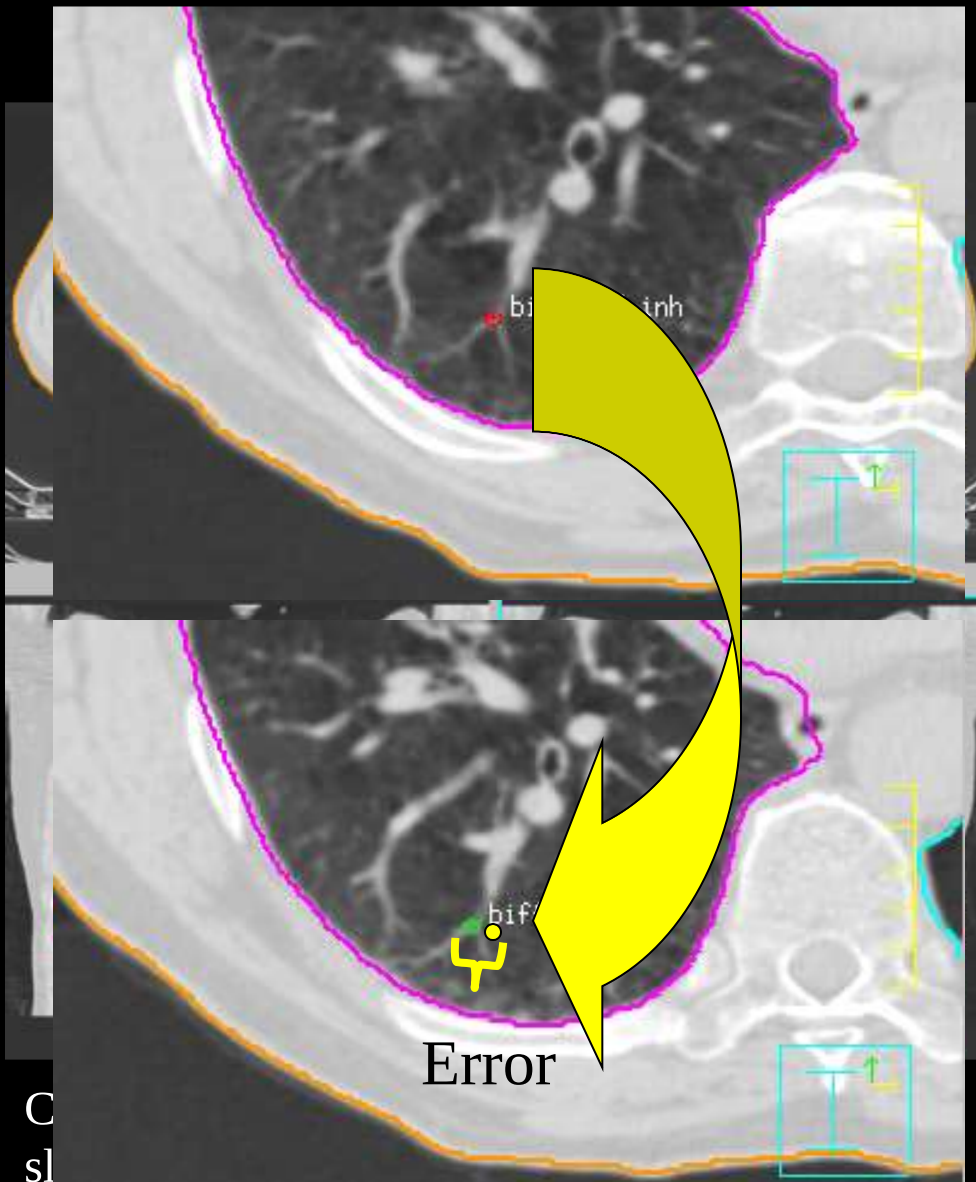
Not enough for Commissioning



Validation Techniques

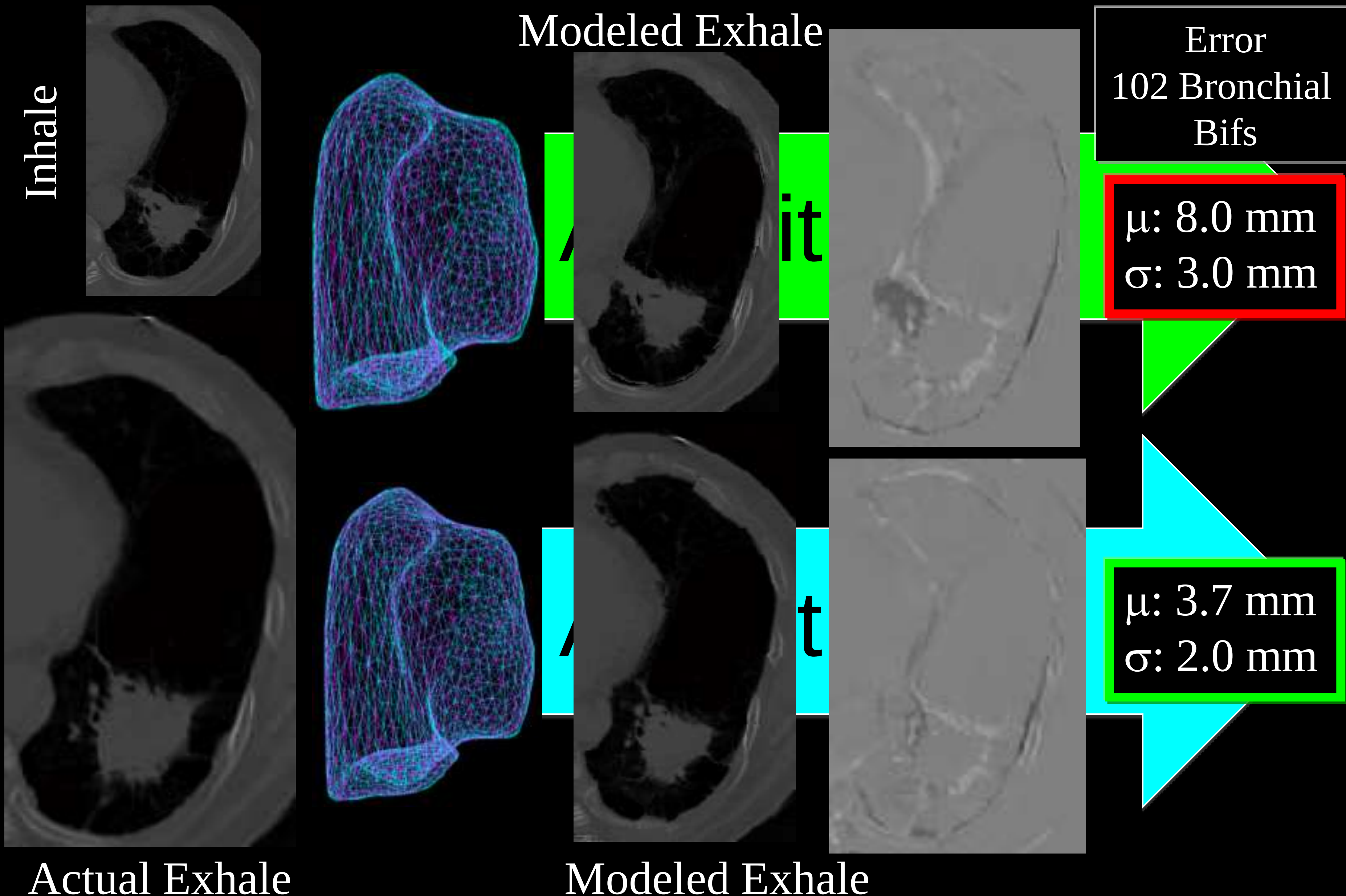
- Matching Boundaries
  - Does the deformable registration map the contours to the new image correctly?
- Volume Overlap
  - DICE, etc
- Intensity Correlation
  - Difference Fusions
  - CC, MI, etc
- Digital/Physical Phantoms
- Landmark Based
  - TRE, avg error, etc

Landmark Based

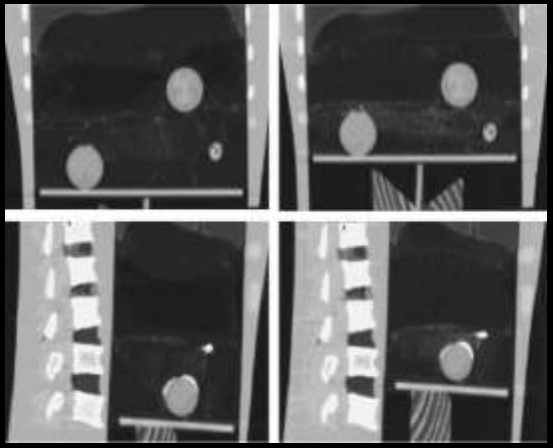


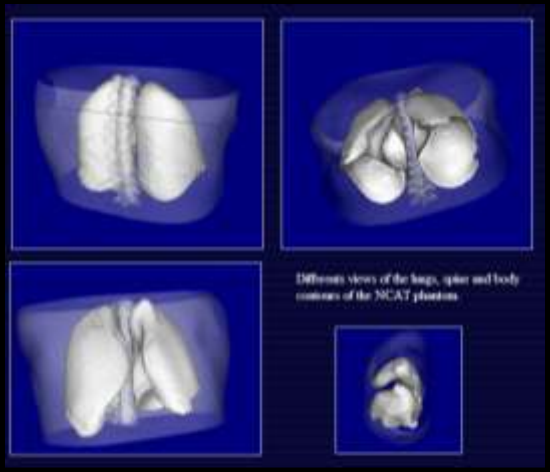
- Reproducibility of point identification is sub-voxel
  - Gross errors
  - Quantification of local accuracy within the target
  - Increasing the number increases the overall volume quantification
- Manual technique
- Can identify max errors

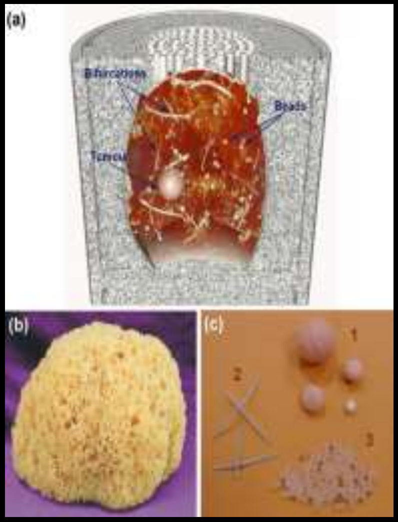
Does Contour Matching Prove Reliability?



Digital or Physical Phantoms



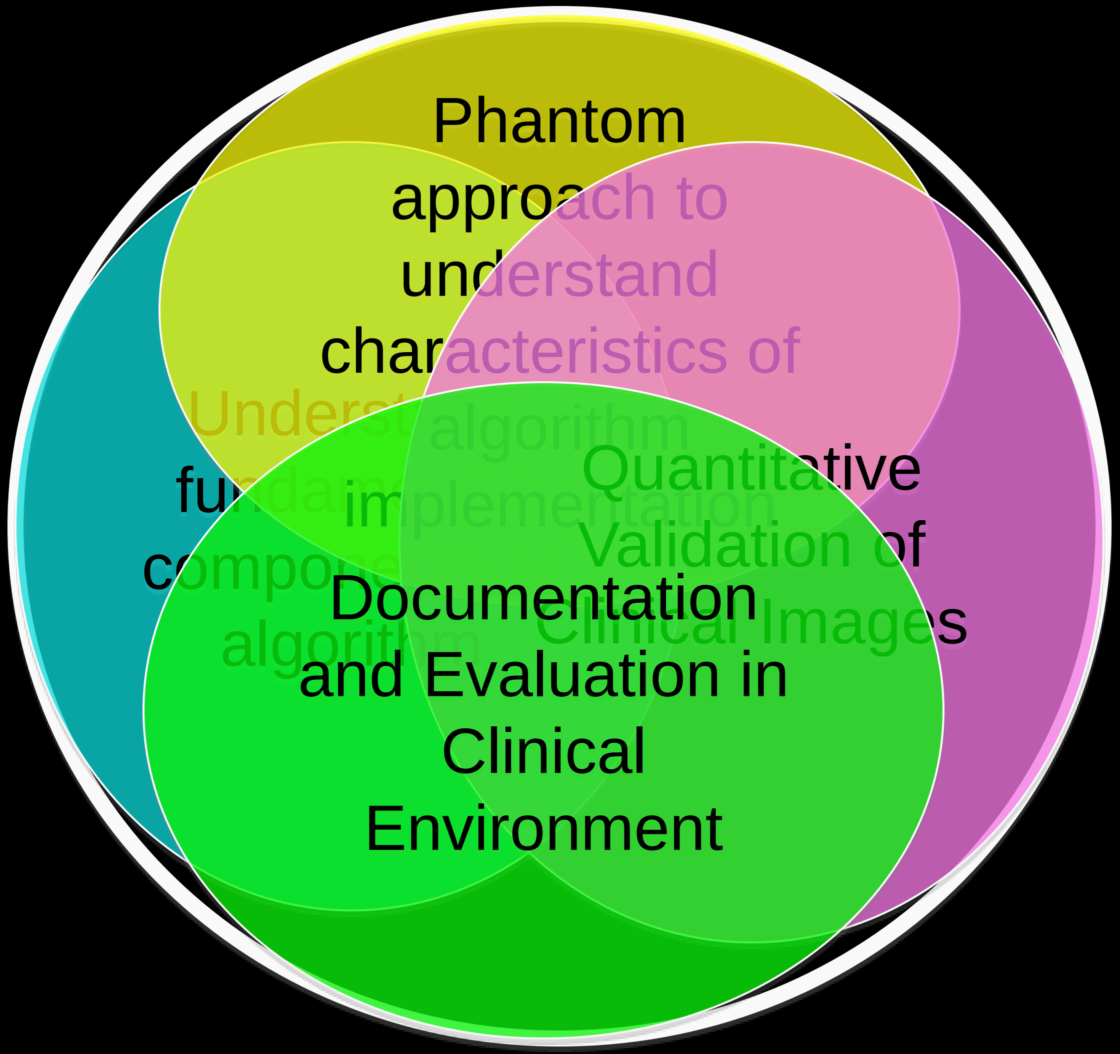




- NCAT Phantom
- U of Mich lung phantom (Kashani, Balter)
- McGill lung phantom (Serban)
- Can know the true motion of all points
- Doesn’t include anatomical noise and variation, likely not as complex as true anatomical motion
- Does give a ‘best case’ scenario for similarity/geometric defm reg algorithms

Commissioning and QA

Understand the whole picture



Validation Tests and Frequencies

Frequency	Quality Metric	Tolerance
Acceptance and Commissioning Annual or Upon Upgrade	System end-to-end tests Data Transfer (including orientation, image size, and data integrity) Using physics phantom	Accurate
	Rigid Registration Accuracy (Digital Phantoms, subset)	Baseline, See details in Table Z
	Deformable Registration Accuracy (Digital Phantoms, subset)	Baseline, see details in Table Z
	Example patient case verification ((including orientation, image size, and data integrity) Using real clinical case	Baseline, see details in Table Z

Validation Tests and Frequencies

Frequency	Quality Metric	Tolerance
Each Patient	Data transfer	Accurate
	Patient orientation	Image Data matches specified orientation (Superior/Inferior, Anterior/Posterior, Left/Right)
	Image size	Qualitative – no observable distortions, correct aspect ratio
	Data Integrity and Import	User defined per TG53 recommendations
	Contour propagation	Visual confirmation that visible boundaries are within 1-2 voxels of contours; documentation of conformity and confidence
	Rigid registration accuracy	At Planning: confirmation that visible, relevant boundaries are within 1-2 voxels; additional error should feed into margins At Tx: confirmation that visible boundaries are within PTV/PRV margins (doesn't account for intrafraction motion)
	Deformable registration accuracy	At Planning: confirmation that visible, relevant boundaries and features are within 1-2 voxels; additional error should feed into margins At Tx: confirmation that visible boundaries are within PTV/PRV margins (doesn't account for intrafraction motion)

Commissioning Datasets*

- Basic geometric phantoms (multi-modality)[1]
- Pelvis phantom (CT and MR)[1]
- Clinical 4D CT Lung[2] with simulated exhale[1]

*To be made publically available following the approval of TG 132 by AAPM

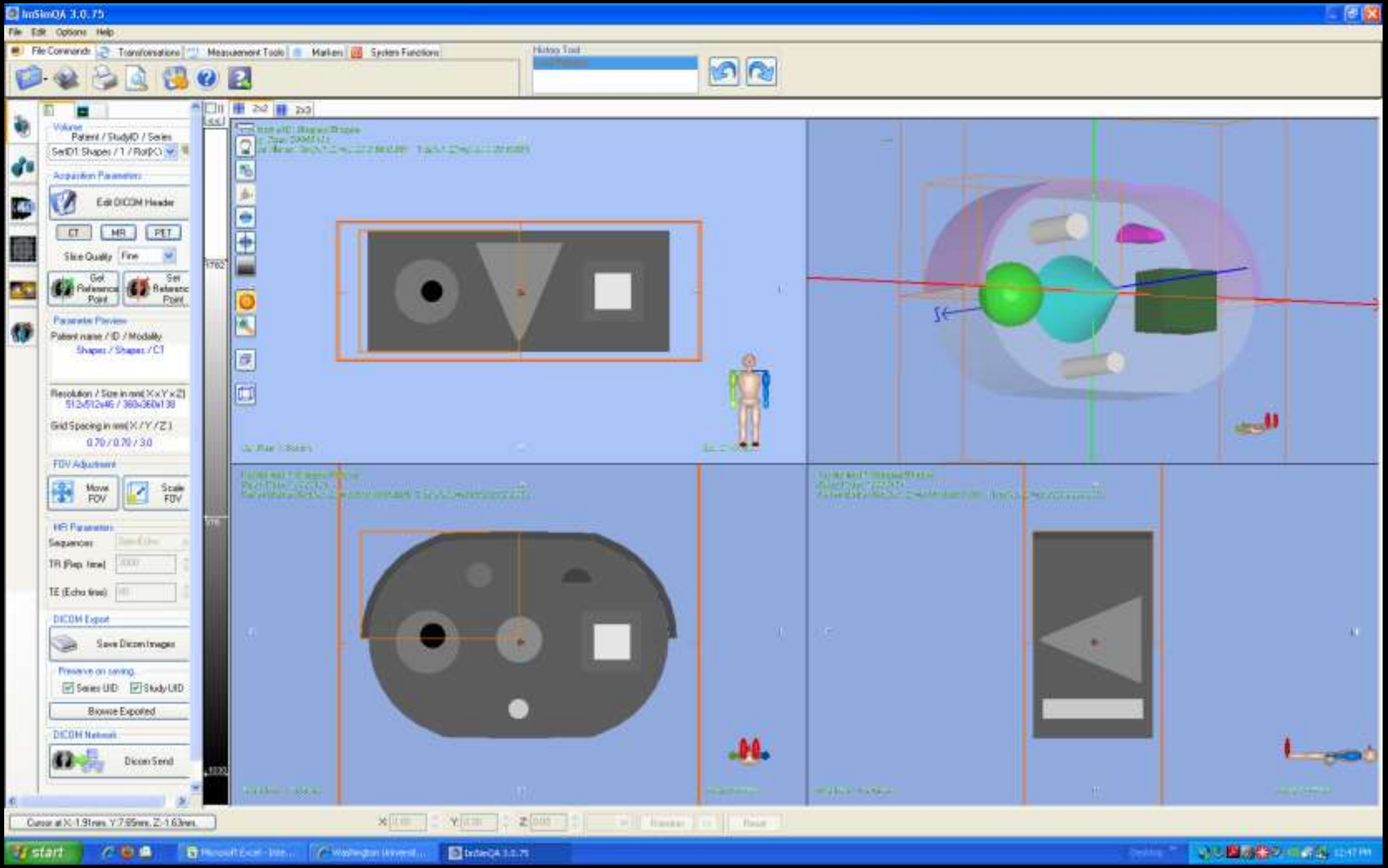
1. Courtesy of ImSim QA
2. Courtesy of DIR Lab, MD Anderson Cancer Center

Why Virtual Phantoms

- Known attributes (volumes, offsets, deformations, etc.)
- Testing standardization – we all are using the same data
- Geometric phantoms – quantitative validation
- Anthropomorphic – realistic and quantitative

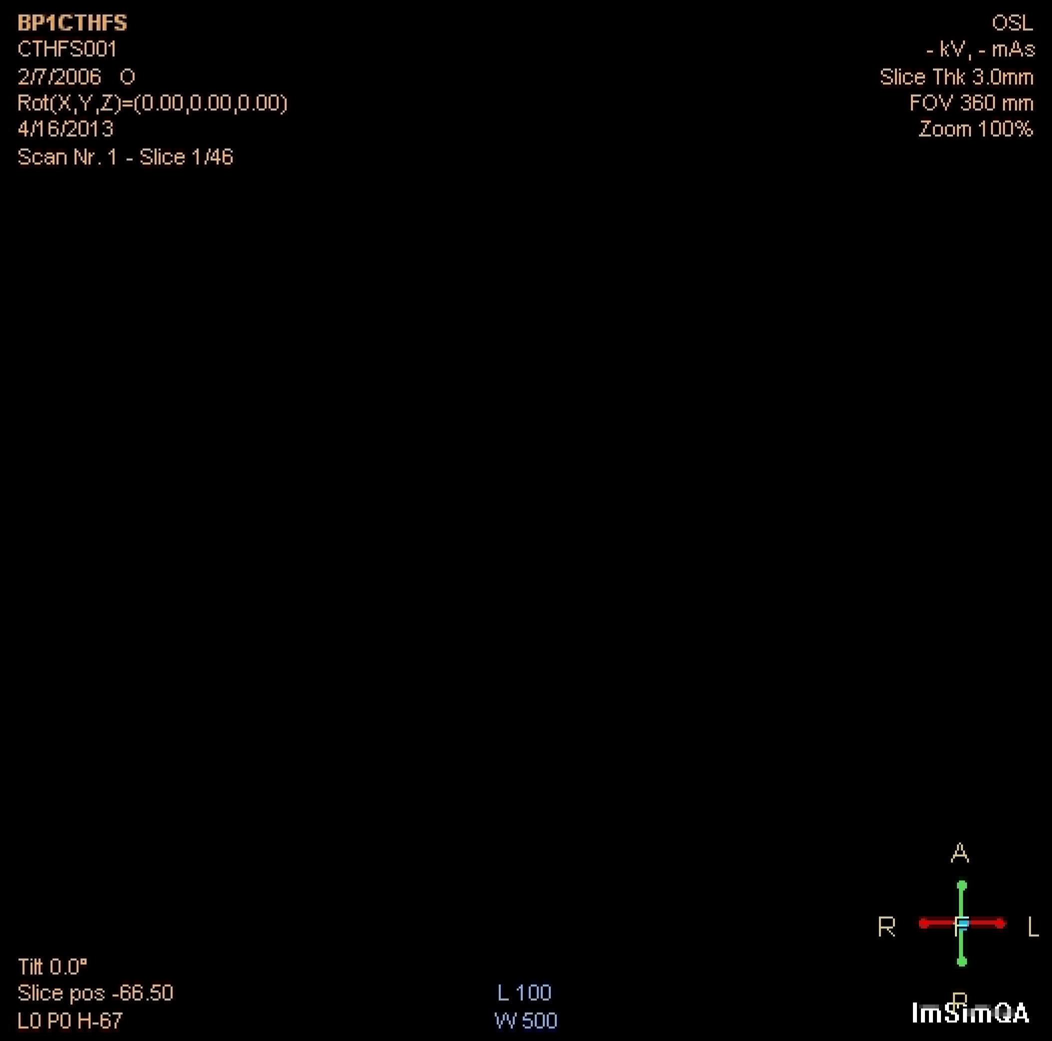
Still need end-to-end physical images

Example Digital Phantoms
Provided by the TG-132 via ImSimQA

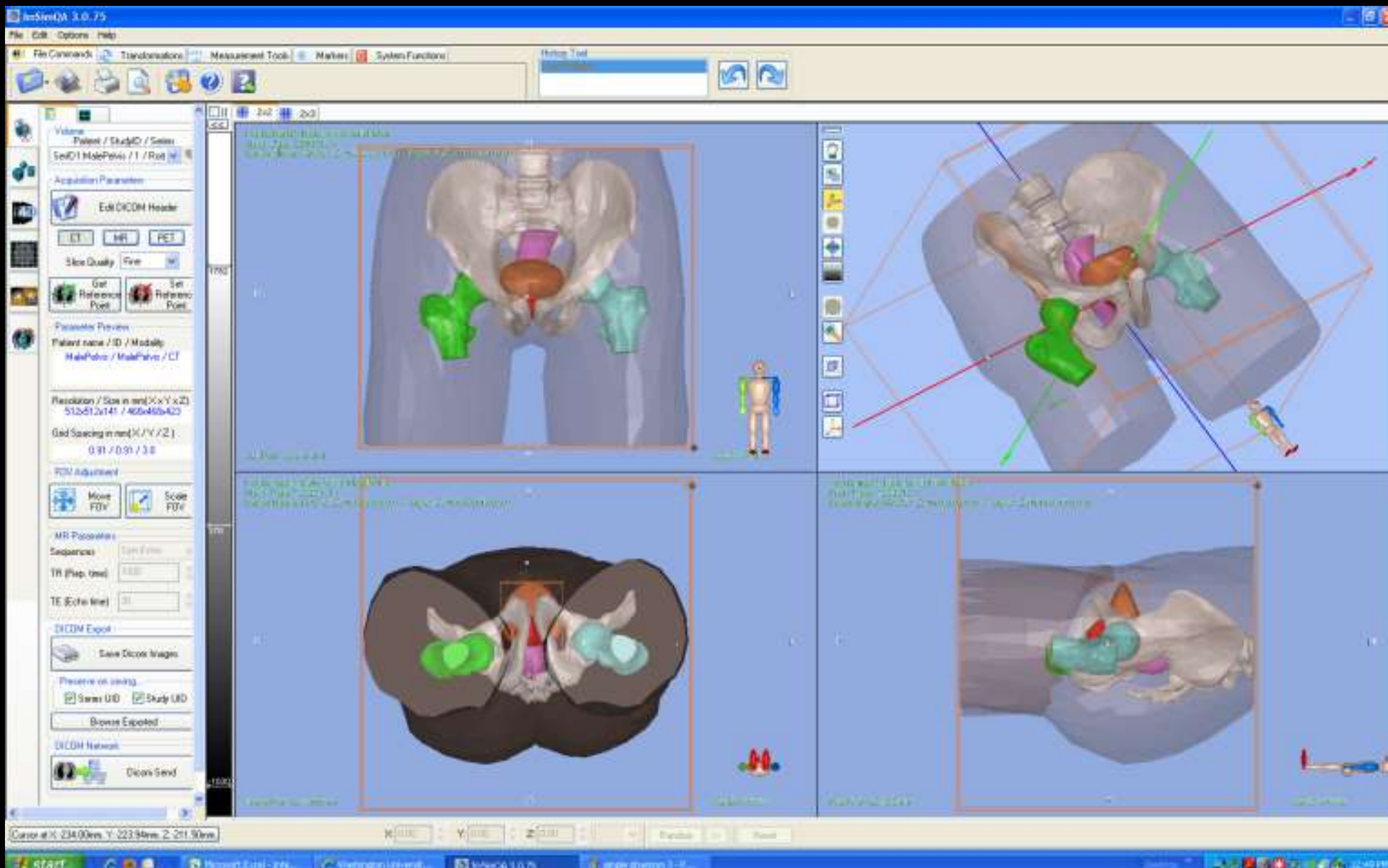


Example Digital Phantoms

Provided by the TG-132 via ImSimQA

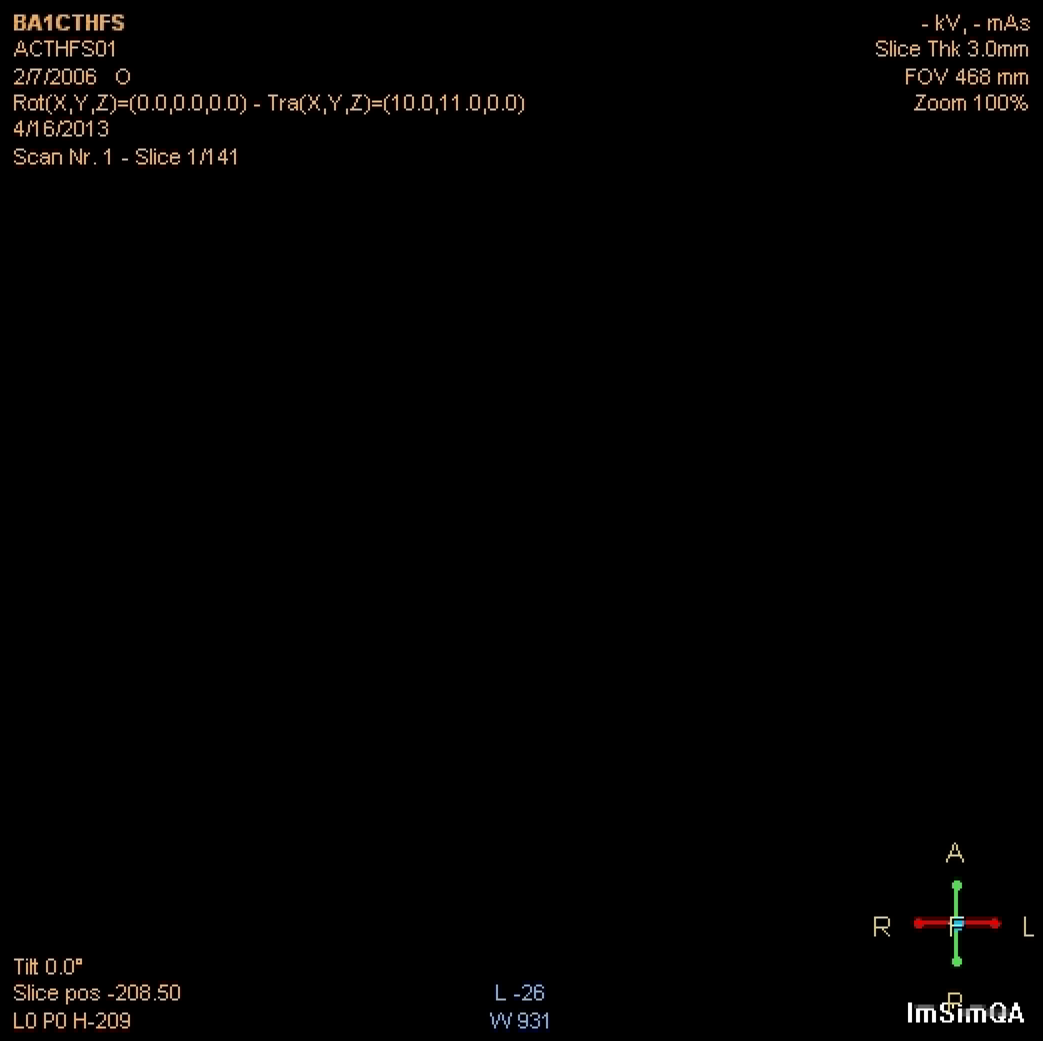


Example Digital Phantoms
Provided by the TG-132



Example Digital Phantoms

Provided by the TG-132



Recommended Tolerances for the Digital Phantom Test Cases

PHANTOM AND TEST	TOLERANCE
Basic geometric phantom registration	
Scale – Dataset 1	0.5 * voxel (mm)
Voxel value – Dataset 1	Exact
Registration – Datasets 2, 3, 4, 5, 6	0.5 * voxel (mm)
Contour propagation – Datasets 2, 3, 4, 5, 6	1 * voxel (mm)
Orientation – Datasets 2, 3, 4, 5, 6	Correct
Basic anatomical phantom registration	
Orientation - Datasets 1, 3, 4	Correct
Scale - Data sets 1, 3, 4	0.5 * voxel (mm)
Voxel value - Datasets 1, 2, 3, 4, 5	± 1 nominal value
Registration - Datasets 2, 3, 4, 5	0.5 * voxel (mm)
Contour propagation - Datasets 2, 3, 4, 5	1 * voxel (mm)
Basic deformation phantom registration	
Orientation - Dataset 2	Correct
Registration - Dataset 2	95% of voxels within 2 mm, max error less than 5 mm
Sliding deformation phantom registration	
Orientation - Dataset 2	Correct
Scale - Dataset 2	0.5 * voxel (mm)
Registration - Dataset 2	95% of voxels within 2 mm, max error less than 5 mm
Volume change deformation phantom registration	
Orientation - Dataset 2	Correct
Scale - Dataset 2	0.5 * voxel (mm)
Registration - Dataset 2	95% of voxels within 2 mm, max error less than 5 mm

Example Clinical Workflow

- Clinic purchased a stand-alone deformable registration system to enable MR-CT registration for SBRT Liver
- Commissioning
- Clinical case validation
- Clinical workflow
- Patient specific QA

Evaluate Registration Products

- Learn how the different solutions work
- Talk to users
- Evaluate clinical integration and flexibility
- Purchase

Commissioning

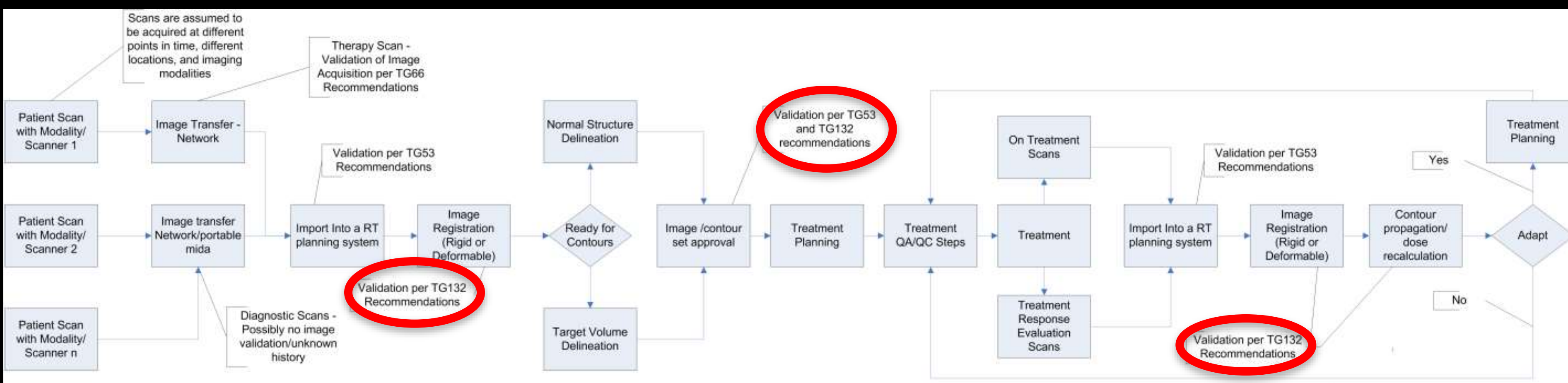
- Perform end-to-end test with physical phantom
- Download electronic phantom datasets from TG 132
  - Perform baseline commissioning
- Use ~ 10 retrospective clinical cases to quantitatively assess accuracy

Clinical Integration

1. Clear guidelines are provided to the personnel implementing the image registration and fusion,
2. An efficient, patient specific validation is performed for each image registration prior to its use (e.g. qualitative assessment of registration results),
3. Secondary checks or validation are performed at a frequency to minimize the effect of errors without prohibiting clinical flow,
4. Clear identification of the accuracy of the registration are provided to the consumer of the image fusion so they are fully aware of and can account for any uncertainties.

Clinical Integration

- Must consider context of registration
  - Timing, Tolerances, Evaluation, etc.
  - Systematic vs. random effects



Request

- Clear identification of the image set(s) to be registered
  - Identification of the primary (e.g. reference) image geometry
- An understanding of the local region(s) of importance
- The intended use of the result
  - Target delineation
- Techniques to use (deformable or rigid)
- The accuracy required for the final use

Report

- Identify actual images used
- Indicate the accuracy of registration for local regions of importance and anatomical landmarks
  - Identify any critical inaccuracies to alert the user
- Verify acceptable tolerances for use
- Techniques used to perform registration
- Fused images in report with annotations
- Documentation from system used for fusion

Assessment Level	Phrase	Description
0	Whole scan aligned	- Anatomy within 1 mm everywhere - Useful for structure definition everywhere - Ok for stereotactic localization
1	Locally aligned	- Anatomy local to the area of interest is un-distorted and aligned within 1mm - Useful for structure definition within the local region - Ok for localization provided target is in locally aligned region
2	Useable with local anatomical variation	- Aligned locally, with mild anatomical variation - Useful for reference only during structure definition on primary image set - Care should be taken when used for localization
3	Useable with risk of deformation	- Acceptable registration required deformation which risks altering anatomy - Shouldn't be used for target definition as target may be deformed - Useable for dose accumulation
4	Useable for diagnosis only	- Registration not good enough to rely on geometric integrity - Possible use to identify general location of lesion (e.g PET hot spot)
5	Alignment not acceptable	- Unable to align anatomy to acceptable levels - Patient position variation too great between scans

TG-132 Product

- Guidelines for understating of clinical tools
- Digital (virtual) phantoms
- Recommendations for commissioning and clinical implementation
- Recommendations for periodic and patient specific QA/QC
- Recommendations for clinical processes

Q & A?

Survey

- Do you use deformable registration in your clinic?
- Did you perform a formal commissioning process?
- Do you trust deformable registration for dose accumulation?