1. I am an employee of RaySearch Laboratories.
2. Images used for this presentation are primarily from RayStation because I have access to it.

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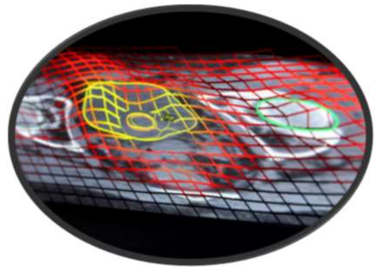
AGENDA

I. Why deformable registration (now)
II. Most Useful Cases
III. Implementation Challenges (why has it taken so long?)
IV. Technical Approaches
V. Key Functionality (getting from A to B)
VI. Examples
VII. Near Future



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WHY IS DIR NEEDED IN THE FIRST PLACE?

- Historically...
  - It was assumed that everything stayed the same for the entire treatment, unless dramatic external changes were noted.
  - Patient position was accounted for with SSD's and port films.
- Once IGRT was "introduced"...
  - We realized that patients move.
  - We noticed how much internal organs move.
  - We could not ignore that we were missing targets on a regular basis (because we were looking).
  - Modalities such as MR, PET/CT and CBCT became commonplace and potentially useful.

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ADAPTIVE TREATMENT PLANNING

- What changes from day to day?
  - Breathing
  - Soft tissue structures
  - Gas or liquid filled structures
  - GTV changes
  - CTV changes
  - Patient body habitus changes

- IGRT and Adaptive treatments attempt to:
  - Counteract motion with daily imaging and repositioning
  - Adapt the plan and dose distribution to correct for all the changes that occur
  - Build more advanced models of patient dynamics

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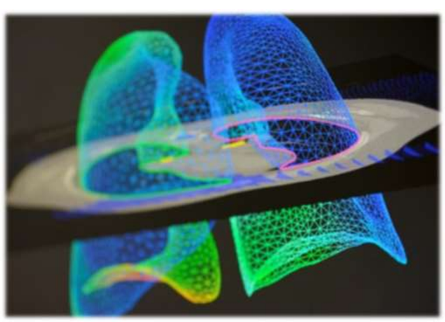
MOST COMMON USE CASES

- Retreatment or treatment to a nearby body site
- Significant physical change that suggests that a new plan is needed
- Regular imaging (CBCT) is needed to "track" the dose (dose escalation, significant OAR, etc.)
- Expert data mapping from an "atlas" data set or sets.
- 4D dataset (lung) multiple phase evaluation



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LEVELS OF ACTION

- IGRT (Observe and correct)
  - Repositioning of the patient at the time of treatment – Got Robotics?
- Dose Tracking (Quantitative observation)
  - Computing fraction dose based on daily imaging (cone beam CT – CBCT)
  - Accumulating dose by deformable registration
  - Evaluating accumulated dose to assess treatment plan success
- Re-planning (Acting on failure of IGRT to correct)
  - Account for patient-specific variations
  - Adapt to systematic geometric changes such as tumor shrinkage
  - Compensate for undesired dose accumulation, e.g., lacking target coverage or excess dose to OARs

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WHY DOESN'T EVERYONE DO IT?

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THERE ARE OTHER REASONS WHY

- The technology is not trivial – not easy to do it right or offer needed options
- What is the right way to deform dose? Several arguments exist on the subject...
- AAPM has been slow to provide direction (TG 132 provides guidance now!)
- Research has been slow and inconclusive primarily because there are so many use cases
- Single platform systems did not exist
- QA (physical or synthetic phantoms) did not exist and/or it was/is not clear how to accept products or perform ongoing QC
- It is (was?) time consuming (computationally and professionally) to perform DIR and Adaptive Therapy
- Lack of clear reimbursement (replanning only?)
- No academic direction as to when a plan should be adapted. What conditions should exist to support re-planning?

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DEFORMABLE IMAGE REGISTRATION

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DIR IN RAYSTATION

- Hybrid DIR (ANACONDA)
  - Anatomically Constrained Deformation Algorithm
  - Combines image information (intensities) with anatomical information (ROIs, POIs)
  - Versatile algorithm
  - Supported image modalities are CT, CBCT and MR
    - CT > CT, CT > CBCT, CT > CT/PET, CT > MR
- Biomechanical DIR (MORFEUS)
  - Licensed from Princess Marget Hospital, Toronto, in March 2011
  - Included in RayStation 4.5 (replacing our ROI based DIR)
  - Boundary conditions from controlling structures defined in reference image and target image
  - Finite element modelling solution
  - Applicable to any image modality

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THE HYBRID APPROACH (FOR RAYSTATION)

- Combines image information (intensities) with anatomical information (ROIs, POIs)
- A non-linear optimization problem solved with an in-house developed state-of-the-art solver
- The objective function is a linear combination of four non-linear terms:
  1. Image similarity term > reference image and deformed target image are voxel-wise ”similar”
  2. Grid regularization term > smooth and invertible grid
  3. Shape based grid regularization term > anatomically reasonable deformation
  4. Penalty term when controlling sturctures are used > controlling sturctures in reference are deformed to corresponding controlling structures in the target.

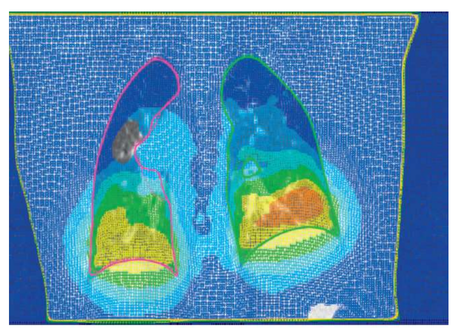

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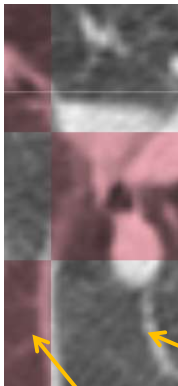
IMAGE SIMILARITY



Reference image

Deformed target image

We measure image similarity between the reference image R and the target image T by the correlation coefficient

$$C(v) = \frac{\sum_{i=1}^{n}(R(x_i) - \bar{R})(T(x_i + v_i) - \bar{T})}{\sqrt{\sum_{i=1}^{n}(R(x_i) - \bar{R})^2}\sqrt{\sum_{i=1}^{n}(T(x_i + v_i) - \bar{T})^2}}$$

where v_i is the displacement for a grid point x_i.

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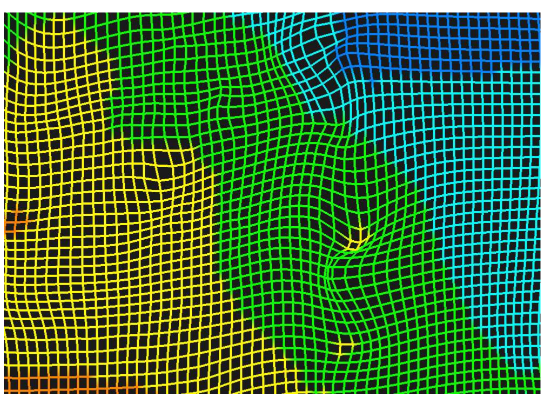
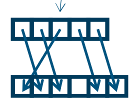
GRID REGULARIZATION



No elements are inverted
Hence this is not supposed to happen



Grid is kept smooth and invertible by minmizing the Dirichlet energy for the coordinate functions
→ harmonic mappings which penalize deviation from the mean value property and are invertible (under reasonable assumptions).

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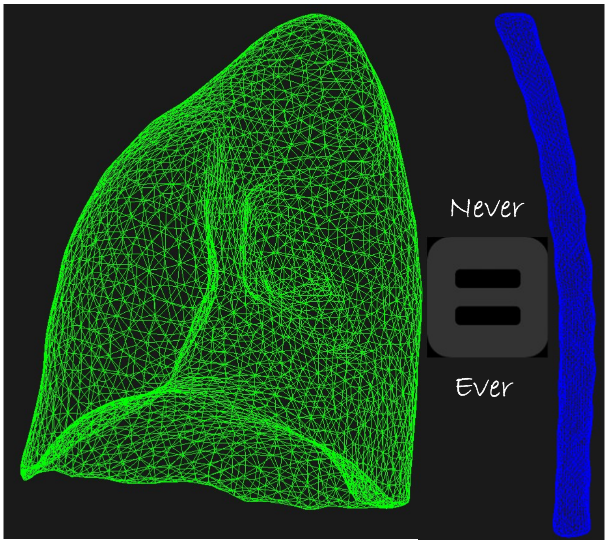
SHAPE BASED GRID REGULARIZATION



A lung will never ever be deformed into a spinal cord…

Uses the same framework as our implementation of model based segmentation

ROIs in the reference image of type ”Organ” or ”Avoidance” are considered

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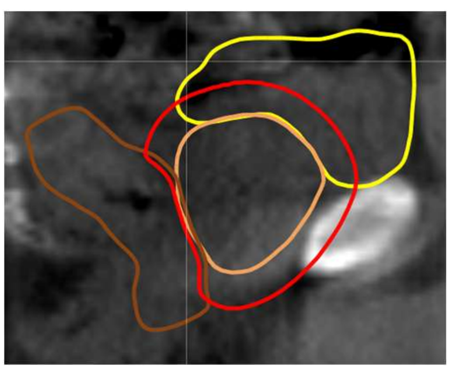
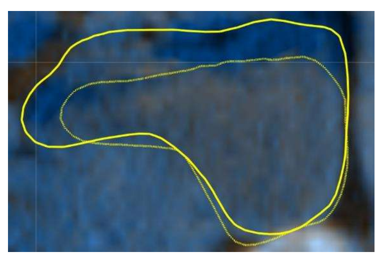
CONTROLLING STRUCTURES

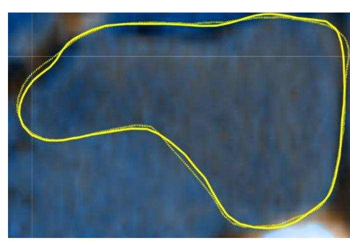
Sometimes we need to help the DIR algorithm…



DIR with no controlling structures
→ Not a good job on the bladder due to low contrast



Using controlling structures we can force the solid (reference image) to deform to the dotted (target image)



DIR with bladder as controlling structure

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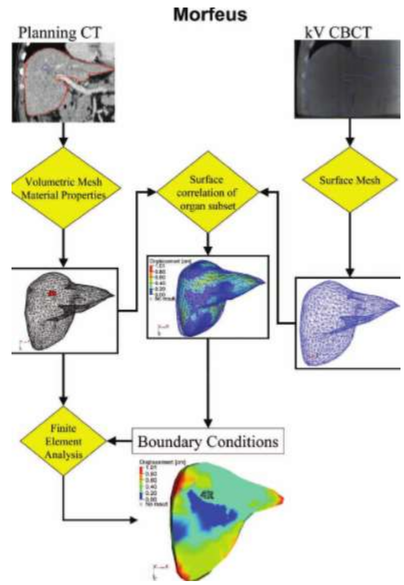
BIOMECHANICAL DIR – MORFEUS

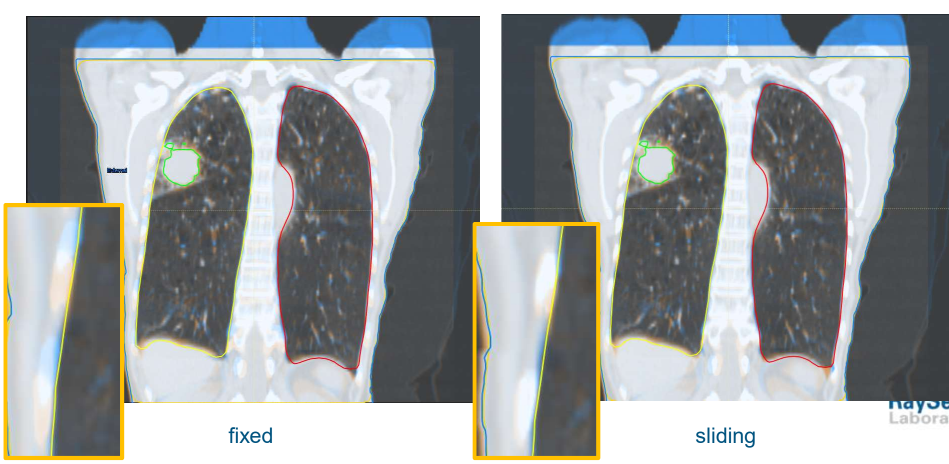
- Boundary conditions from mesh ROIs with point-to-point correspondence
  - -Displacement of boundary conditions on the surface
  - MBS
  - Convert contour ROIs to controlling ROIs method.
    - Handles ROI intersections
- Linear elastic material properties for each ROI
  - -Interior deforms according to the biomechanical properties of tissue
- Sliding interfaces possible



Morfeus references:
Brock, K.K., et al.. Accuracy of finite element model-based multi-organ deformable image registration, Medical Physics, 32(6):1647-1659, 2005.
and following

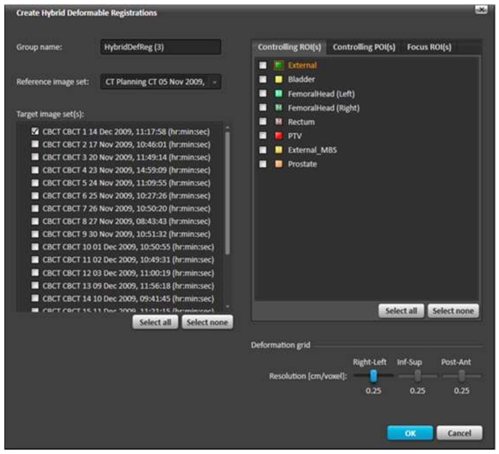
SLIDING INTERFACES

Why sliding interfaces?
The pleural cavity is the space between the two pleurae of the lungs. This thin space, filled with pleural fluid, allows the lungs to ”slide” along the ribs during breathing.



fixed   sliding

KEY FUNCTIONALITY (IN ANY SYSTEM)



Ability to create deformation between any two datasets. Controlling ROIs or some anatomical constraint (we believe) is a necessity.

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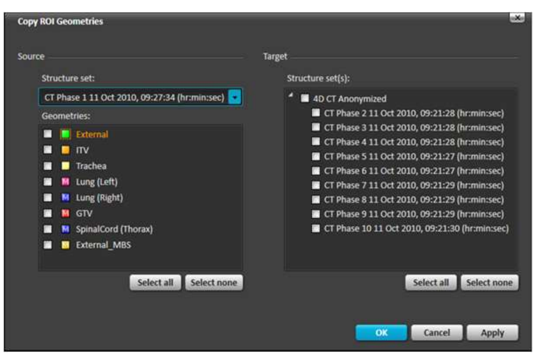
KEY FUNCTIONALITY (IN ANY SYSTEM)



Simple copying of ROIs from one dataset to another. (Can also use MBS upon copy)

Mapping of ROIs across deformed grid.

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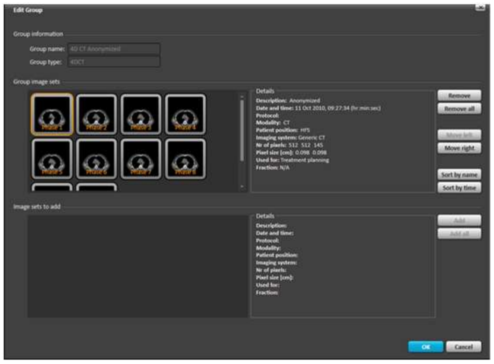
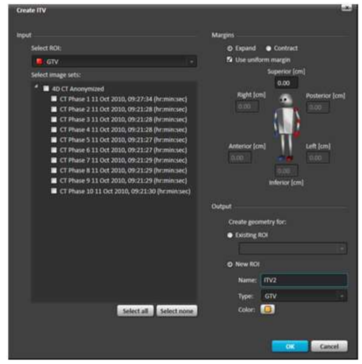
AAMD American Association of Medical Dosimetrists

KEY FUNCTIONALITY (IN ANY SYSTEM)





- For 4D datasets, the ability to group for multiple purposes.
- Ability to create a MIP from the group.
- Ability to create ITV's from multiple phases in any view
- View the phases in a cine loop.

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"ANYTIME" IMAGE IMPORT & 4D DISPLAY

Datasets should be able to be imported "at will" and grouped (in this example with a 4D CT)

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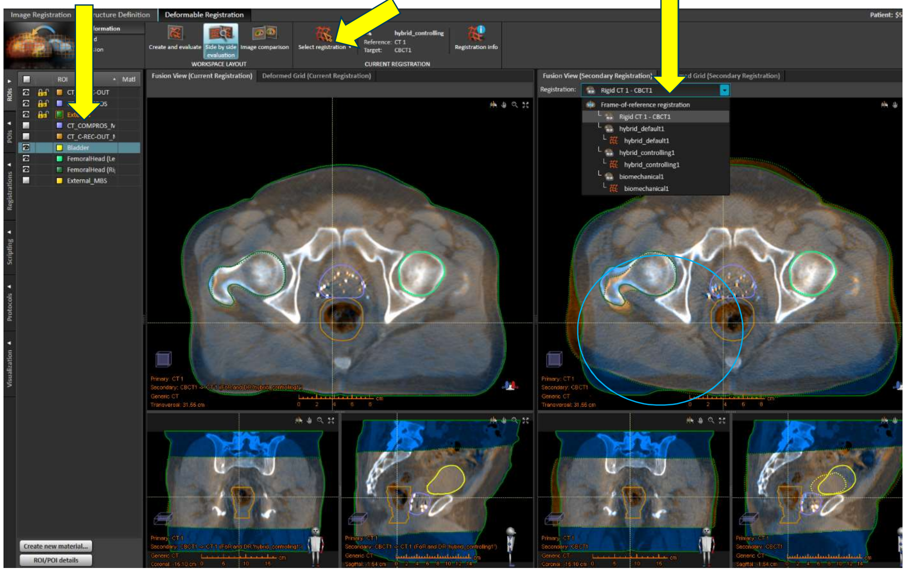
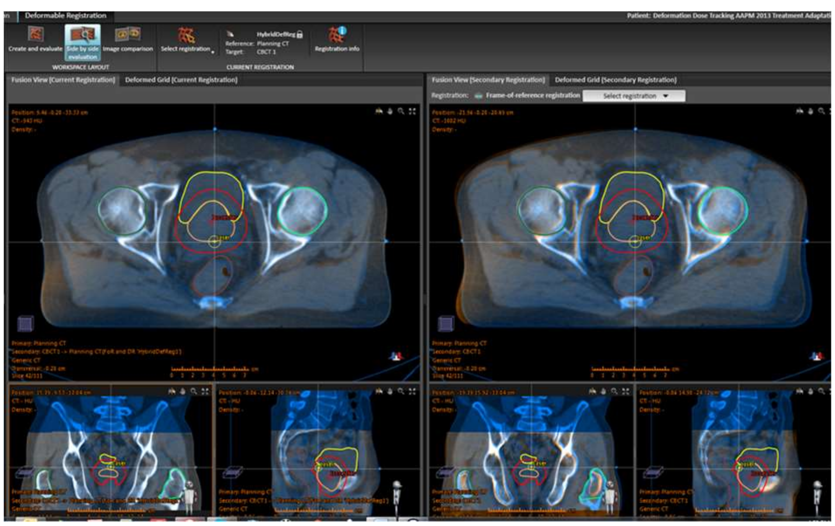
EVALUATION

Select ROI visualization — Select View — Select registration



EVALUATION



Fairly conventional view – overlay on left of deformed data set on primary, and on right a rigid overlay.

EVALUATION

Display on the left is the planning CT showing the extent of deformation that the CBCT had to go through. The newly created deformed view of the CBCT is on the right.

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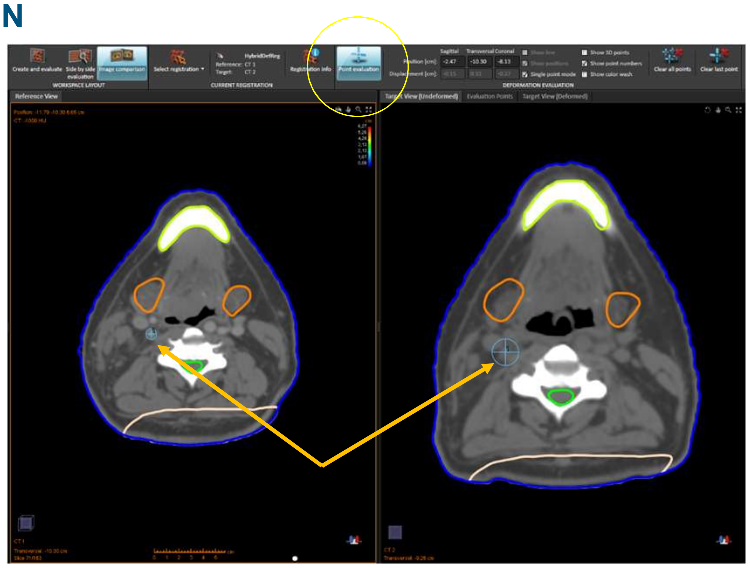
EVALUATION



Point mapping between various data sets.

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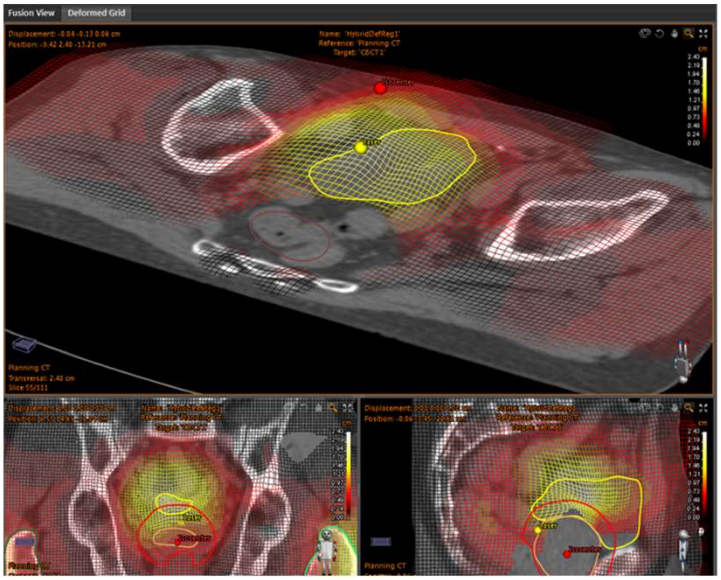
EVALUATION



2D/3D view where the user can scroll in any of the three reconstructions and rotate the data set to view the deformed grid.

Instead of a grid, vector lines can be displayed to show the user which direction the voxels have gone.

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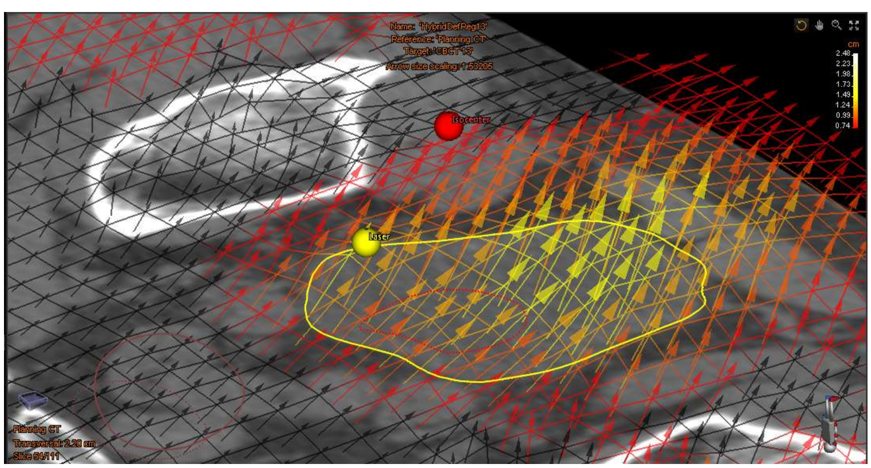
EVALUATION



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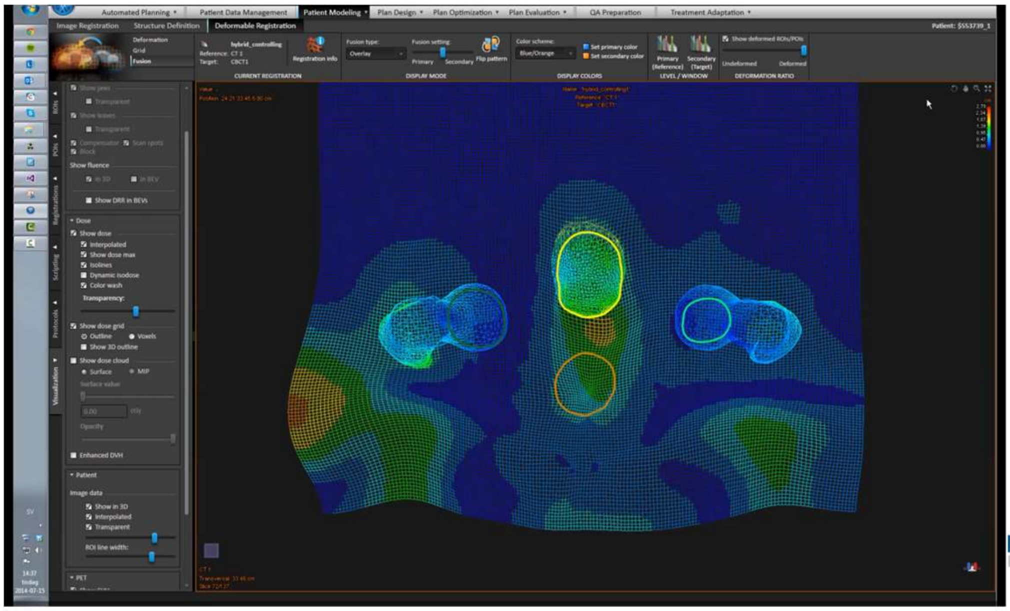
EVALUATION



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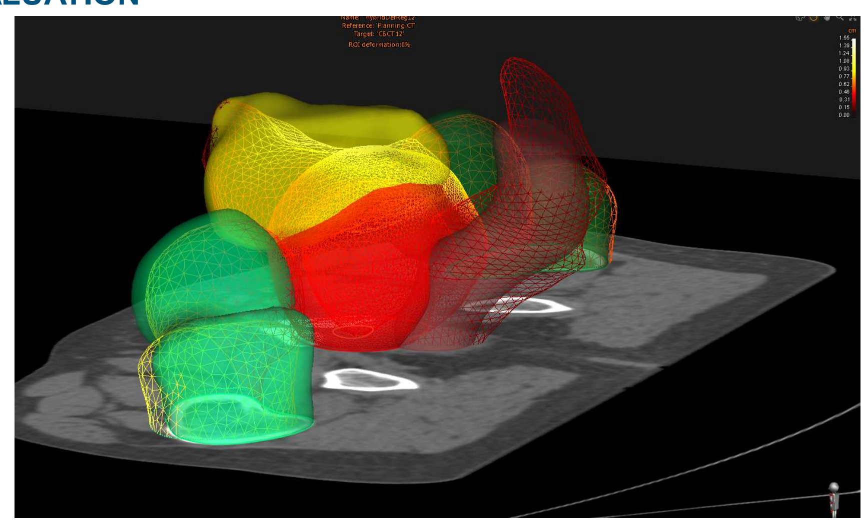
EVALUATION



View showing the reference ROIs and the deformed ROIs so that the user can assess more cleanly what happened between data sets.

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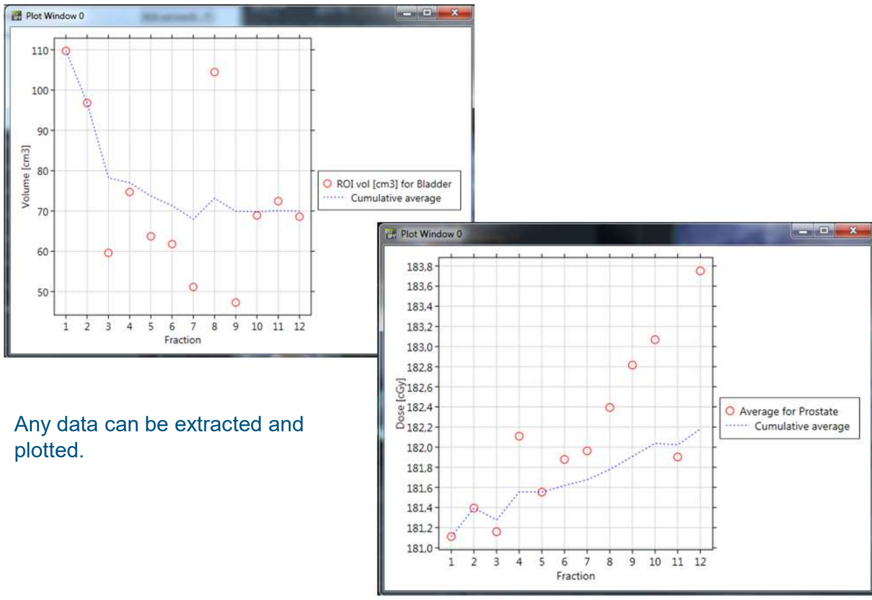
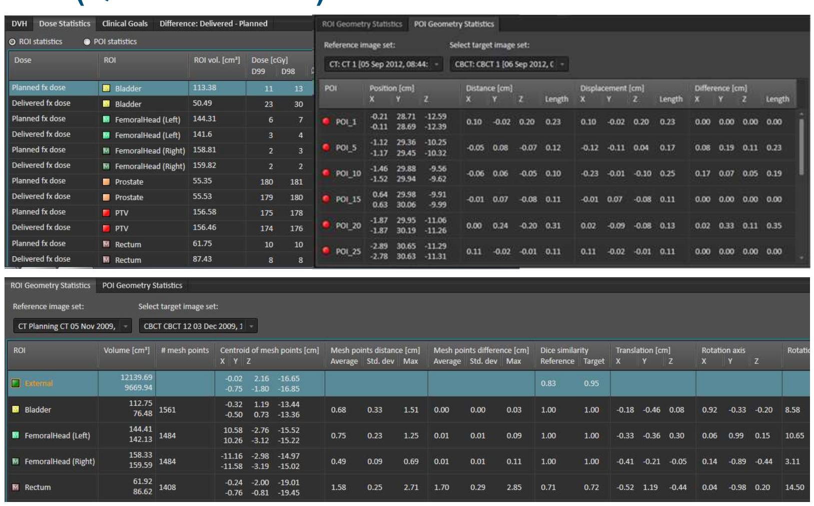
EVALUATION (QUANTITATIVE)



Any data can be extracted and plotted.

EVALUATION (QUANTITATIVE)



DVH | Dose Statistics | Clinical Goals | Difference: Delivered - Planned

ROI statistics | POI statistics

Dose	ROI	ROI vol. [cm³]	Dose [cGy] D99	D98
Planned fx dose	Bladder	113.38	11	13
Delivered fx dose	Bladder	50.49	23	30
Planned fx dose	FemoralHead (Left)	144.31	6	7
Delivered fx dose	FemoralHead (Left)	141.6	3	4
Planned fx dose	FemoralHead (Right)	158.81	2	3
Delivered fx dose	FemoralHead (Right)	159.82	2	2
Planned fx dose	Prostate	55.35	180	181
Delivered fx dose	Prostate	55.53	179	180
Planned fx dose	PTV	156.58	175	178
Delivered fx dose	PTV	156.46	174	176
Planned fx dose	Rectum	61.75	10	10
Delivered fx dose	Rectum	87.43	8	8

ROI Geometry Statistics | POI Geometry Statistics

Reference image set: CT: CT 1 [05 Sep 2012, 08:44:
Select target image set: CBCT: CBCT 1 [06 Sep 2012, C

POI	Position [cm] X	Y	Z	Distance [cm] X	Y	Z	Length	Displacement [cm] X	Y	Z	Length	Difference [cm] X	Y	Z	Length
POI_1	-0.21 -0.11	28.71 28.69	-12.59 -12.39	0.10	-0.02	0.20	0.23	0.10	-0.02	0.20	0.23	0.00	0.00	0.00	0.00
POI_5	-1.12 -1.17	29.36 29.45	-10.25 -10.32	-0.05	0.08	-0.07	0.12	-0.12	-0.11	0.04	0.17	0.08	0.19	0.11	0.23
POI_10	-1.46 -1.52	29.88 29.94	-9.56 -9.62	-0.06	0.06	-0.05	0.10	-0.23	-0.01	-0.10	0.25	0.17	0.07	0.05	0.19
POI_15	0.64 0.63	29.98 30.06	-9.91 -9.99	-0.01	0.07	-0.08	0.11	-0.01	0.07	-0.08	0.11	0.00	0.00	0.00	0.00
POI_20	-1.87 -1.87	29.95 30.19	-11.06 -11.26	0.00	0.24	-0.20	0.31	0.02	-0.09	-0.08	0.13	0.02	0.33	0.11	0.35
POI_25	-2.89 -2.78	30.65 30.63	-11.29 -11.31	0.11	-0.02	-0.01	0.11	0.11	-0.02	-0.01	0.11	0.00	0.00	0.00	0.00

ROI Geometry Statistics | POI Geometry Statistics

Reference image set: CT Planning CT 05 Nov 2009,
Select target image set: CBCT CBCT 12 03 Dec 2009, 1

ROI	Volume [cm³]	# mesh points	Centroid of mesh points [cm] X	Y	Z	Mesh points distance [cm] Average	Std. dev	Max	Mesh points difference [cm] Average	Std. dev	Max	Dice similarity Reference	Target	Translation [cm] X	Y	Z	Rotation axis X	Y	Z	Rotatic
External	12139.69 9669.94		-0.02 -0.75	2.16 -1.80	-16.65 -16.85							0.83	0.95							
Bladder	112.75 76.48	1561	-0.32 -0.50	1.19 0.73	-13.44 -13.36	0.68	0.33	1.51	0.00	0.00	0.03	1.00	1.00	-0.18	-0.46	0.08	0.92	-0.33	-0.20	8.58
FemoralHead (Left)	144.41 142.13	1484	10.58 10.26	-2.76 -3.12	-15.52 -15.22	0.75	0.23	1.25	0.01	0.01	0.09	1.00	1.00	-0.33	-0.36	0.30	0.06	0.99	0.15	10.65
FemoralHead (Right)	158.33 159.59	1484	-11.16 -11.58	-2.98 -3.19	-14.97 -15.02	0.49	0.09	0.69	0.01	0.01	0.11	1.00	1.00	-0.41	-0.21	-0.05	0.14	-0.89	-0.44	3.11
Rectum	61.92 86.62	1408	-0.24 -0.76	-2.00 -0.81	-19.01 -19.45	1.58	0.25	2.71	1.70	0.29	2.85	0.71	0.72	-0.52	1.19	-0.44	0.04	-0.98	0.20	14.50

ROI/POI statistics, DICE similarity scores, registration errors between any two datasets.

DICE SIMILARITY INDEX

- statistic used for comparing the similarity of two samples
- Map over a contour from source image and measure overlap with the corresponding contour in the target image
- Dice similarity between two regions A and B: $\frac{2|A \cap B|}{|A|+|B|}$

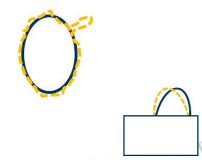
- Several options in RayStation:
  - Dice is reported in ROI geometry statistics (original vs mapped)
  - Scale between 0-1
  - Numbers closer to one indicate a higher degree of overlap
  - Can also be displayed for selected ROIs through dice_similarity_for_mapped_structures script
  - Comparison between two arbitrary ROIs through roi_comparison script

Fusion View | Deformed Grid | ROI Geometry Statistics | POI Geometry Statistics

Reference image set: CT: Planning CT [05 Nov 2005
Select target image set: CBCT: CBCT 1 [17 Nov 2009, :

ROI	Volume [cm³]	# mesh points	Centroid of mesh points [cm] X	Y	Z	Mesh points distance [cm] Average	Std. dev	Max	Mesh points difference [cm] Average	Std. dev	Max	Dice similarity Reference	Target	Translation [cm] X	Y	Z	Rotation axis X	Y	Z	Rotation angle [deg]
Bladder	113.40 109.86	1561	-0.32 -0.36	1.19 0.75	-13.44 -12.99	0.90	0.28	1.77	0.58	0.30	1.45	0.97	0.98	-0.04	-0.44	0.45	-0.89	0.01	-0.46	12.96
FemoralHead (Left)	144.98 140.58	1484	10.58 10.56	-2.76 -3.18	-15.52 -14.80	0.92	0.31	1.57	0.17	0.09	0.46	0.99	0.99	-0.02	-0.42	0.72	0.02	1.00	0.10	9.69
FemoralHead (Right)	158.89 158.33	1484	-11.16 -11.34	-2.98 -3.25	-14.97 -14.49	0.64	0.24	1.09	0.13	0.08	0.40	0.99	0.99	-0.17	-0.27	0.47	0.04	-1.00	-0.04	7.20
Rectum	62.06 102.12	1408	-0.24 -0.21	-2.00 -1.72	-19.01 -18.92	0.94	0.24	1.48	0.78	0.38	1.74	0.98	0.99	0.03	0.28	0.09	0.61	0.75	0.26	2.14

Dice considerations



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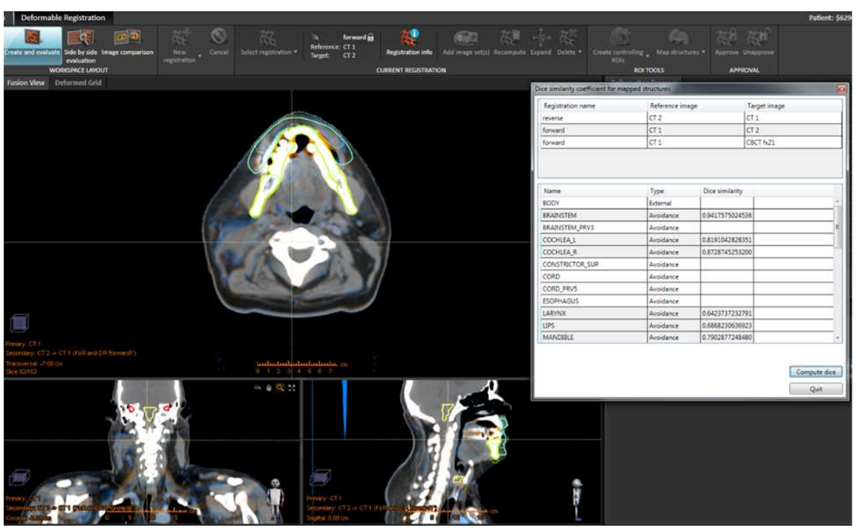
EVALUATION (QUANTITATIVE)



Dice similarity (extended information via Python Scripting)

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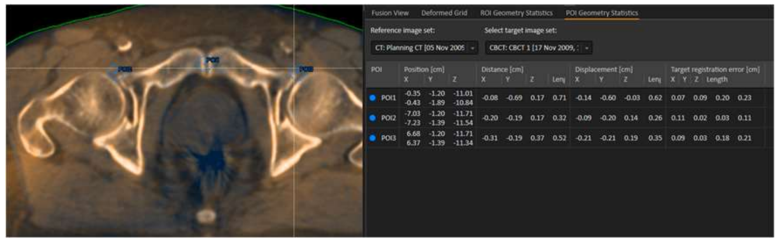
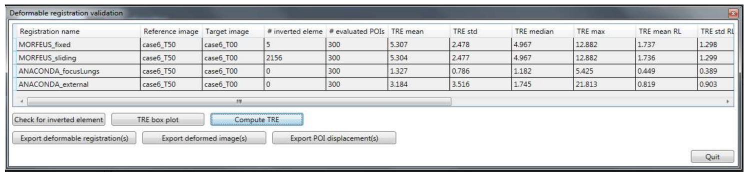
TARGET REGISTRATION ERROR (TRE)

- TRE: how far away from POI_id in target, POI_id mapped from reference is
- Two options in RayStation:
  - TRE for each POI is reported in POI geometry statistics ("Difference" column)
  - Total TRE statistics by running deformable_registration_validation.py
  - Requires numpy installed
  - Mark the DIR you want to validate and press "Compute TRE"
  - Time: 4DIR, 300 POIs takes 4min





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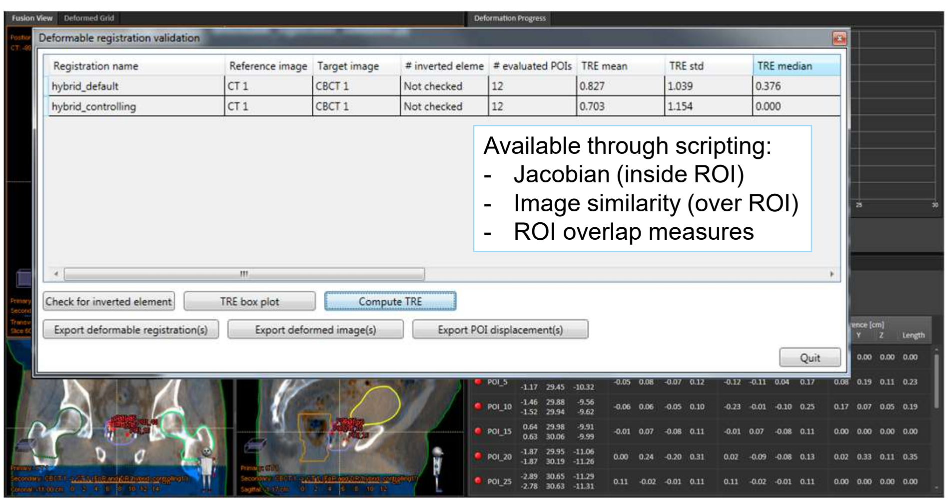
EVALUATION (QUANTITATIVE)



Available through scripting:
- Jacobian (inside ROI)
- Image similarity (over ROI)
- ROI overlap measures

Target Registration Error Analysis

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EVALUATION

DVH | Dose Statistics | Clinical Goals | Difference: Accumulated Delivered - Planned Accumulated

Add physical... | Edit... | Copy | Delete | Load template... | Create template...

Dose	ROI/POI	Clinical goal	Value	Result	% outside grid
Planned accumulated dose [scaled]	Bladder	At most 4000 cGy dose at 80.00 % volume	2228 cGy	✓	0 %
Planned accumulated dose [scaled]	Bladder	At most 6900 cGy dose at 50.00 % volume	5960 cGy	✓	0 %
Accumulated delivered dose [scaled]	Bladder	At most 4000 cGy dose at 80.00 % volume	4290 cGy	!	0 %
Accumulated delivered dose [scaled]	Bladder	At most 6900 cGy dose at 50.00 % volume	6577 cGy	✓	0 %
Planned accumulated dose [scaled]	Prostate	At least 7920 cGy dose at 95.00 % volume	7987 cGy	✓	0 %
Accumulated delivered dose [scaled]	Prostate	At least 7920 cGy dose at 95.00 % volume	7966 cGy	✓	0 %
Planned accumulated dose [scaled]	PTV	At least 7920 cGy dose at 95.00 % volume	7920 cGy	✓	0 %
Accumulated delivered dose [scaled]	PTV	At least 7920 cGy dose at 95.00 % volume	7631 cGy	!	0 %
Planned accumulated dose [scaled]	Rectum	At most 4100 cGy dose at 50.00 % volume	4199 cGy	!	0 %
Planned accumulated dose [scaled]	Rectum	At most 5300 cGy dose at 35.00 % volume	5464 cGy	!	0 %
Accumulated delivered dose [scaled]	Rectum	At most 4100 cGy dose at 50.00 % volume	4801 cGy	!	0 %
Accumulated delivered dose [scaled]	Rectum	At most 5300 cGy dose at 35.00 % volume	6550 cGy	!	0 %

Comparative DVH data and clinical goal comparisons (scaled to the end of the projected treatment based on Rx)

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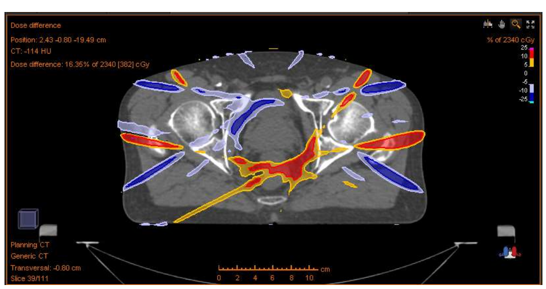
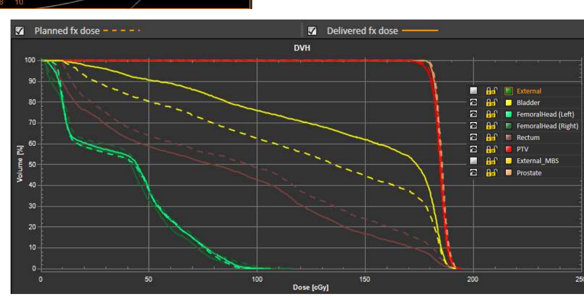
EVALUATION





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COMPUTE FRACTION DOSE: STEPS

- 1. Import the CBCT acquired during treatment
- 2. Set **imaging system** and **fraction number** in Properties
- 3. Align the CBCT to the planning CT image via **treatment position alignment**
- 4. Create a **CBCT density table**
- 5. Generate the **external ROI** for the CBCT. Use the tools for handling **limited field of view** to generate the external if necessary
- 6. Add **rigid transform**
- 7. Define and map ROIs on the acquired CBCT via a **deformable registration**
- 8. **Compute fraction dose** in Dose tracking

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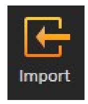
1. IMPORT CT IMAGE

- DICOM import the CBCT into the current patient in Patient Data Management



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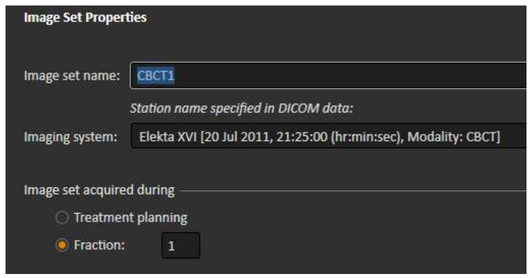
2. SET IMAGE PROPERTIES

- Set name, CBCT imaging system and fraction number in **Properties** of the CBCT in Patient Data Management
- The CBCT is likely to be imported in as a CT; rename the image set if desired
  - **N.B.** Fraction number cannot be set unless Initialize treatment adaptation has started



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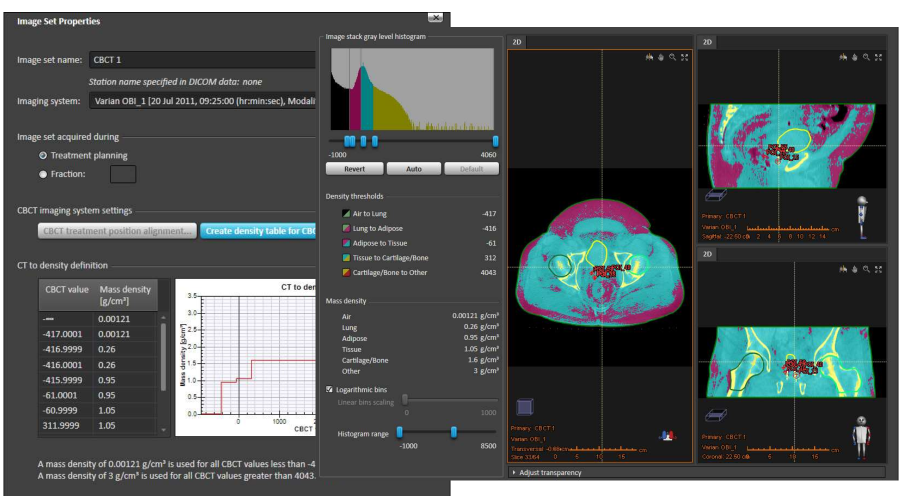
PLANNING ON ANY DATASET (CBCT)



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MASS DENSITY VALUES

- A density table is created by mapping mass density values in g/cm^3 to the CBCT grey levels for 6 different tissues:
  - Air
  - Lung
  - Adipose
  - Tissue
  - Cartilage/Bone
  - Other (ie. high density materials)

Mass density

Air	0.00121 g/cm³
Lung	0.26 g/cm³
Adipose	0.95 g/cm³
Tissue	1.05 g/cm³
Cartilage/Bone	1.6 g/cm³
Other	3 g/cm³

- Transformed to HU-like values for MBS, external creation, gray level threshold, level/window preset values and creating a field-of-view

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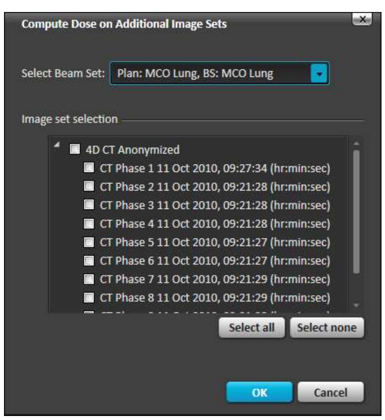
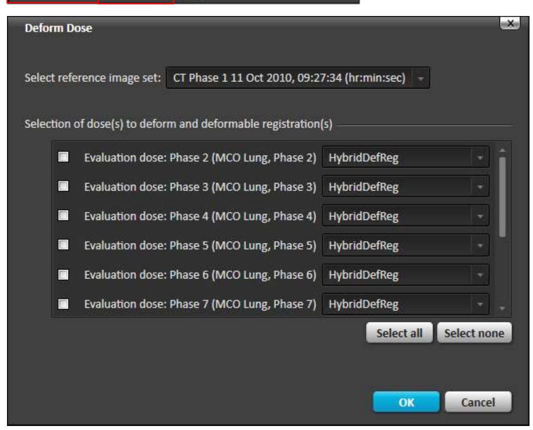
DOSE HANDLING



Simple computation on registered datasets.



Deformation of dose across any map.

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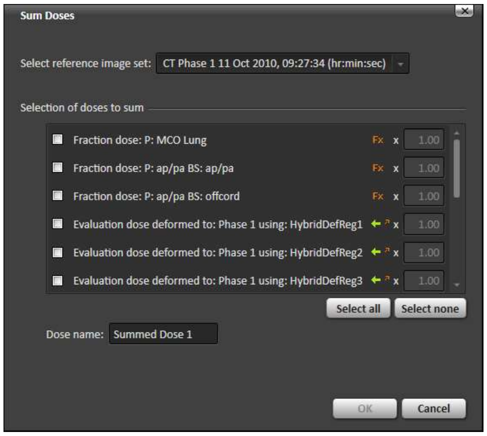
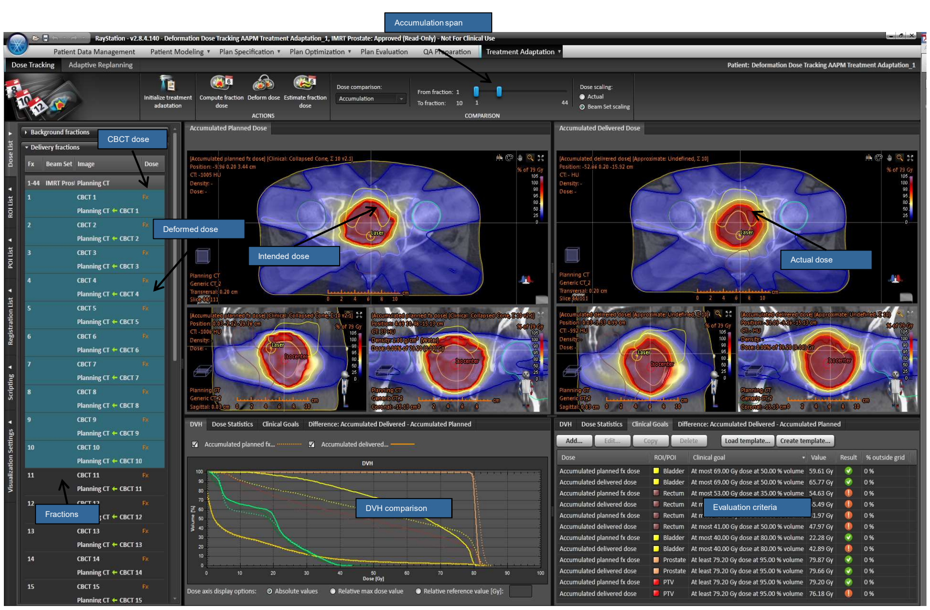
DOSE HANDLING



When all maps are created and doses are assessed, it will be important to view a summed dose that takes everything into account (including adapted plans).

DOSE TRACKING



PLANNING ON ANY DATASET (CBCT)

Computing dose on a CBCT and mapping to the original planning CT makes sense, but mapping to a CBCT may not.

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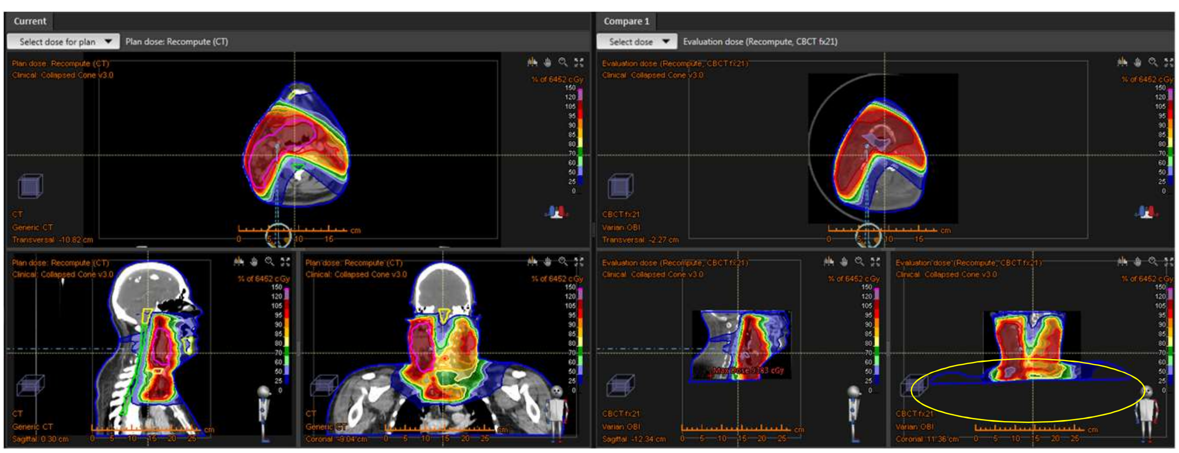
PLANNING ON ANY DATASET (FOV)



Missing tissue due to FOV can be accounted for by using deformable registration with the original dataset.

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ADAPTIVE REPLANNING

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LEVELS OF ADAPTATION

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LEVELS OF ADAPTATION....EASY

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LEVELS OF ADAPTATION

FOOTBALL

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LEVELS OF ADAPTATION… HARD

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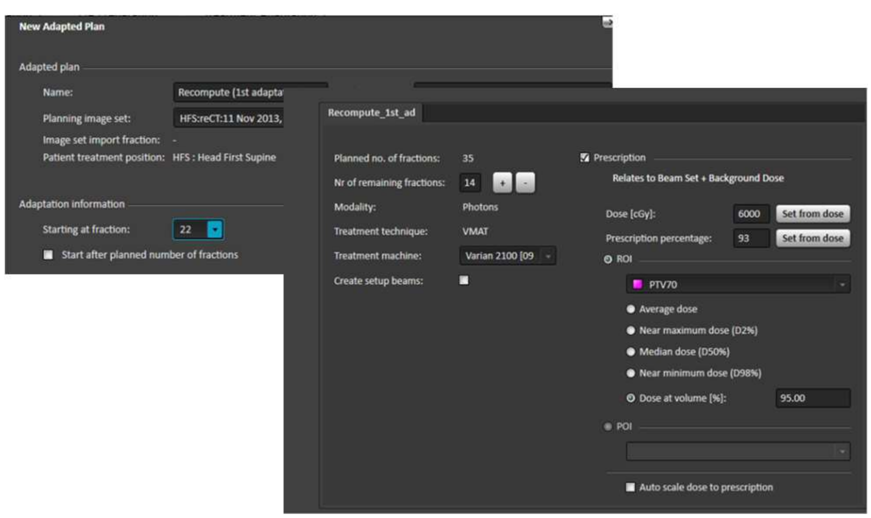
ADAPTIVE THERAPY



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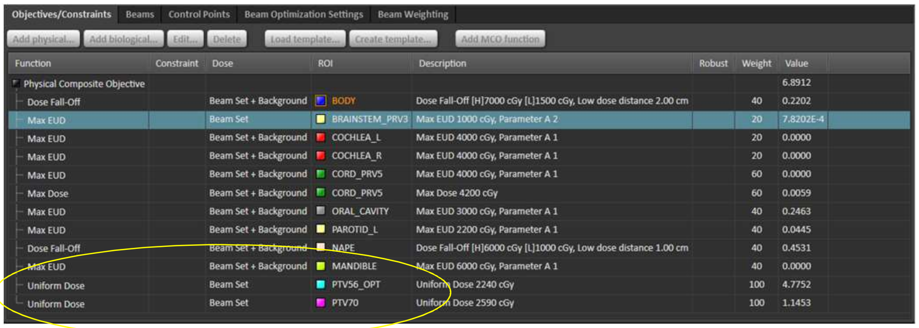
OPTIMIZE OVER PREVIOUS DOSE



Function	Constraint	Dose	ROI	Description	Robust	Weight	Value
Physical Composite Objective							6.8912
Dose Fall-Off		Beam Set + Background	BODY	Dose Fall-Off [H]7000 cGy [L]1500 cGy, Low dose distance 2.00 cm		40	0.2202
Max EUD		Beam Set	BRAINSTEM_PRV3	Max EUD 1000 cGy, Parameter A 2		20	7.8202E-4
Max EUD		Beam Set + Background	COCHLEA_L	Max EUD 4000 cGy, Parameter A 1		20	0.0000
Max EUD		Beam Set + Background	COCHLEA_R	Max EUD 4000 cGy, Parameter A 1		20	0.0000
Max EUD		Beam Set + Background	CORD_PRV5	Max EUD 4000 cGy, Parameter A 1		60	0.0000
Max Dose		Beam Set + Background	CORD_PRV5	Max Dose 4200 cGy		60	0.0059
Max EUD		Beam Set + Background	ORAL_CAVITY	Max EUD 3000 cGy, Parameter A 1		40	0.2463
Max EUD		Beam Set + Background	PAROTID_L	Max EUD 2200 cGy, Parameter A 1		40	0.0445
Dose Fall-Off		Beam Set + Background	NAPE	Dose Fall-Off [H]6000 cGy [L]1000 cGy, Low dose distance 1.00 cm		40	0.4531
Max EUD		Beam Set + Background	MANDIBLE	Max EUD 6000 cGy, Parameter A 1		40	0.0000
Uniform Dose		Beam Set	PTV56_OPT	Uniform Dose 2240 cGy		100	4.7752
Uniform Dose		Beam Set	PTV70	Uniform Dose 2590 cGy		100	1.1453

Original plan is "moved forward" maintaining segments, objectives are created automatically to accomplish goals.

Note that background dose does not have to be included.

This may be preferred when a hot target should not be compensated for.

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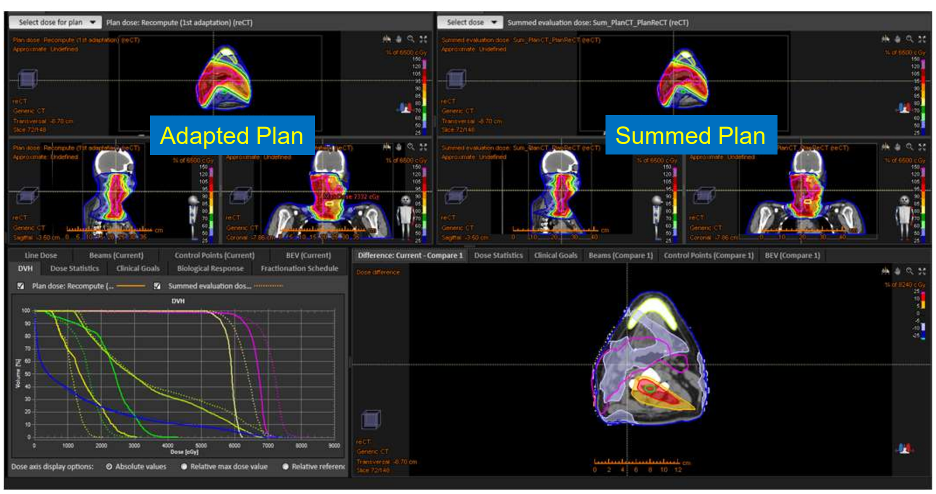
OPTIMIZE OVER PREVIOUS DOSE



Adapted plan is better than plans done independently on old and new data sets, and then summed. This could be iterated to get better results, but adapted plans are better and more efficient.

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USE CASE:
REPLANNING AFTER 10 FRACTION BASED NEW PLANNING CT

- E.g. Head & neck where the shrinkage is known to be such that replanning is required
- Two alternatives:
  - ”Blind” replanning by using adjusted prescription, objectives / constraints etc.
  - Use planned dose on *plan CT* for the 10 first fractions mapped to the new planning CT, *replan CT*, as background dose in the optimization

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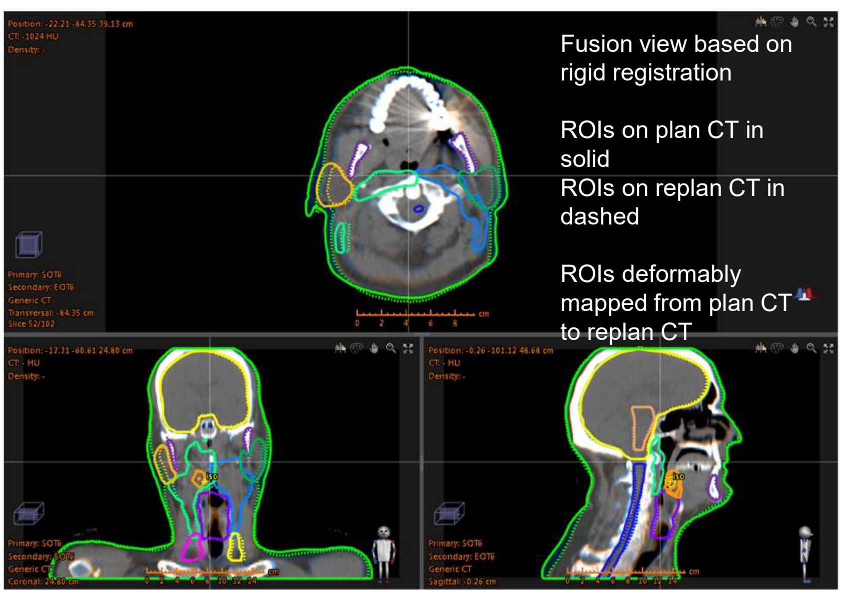
PLAN AND REPLAN CT



Data from ”Deformable image registration evaluation project”: https://sites.google.com/site/dirphantoms/

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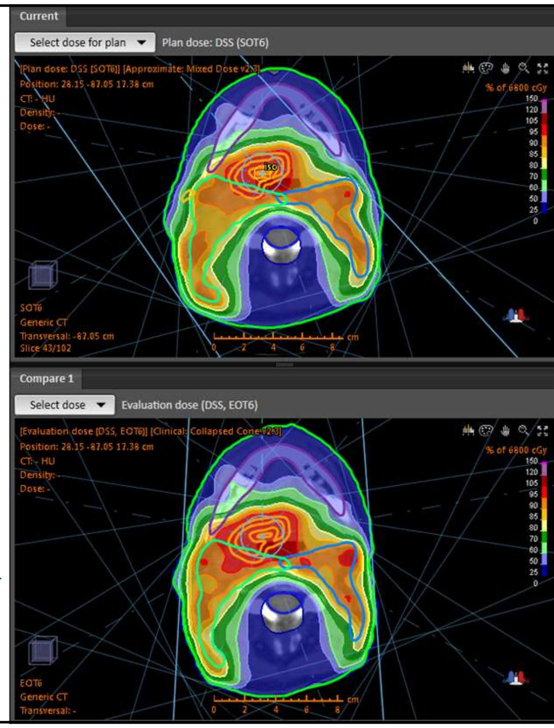
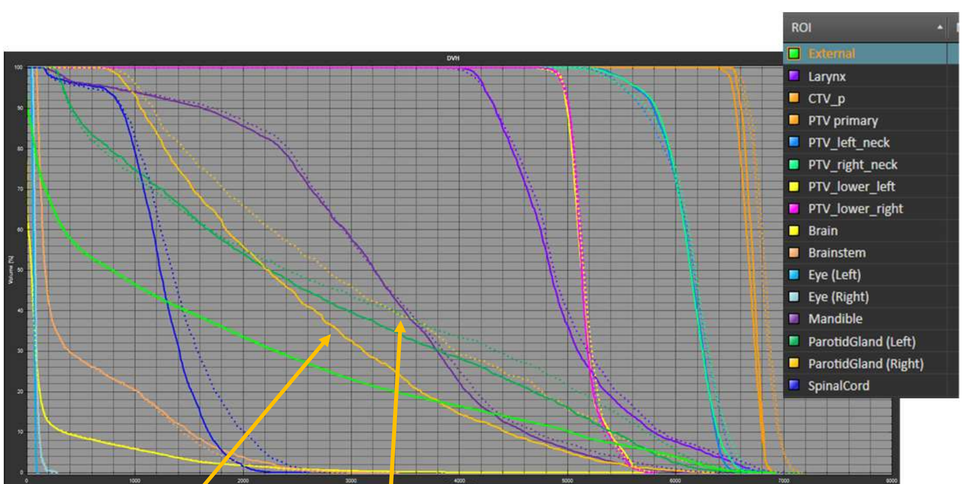
WHAT HAPPENS IF WE CONTINUE THE DELIVERY AS PLANNED?

Planned dose on plan CT

Planned dose on replan CT



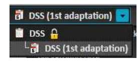
WHAT HAPPENS IF WE CONTINUE THE DELIVERY AS PLANNED?

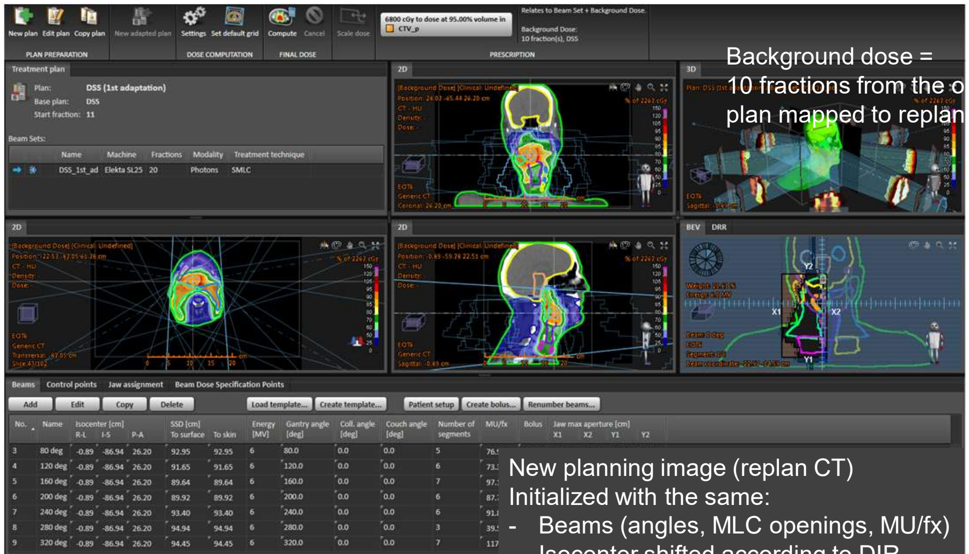


Right parotid on plan CT

Right parotid on replan CT

ADAPTED PLAN FROM FRACTION 11





Background dose = 10 fractions from the o plan mapped to replan

New planning image (replan CT)
Initialized with the same:
- Beams (angles, MLC openings, MU/fx)
- Isocenter shifted according to DIR
- Objectives / constraints

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USE CASE: TREATMENT EVALUATION AND (IF NECESSARY) REPLANNING BASED ON DAILY CBCT

Prerequisites

- A patient with an approved plan
- Daily (or nearly daily) images acquired

Main steps

- Compute fraction dose
- Deform dose to planning CT
- Accumulate dose
- Evaluation & decision
- Replanning

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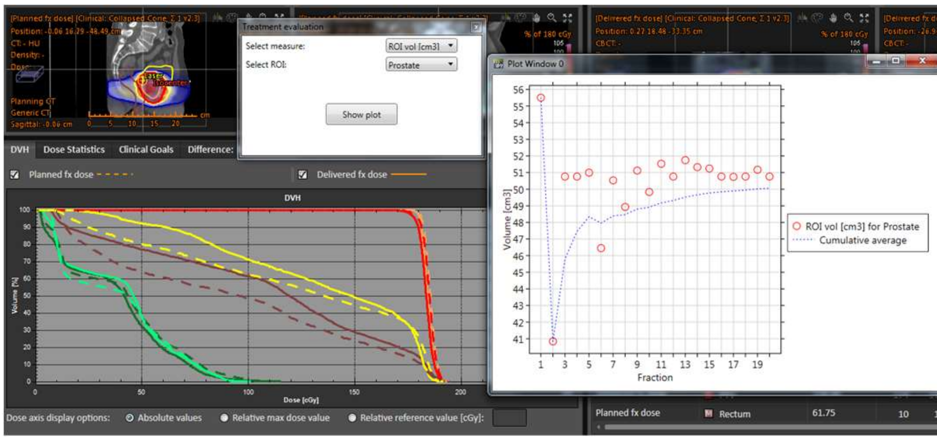
EVALUATION

Accumulated dose

- Comparison between planned and delivered dose shows unacceptable difference

ROIs over time

- Systematic changes in the patient geometry is detected: volume, translation, ...



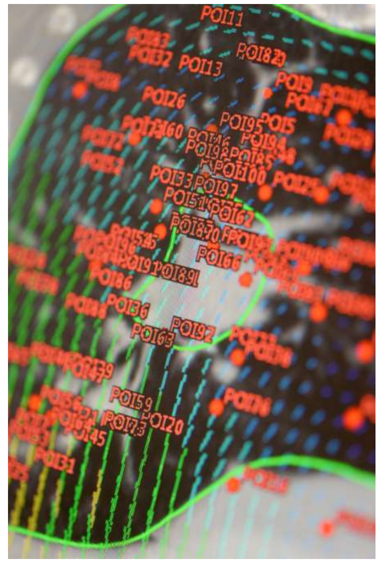
QA

QA

Virtual Phantoms available via TG 132

- Basic geometric phantoms (multi-modality) – ImSim QA
- Pelvis Phantom (CT and MR) – ImSim QA
- Clinical 4D CT Lung with simulated exhale (DIRlab MD Anderson)

Other physical phantoms will become available over time for proper end-to-end testing.



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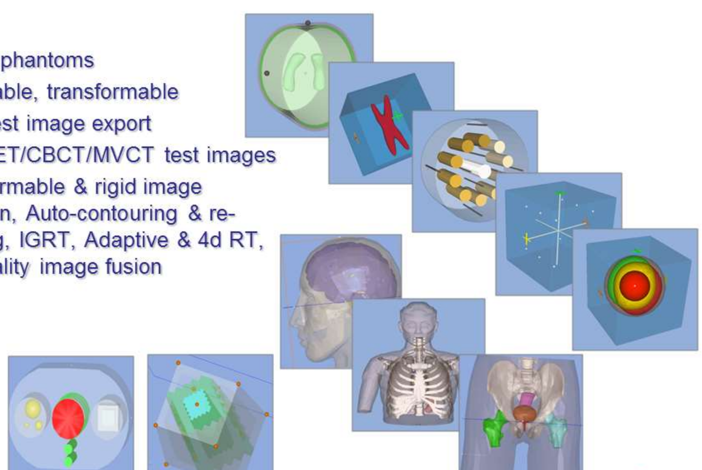
MORE COMMERCIAL QA

Virtual Phantoms in ImSimQA

- 15 virtual phantoms
- Fully editable, transformable
- DICOM test image export
- CT/MR/PET/CBCT/MVCT test images
- Test Deformable & rigid image registration, Auto-contouring & re-contouring, IGRT, Adaptive & 4d RT, Multimodality image fusion



OSL ONCOLOGY SYSTEMS LIMITED ImSimQA

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DIR QA: Summary

1. Import DICOM images into ImSimQA → 2. Virtually Deform images locally or globally → 3. Export deformed images and DVF to the DIR test system. → 4. Run DIR between deformed and original data. Export DIR images, and DVF back to ImSimQA → 5. Evaluate results in ImSimQA

Decide on Algorithm performance

<table>
<tr><th></th><th colspan="2">Image Deformation</th><th colspan="2">Contour Deformation</th><th colspan="2">DVF response</th></tr>
<tr><th></th><th>Pass</th><th>Fail</th><th>Pass</th><th>Fail</th><th>Pass</th><th>Fail</th></tr>
<tr><td rowspan="2">Anatomical Sites</td><td>Head & Neck</td><td>Pelvis, Prostate</td><td>Head & Neck</td><td>Pelvis, Prostate</td><td>Head & Neck</td><td>Chest</td></tr>
<tr><td colspan="2">Chest</td><td>Chest</td><td></td><td colspan="2">Pelvis, Prostate</td></tr>
<tr><td rowspan="2">Type of DIR Algorithm</td><td>Head & Neck</td><td>Pelvis, Prostate</td><td>Head & Neck</td><td>Pelvis, Prostate</td><td>Head & Neck</td><td>Chest</td></tr>
<tr><td colspan="2">Chest</td><td>Chest</td><td></td><td colspan="2">Pelvis, Prostate</td></tr>
</table>

OSL ImSimQA
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THE NEAR FUTURE

- GPU operations to add speed already in play!
  - Needed to enable online adaptation
  - Dramatic increase in speed

  Depending on case,
  GPU specifications

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THE NEAR FUTURE

- Automated assessment and protocol driven adaptation
- Data mining for better automatic planning and reporting
  - Set notification for when x% discrepancy in PTV occurs?
  - Determination of what x is?
- EPID based online monitoring and retrospective analysis
- Better extrapolation of dose accumulation and overall plan effectiveness based on ROI shape, location and dose variation of previous fractions
  - Incorporate model motion from this patient?
- Biological factor incorporation into optimization and adaptive treatment
- Incorporation of more functional imaging.

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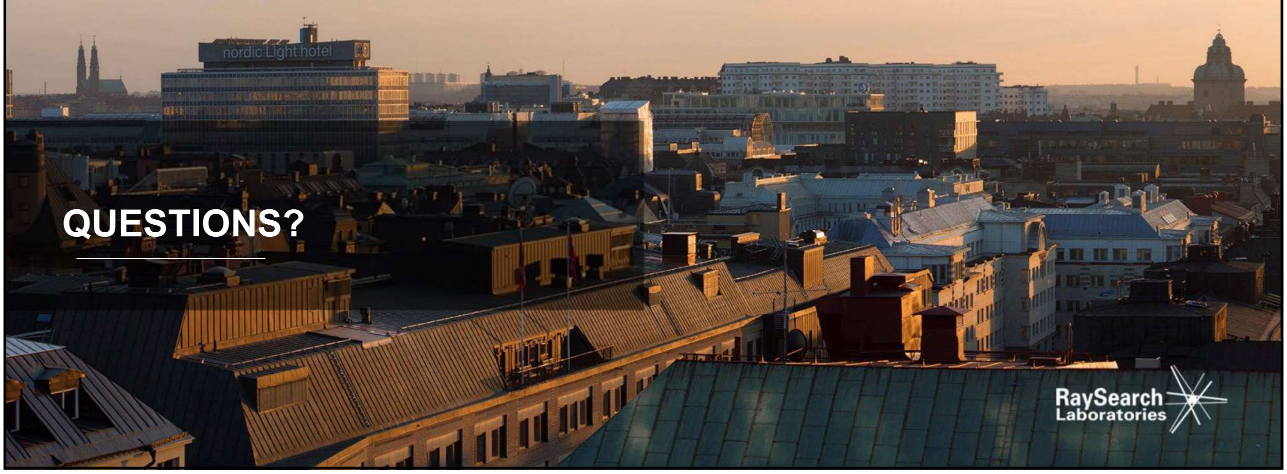
SPECIAL THANK YOU…

STINA SVENSSON- LEAD DEVELOPER RAYSEARCH LABORATORIES

FREDDIE CARDEL – DIRECTOR OF CUSTOMER SUPPORT RSA

MARC MLYN- PRESIDENT OF RAYSEARCH AMERICAS

DAYNA BODENSTEINER- DIRECTOR OF PRODUCT MANAGEMENT- RSA



QUESTIONS?

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