Quality Assurance of Deformable Registration Fields in Clinical Settings

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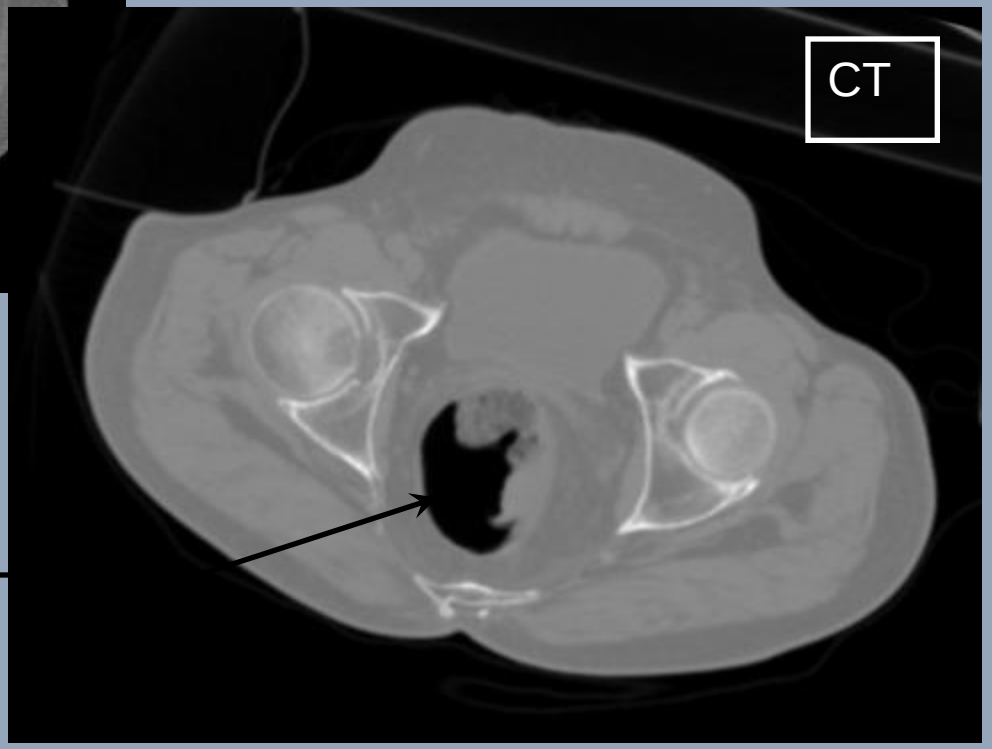
Outline

- What is deformable registration?
- Clinical example
- How do we evaluate results ?

What’s Deformable Registration ?

Image Registration

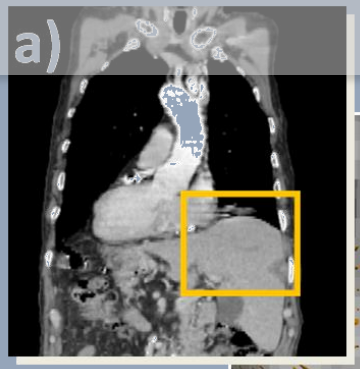
Aim: To best correlate patient position in the two images

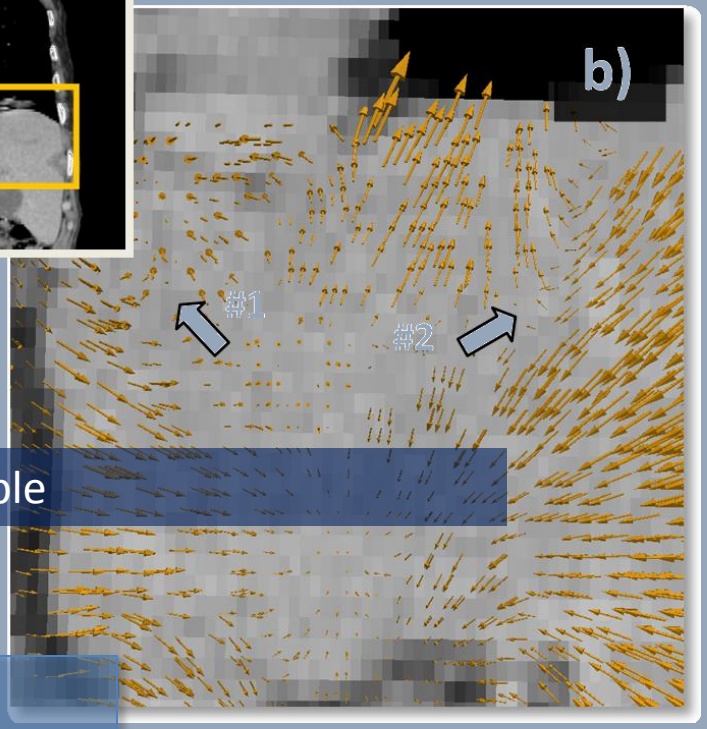


A translation is observed, possible rotation and rectum/bladder deformation

Patient Model

Rigid



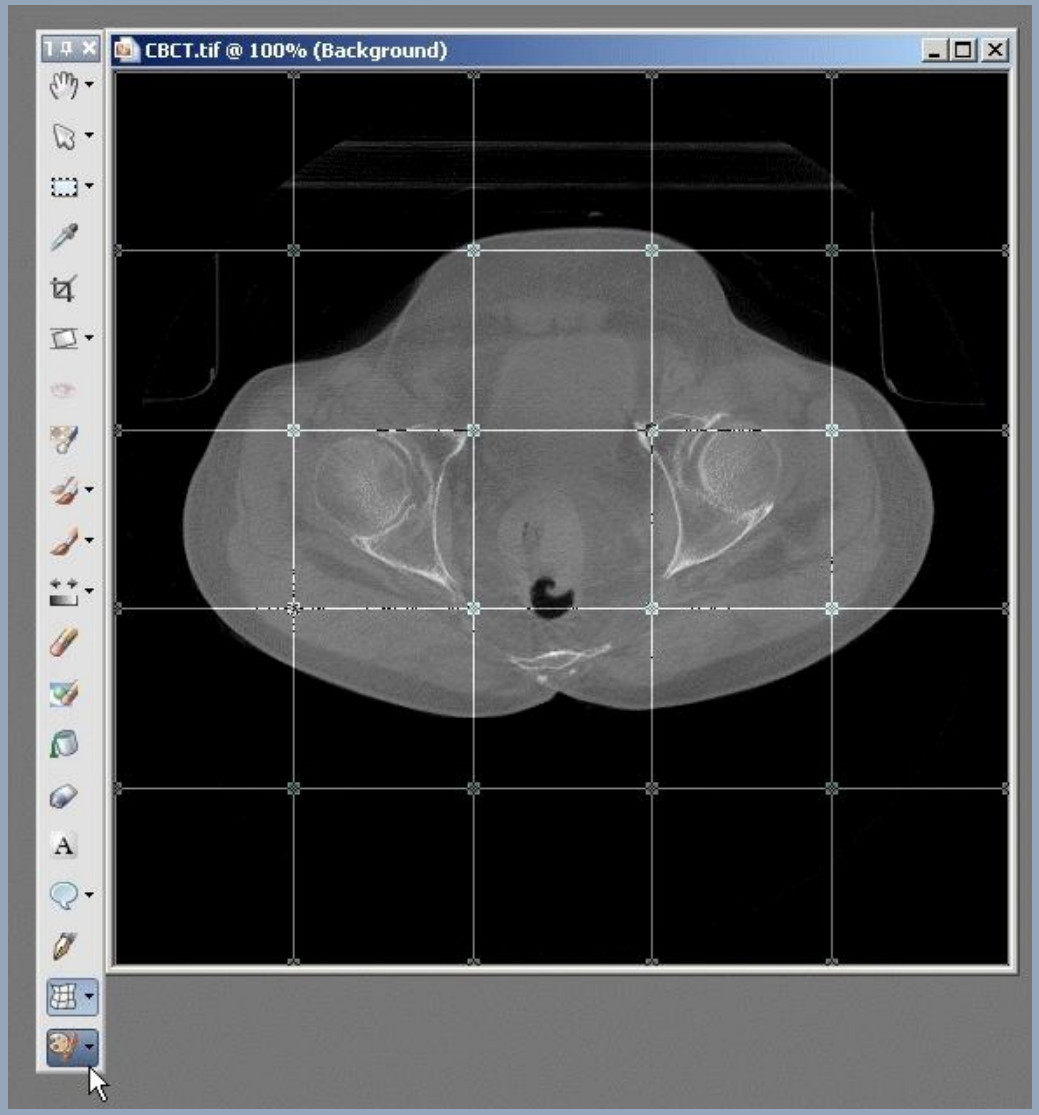


Deformable

Rigid registration finds shifts for the whole body.

Deformable registration considers shifts for each voxel. It is therefore, much more complex.

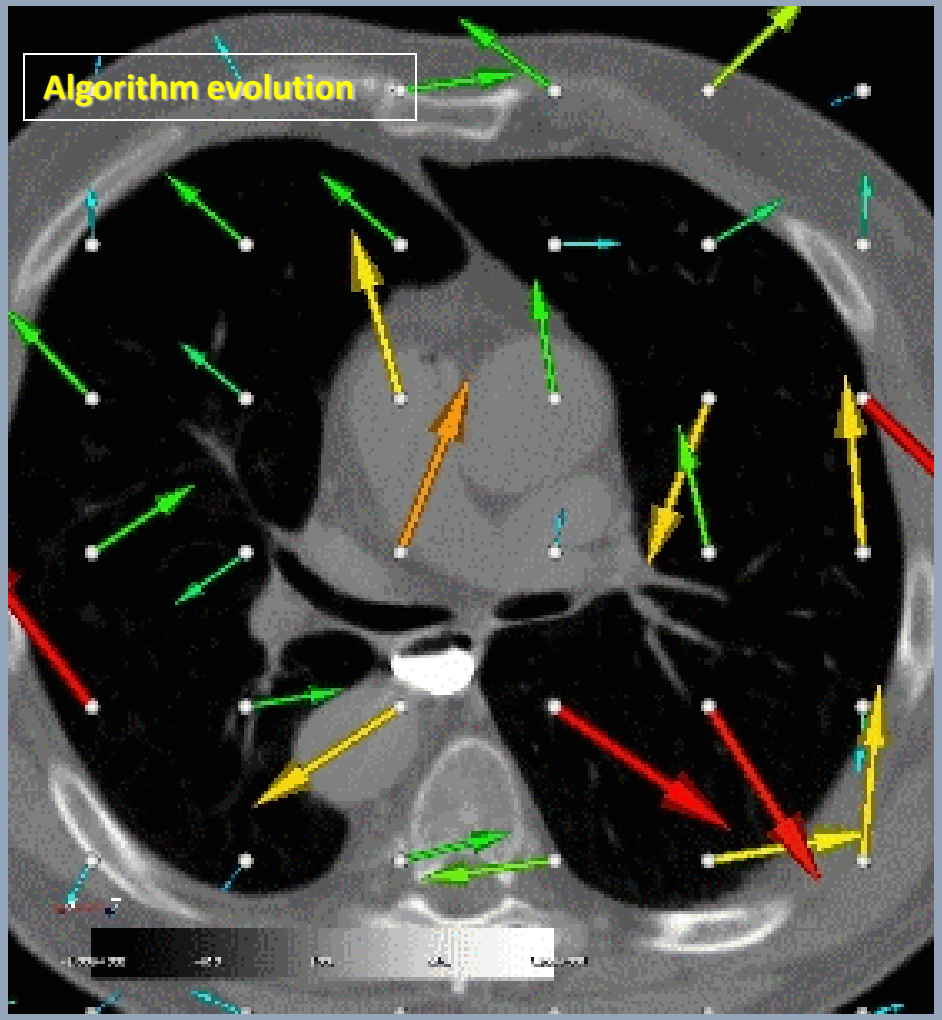
BSpline: Defining Deformations



Displacements defined on set of control points stretched over the image

For any arbitrary location, corresponding displacements deduced by interpolation of closest points

Deformable Registration Output



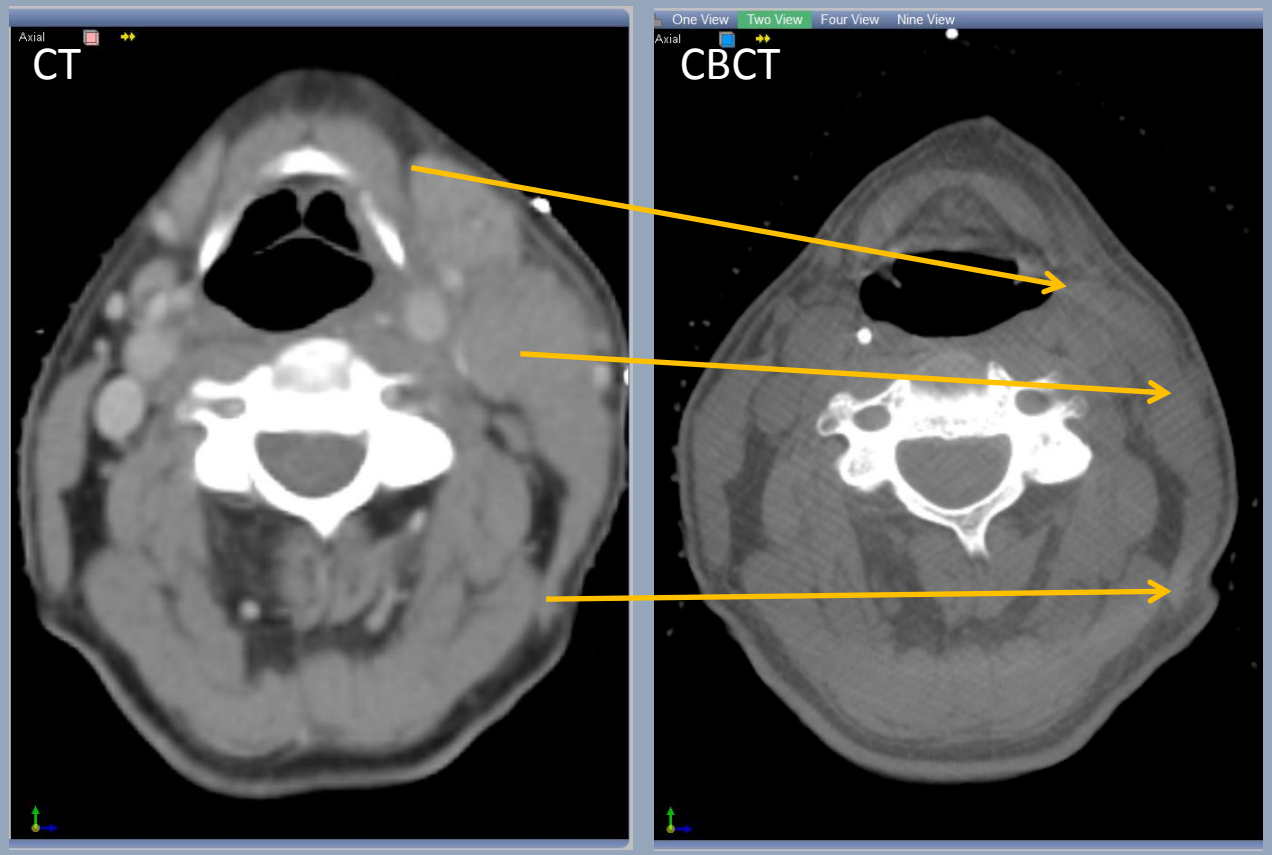
Example of algorithm evolution

Each frame corresponds to one optimization step

Arrow length and color corresponds to deformation intensity

Voxel Tracking

Deformable registration tracks every voxel in your datasets

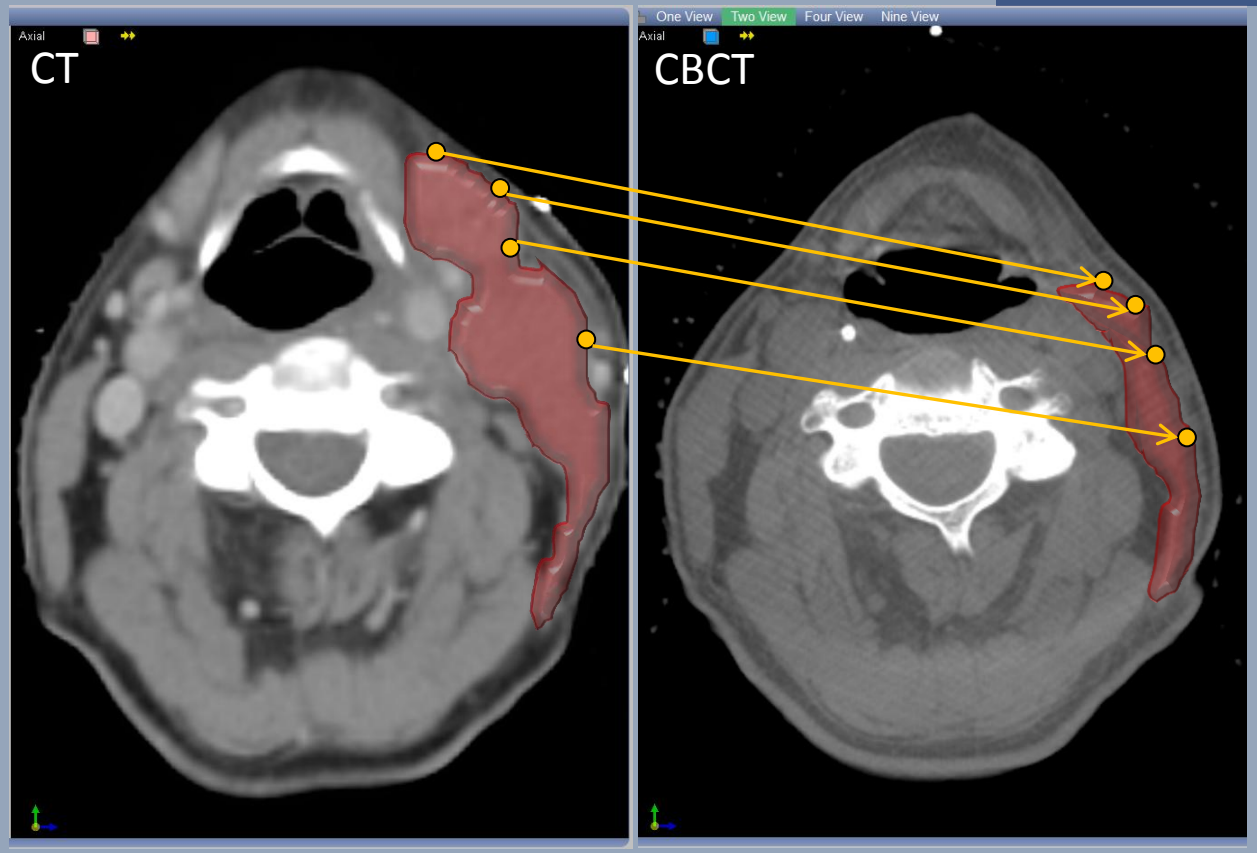


Deformable registration finds location-dependent displacements

Contour, Dose, SUV Tracking

Same transform can be applied on :

Dose (dose tracking)
SUV values (response assessment)



The deformation field between two image scans obtained from the deformable registration can be used to deduce displacements on the contours

Various Algorithms

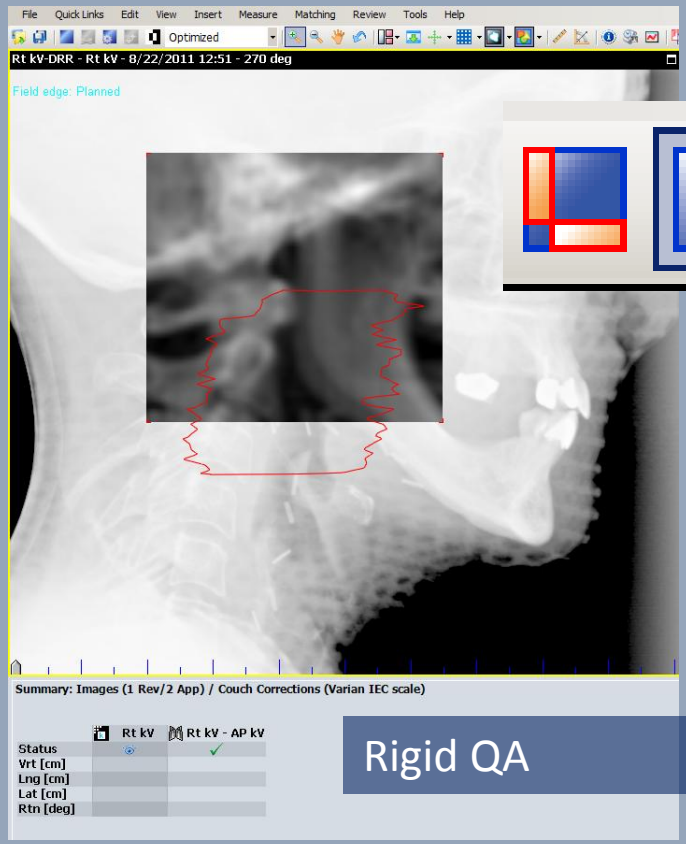
No clear winner – Various implementations of the algorithms available –demons, BSpline, FEM

Assumptions - Each algorithm makes a trade-off between accuracy and speed by simplifying the problem.

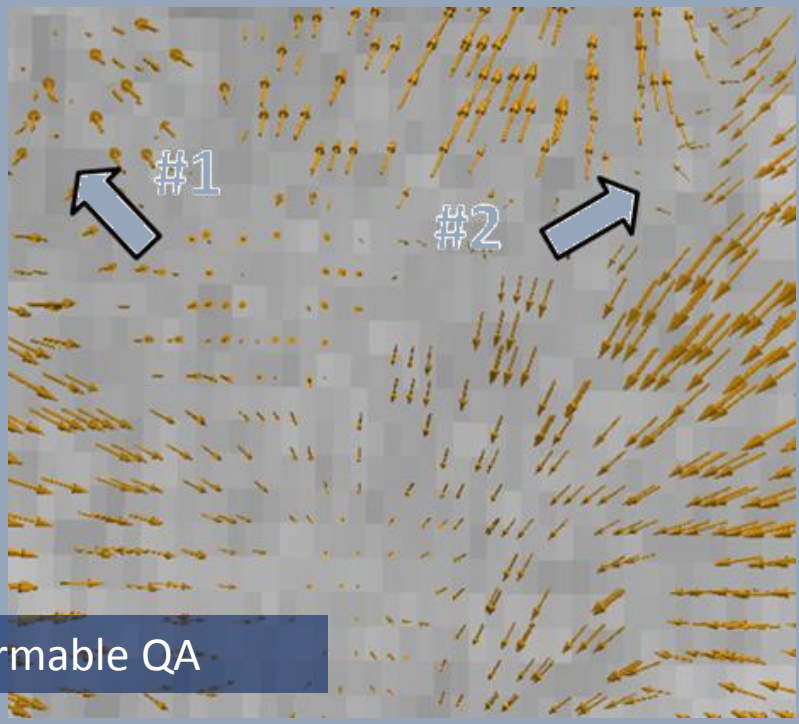
QA Procedure – Should check that the assumptions are met clinically **for each case**.

Take Home Message

Displacement (Vector) Field –should be used as complimentary source of information



Rigid QA



Deformable QA

Clinical Example:
CT-CBCT Deformable Registration

Sample Case

Is dose still valid ? Should re-sim ? Is it worth going through the whole segmentation and planning process ?

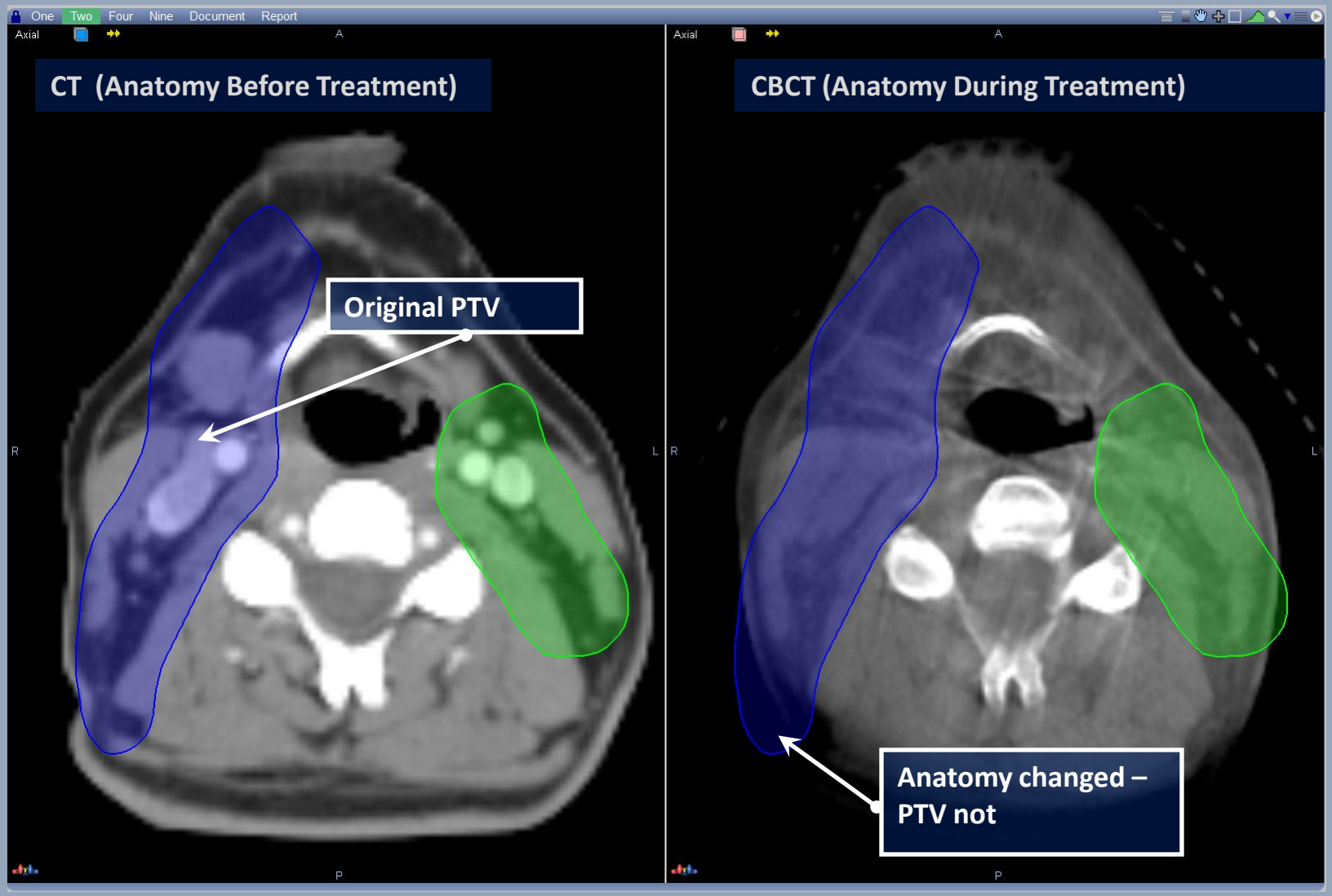
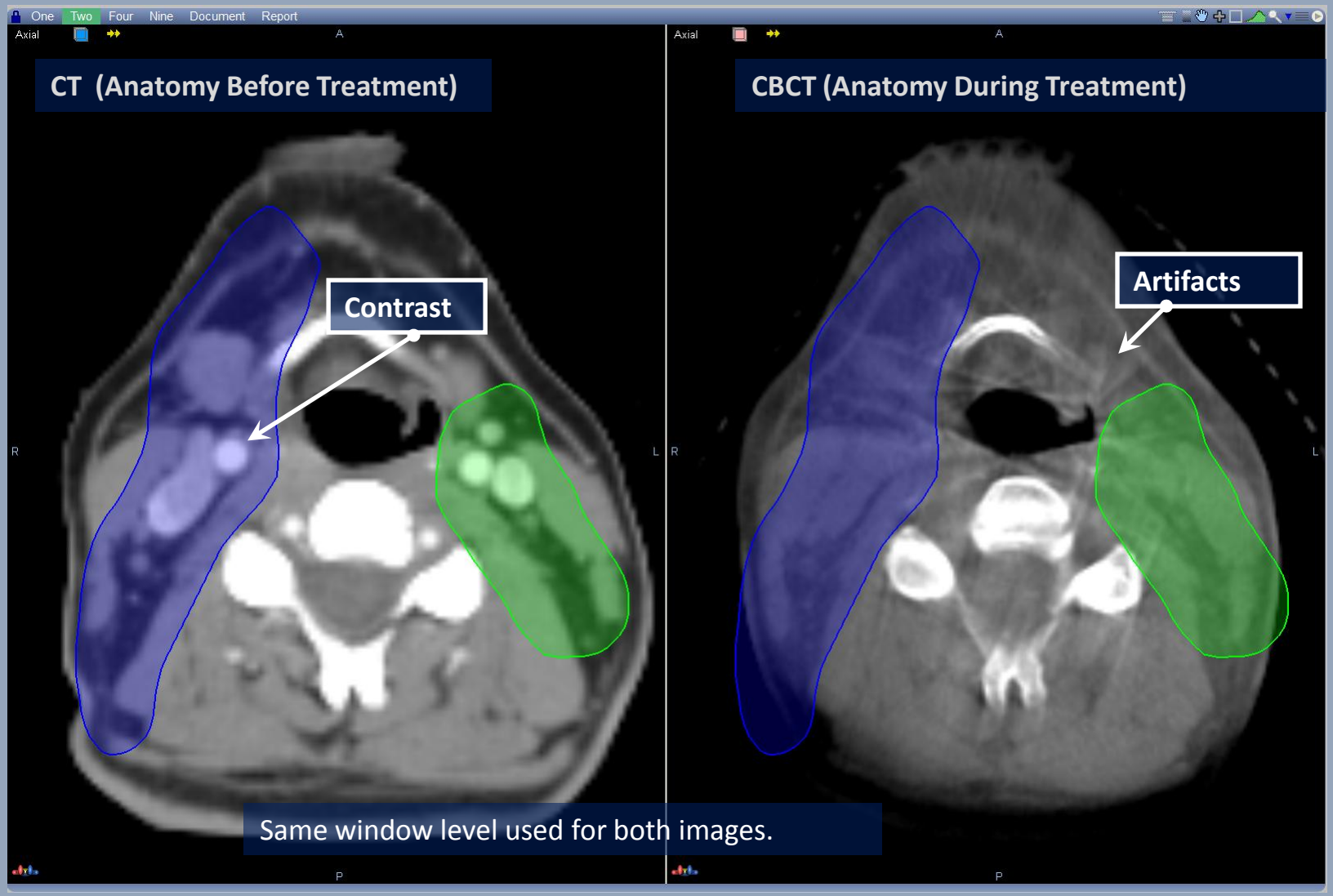


Image Quality

- Assume same modality
- Different image quality



Mono-Modality Registration

Demons algorithm to quantify changes

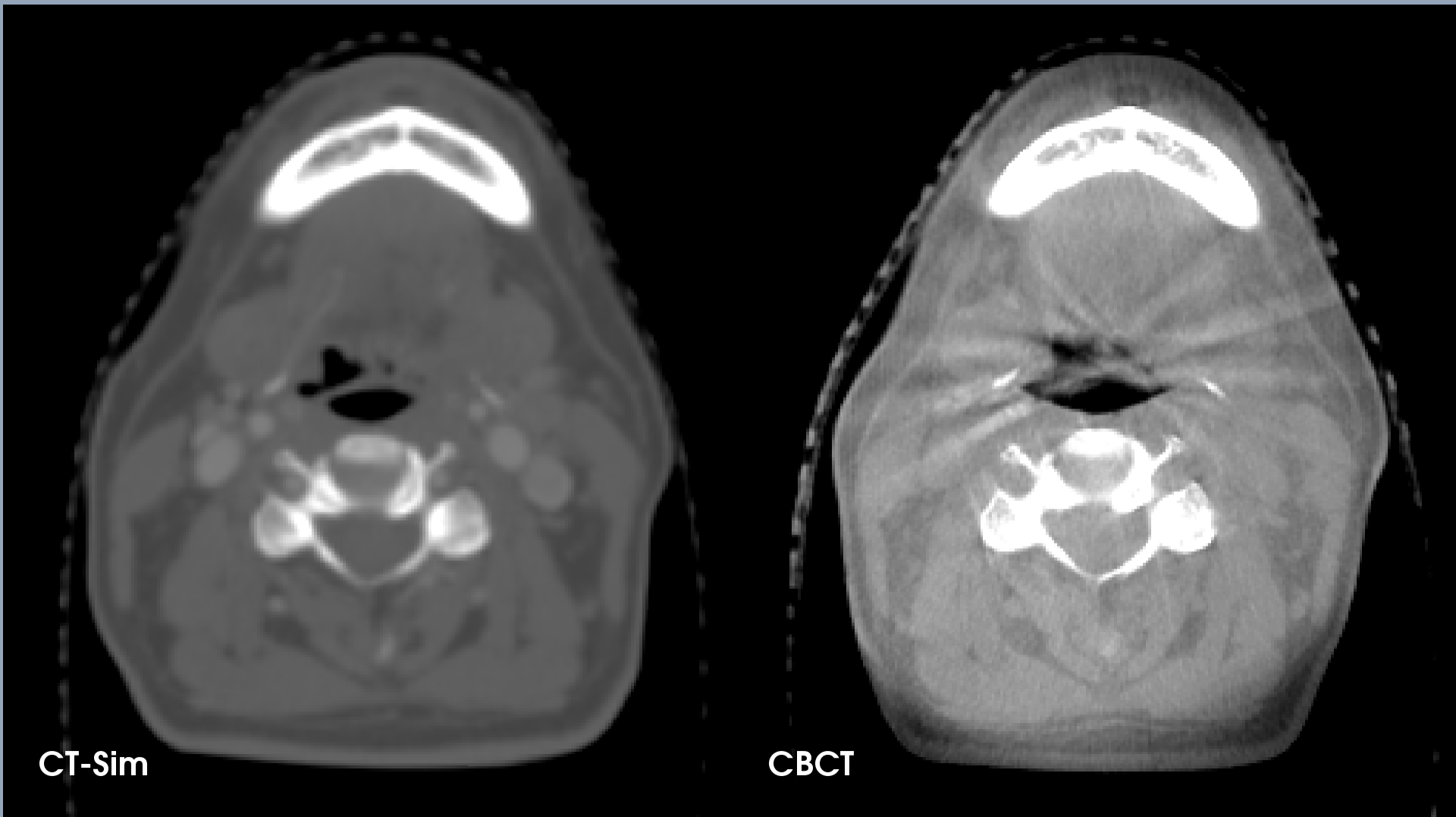
This is a mono-modality algorithm that assumes a structure has the same HU in both CT and CBCT

Then estimating dose using voxel tracking

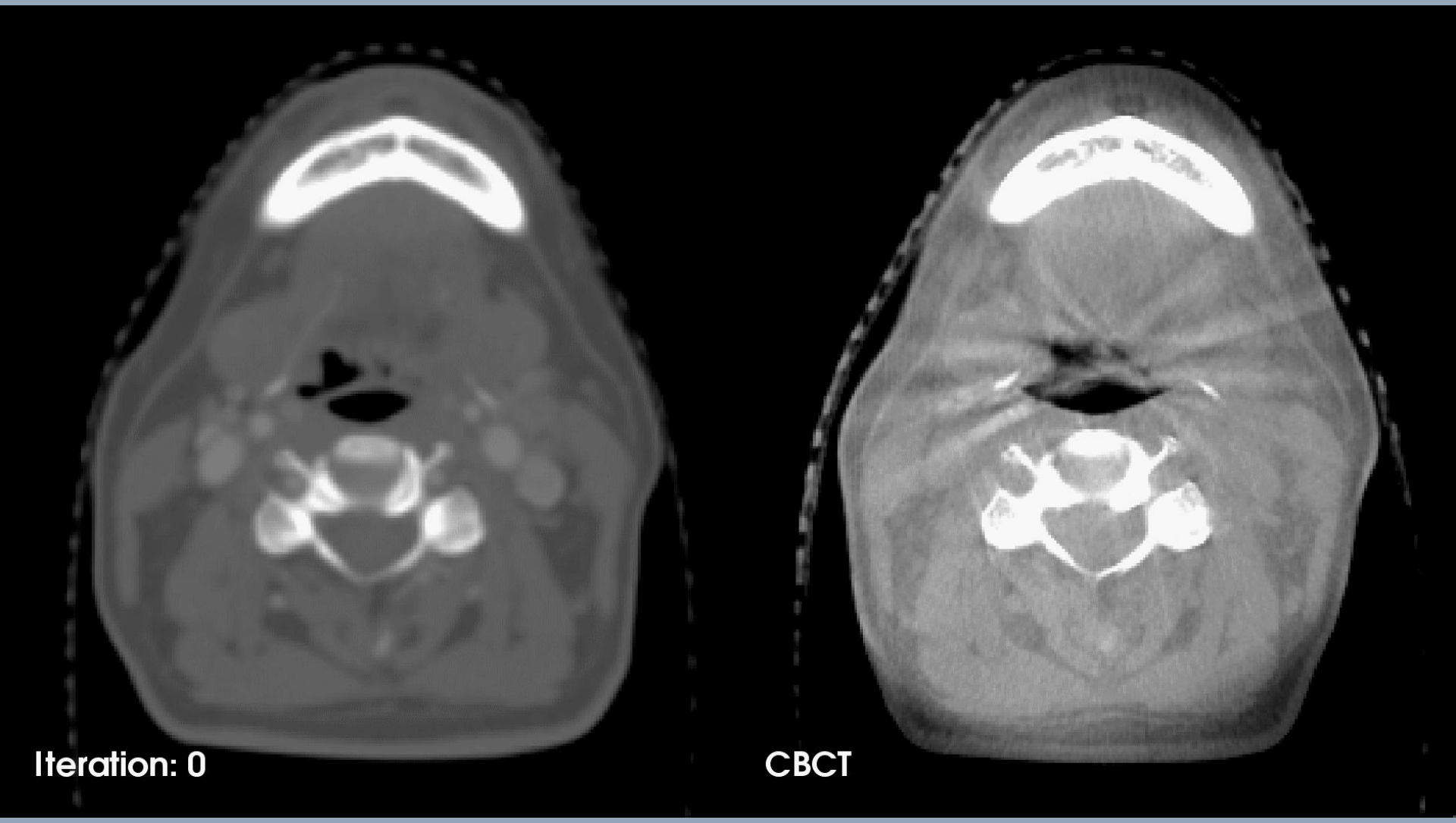
Displacement field applied on structures for auto-segmentation

Applied on dose for estimating DVHs.

Before Registration

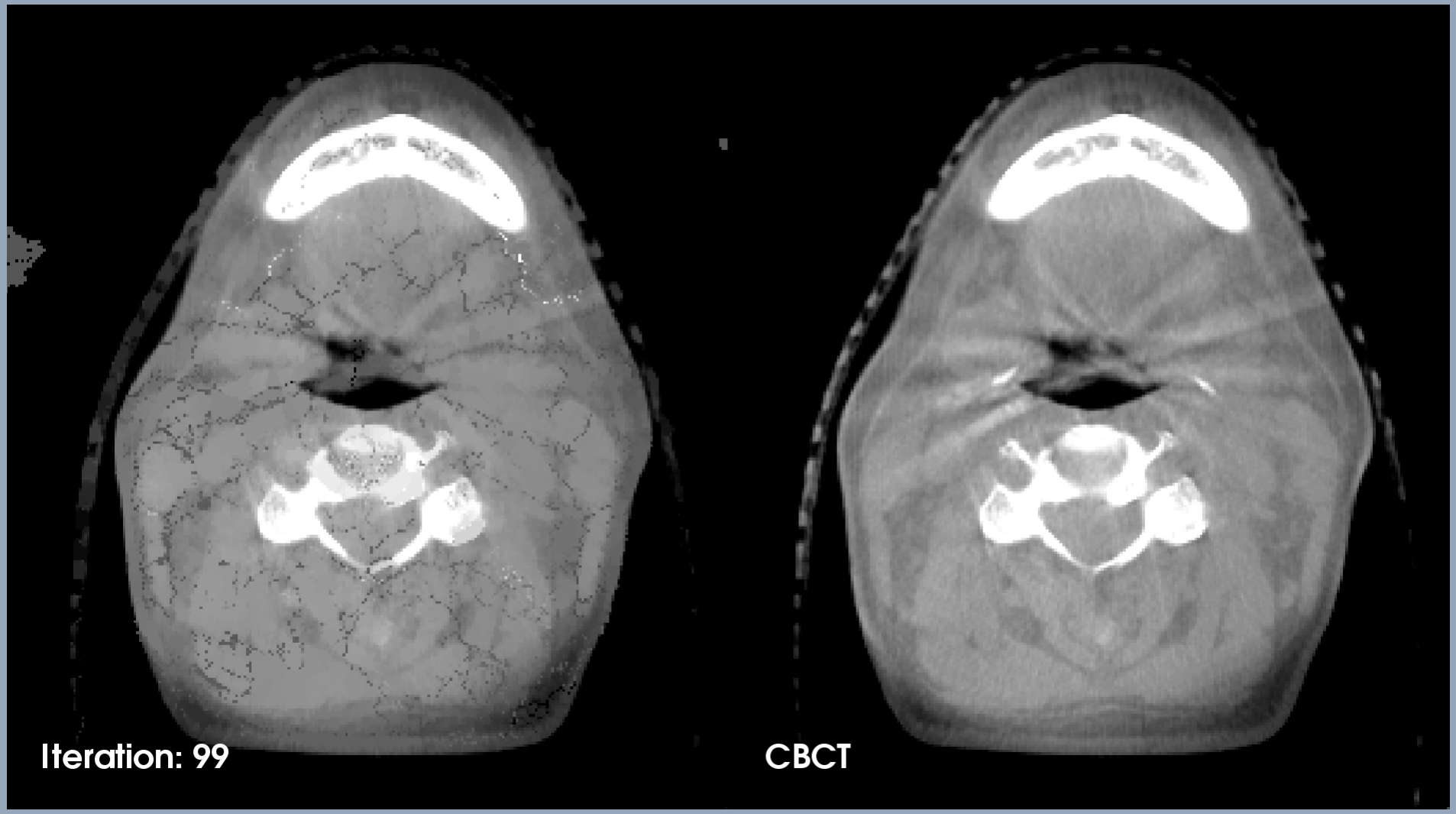


Iterations of Demons



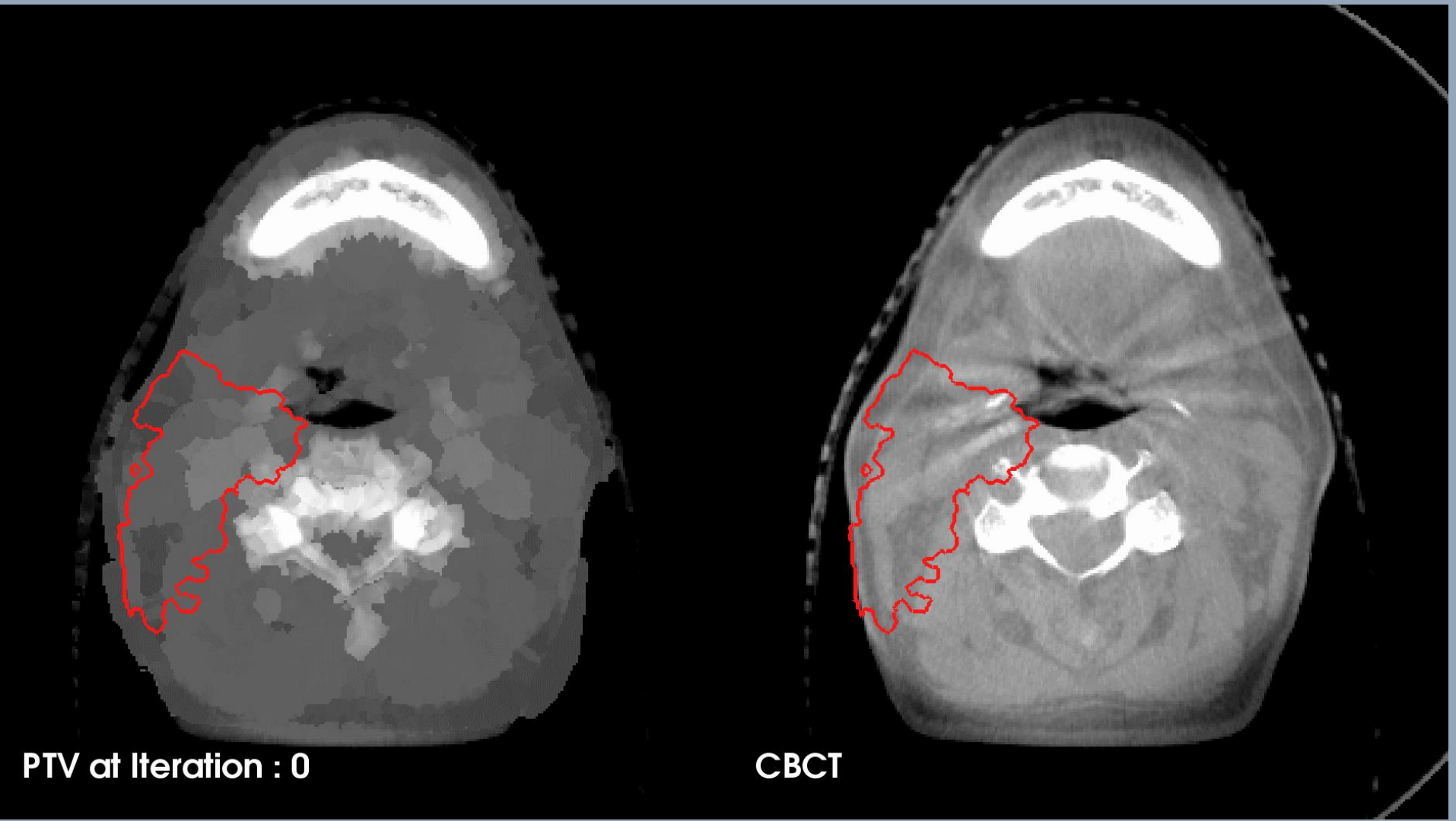
Final Result

- Details are matched with highest accuracy
- Image-wise, results look perfect



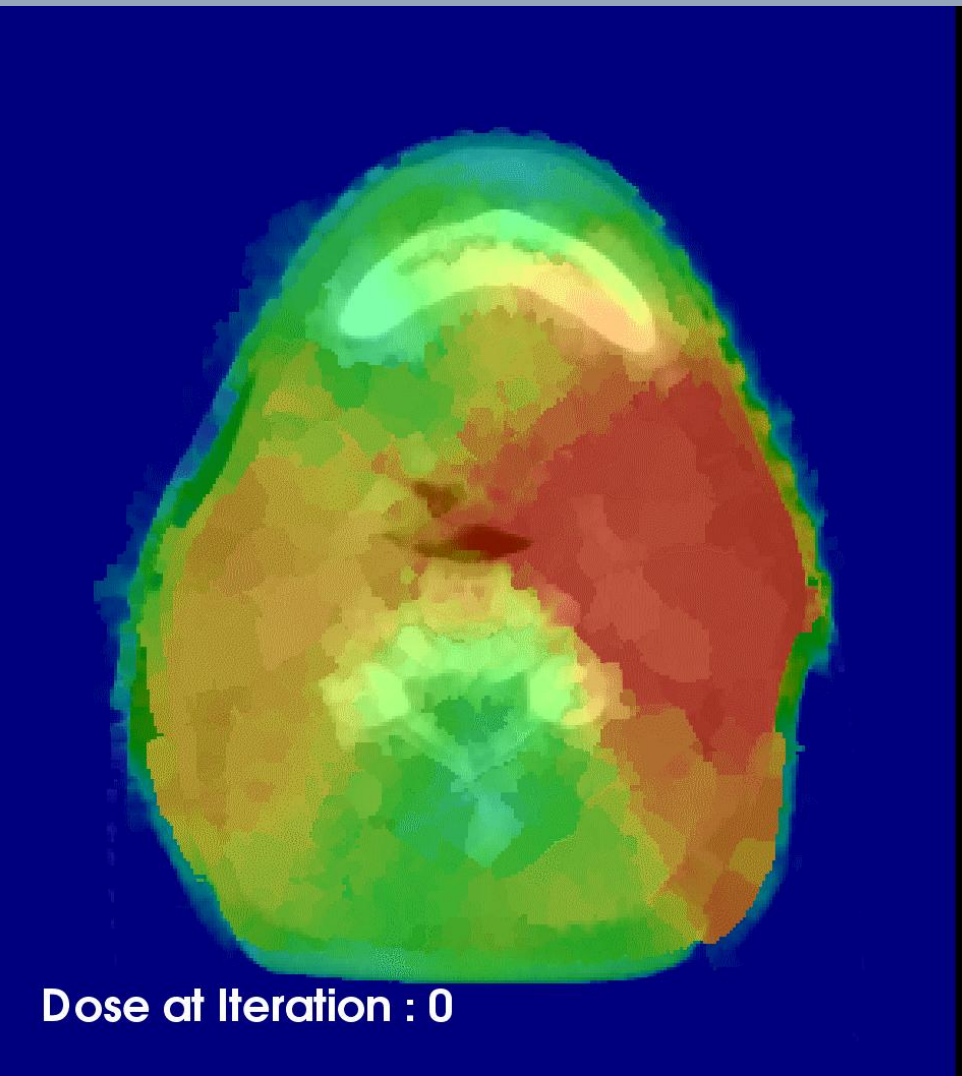
Deformable Applied on Structures

- Segmentation warped with the result
- PTV mapped to soft tissue (same HU)



Deformable Applied on Dose

- Resulting deformation applied on dose
- Warping unrealistic clinically



Multi-Modality Registration

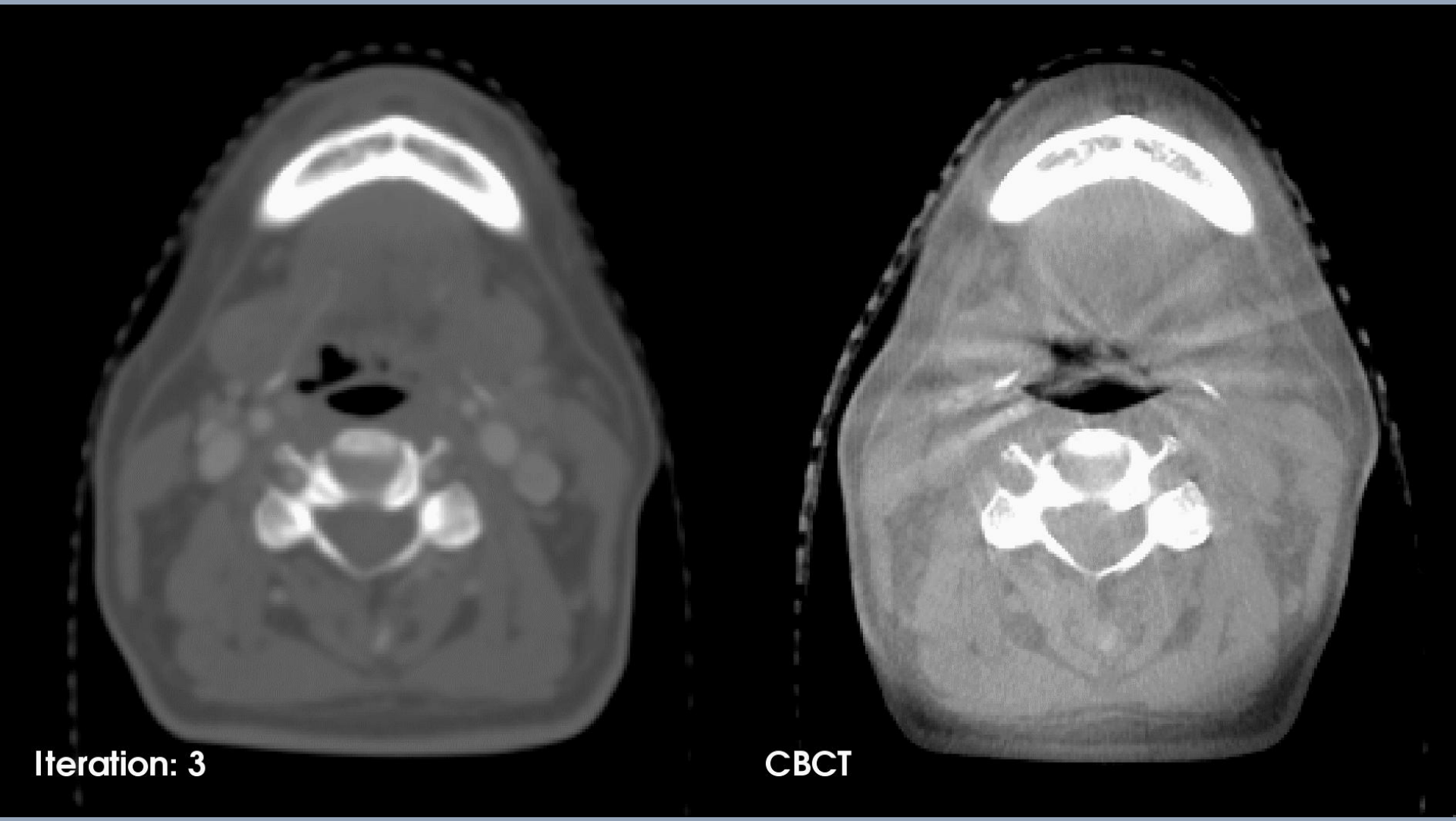
BSpline algorithm to quantify changes

- **It's ok to have changes in HU and artifacts between CT and CBCT**

Then estimating dose

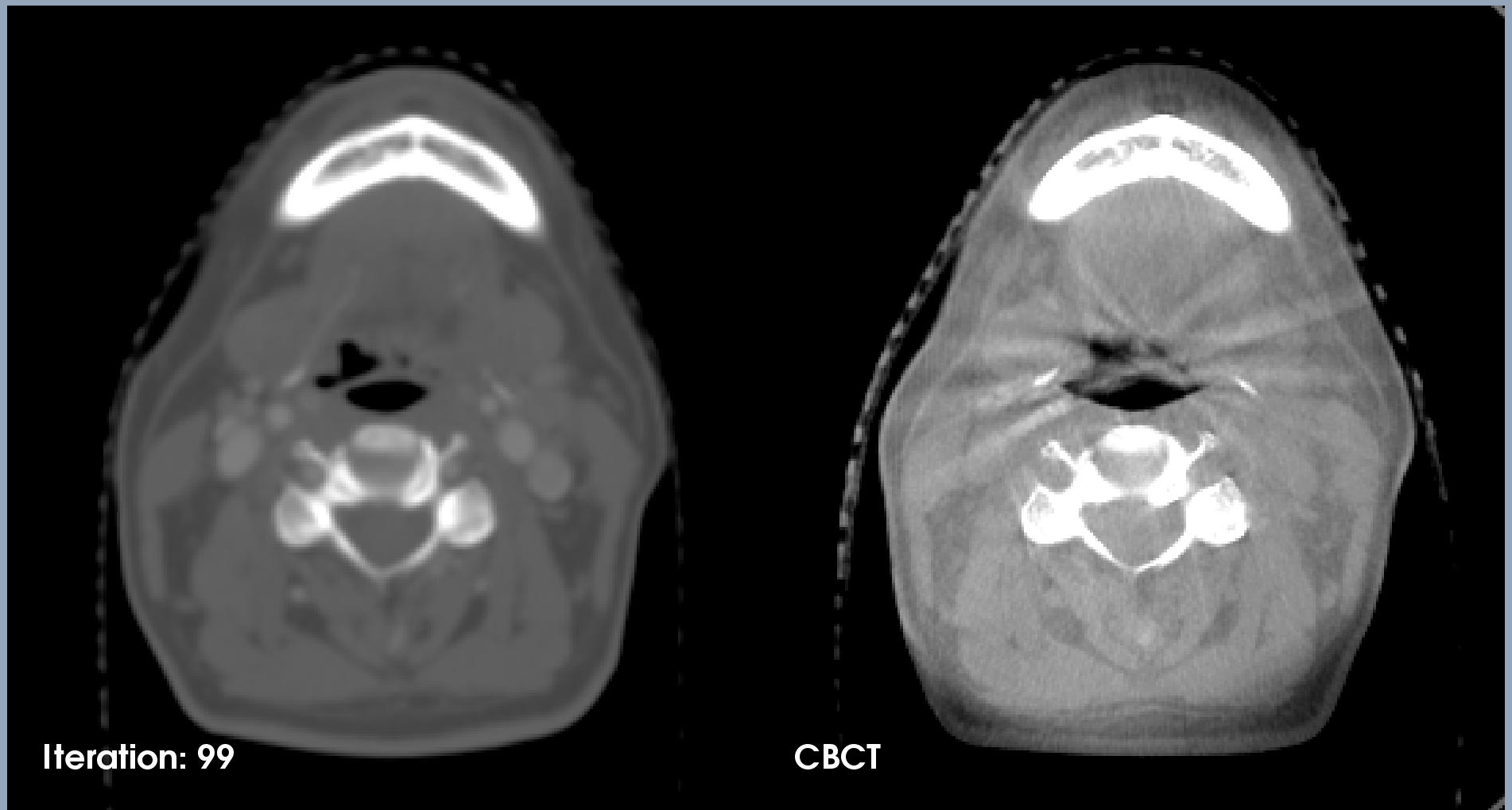
- Displacement field applied on structures for auto-segmentation
- Applied on dose for estimating DVHs.

Iterations of BSpline



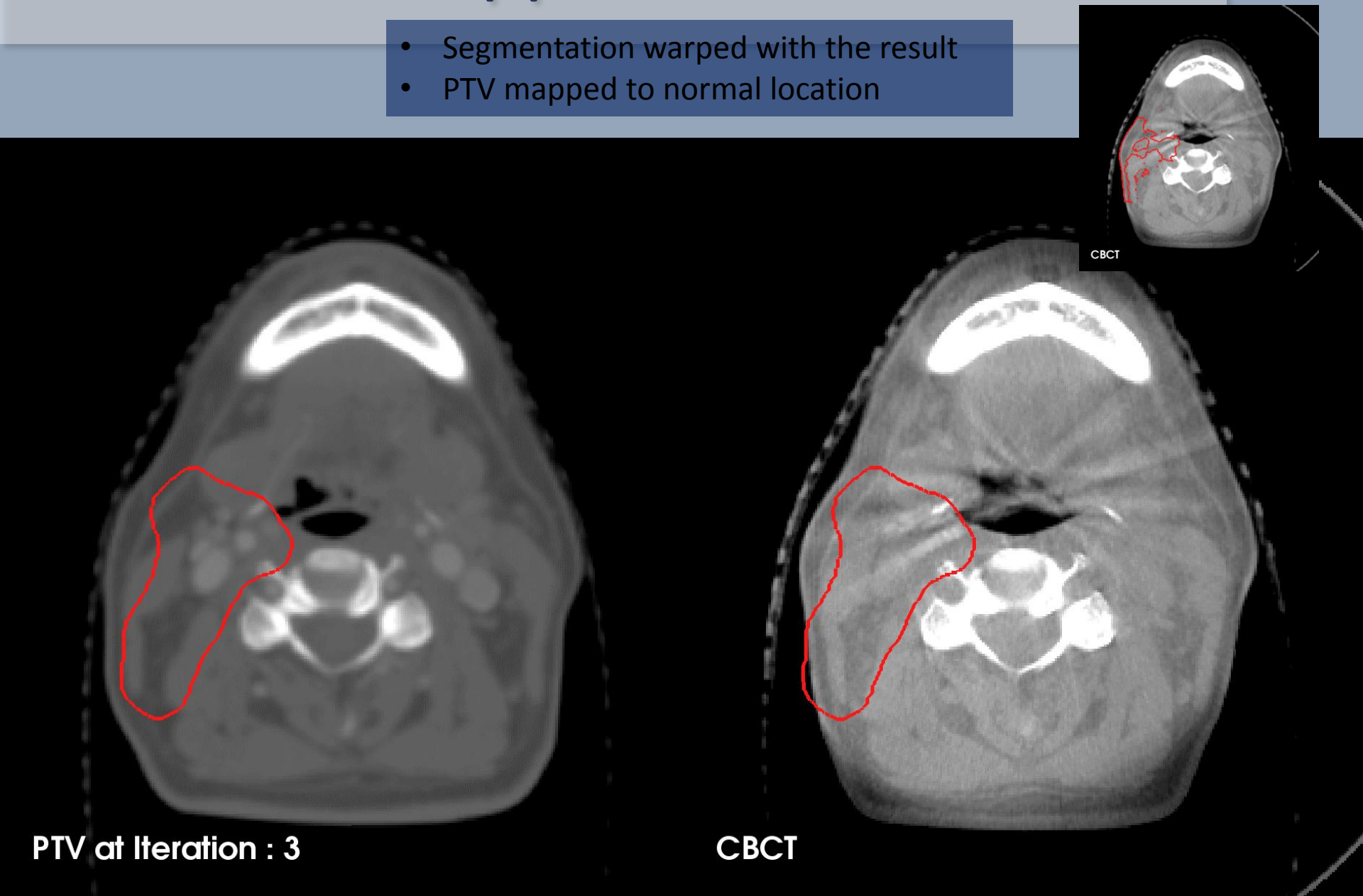
Final Result

- HU are preserved
- Displacement field plausible



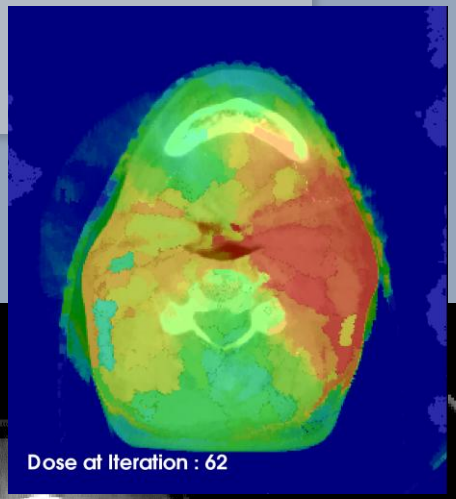
Deformable Applied on Structures

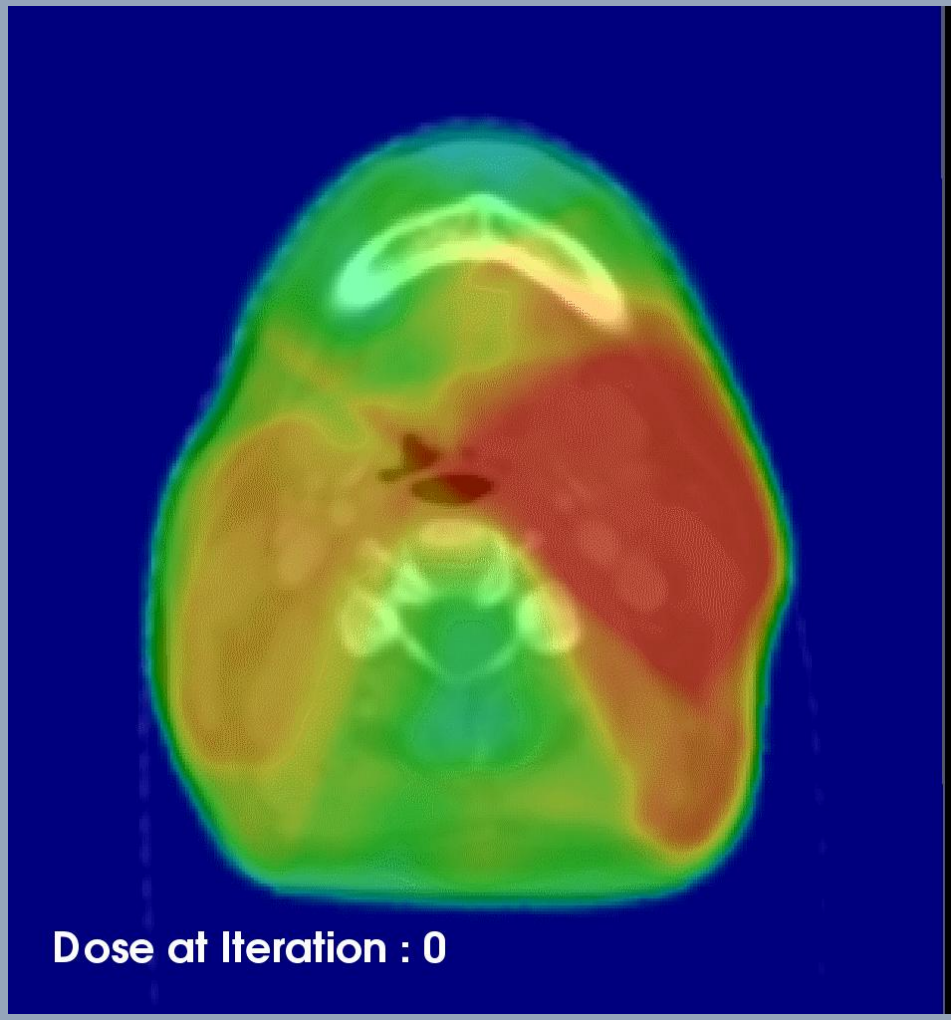
- Segmentation warped with the result
- PTV mapped to normal location

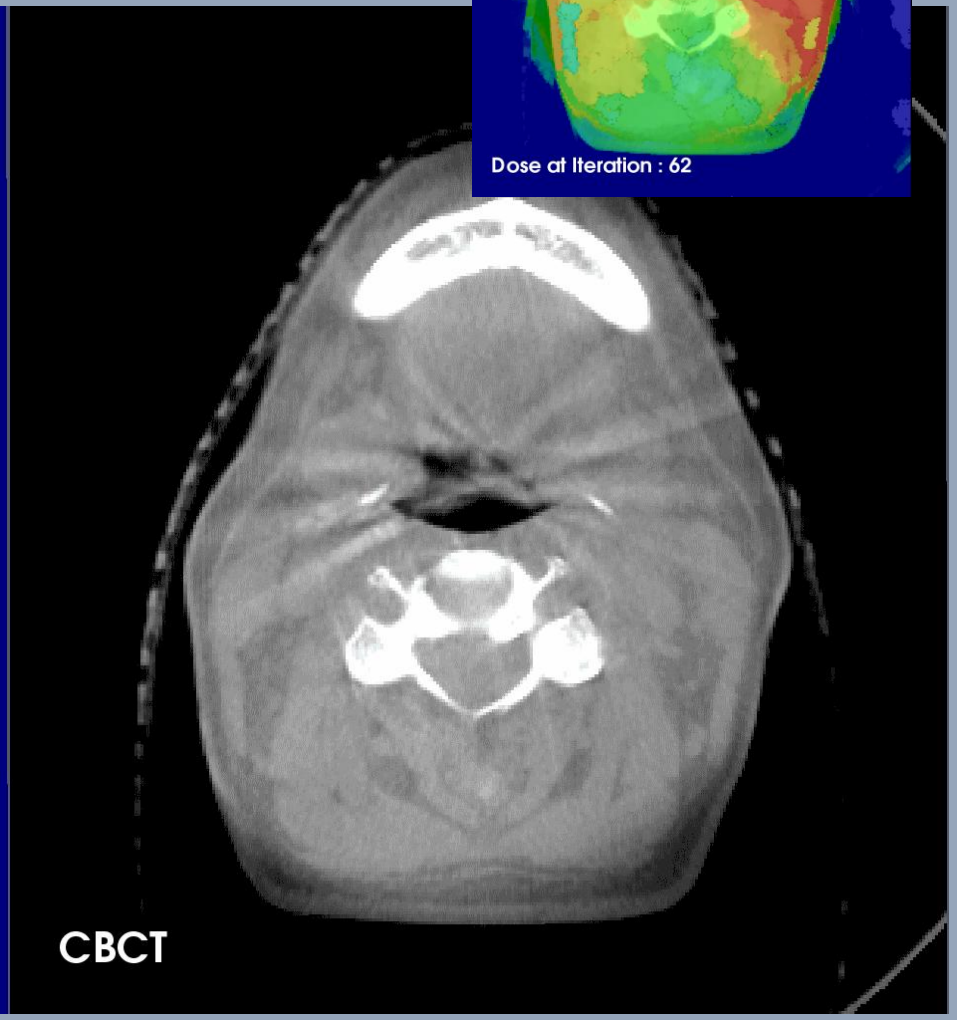


Deformable Applied on Dose

Preserves dose distribution shape



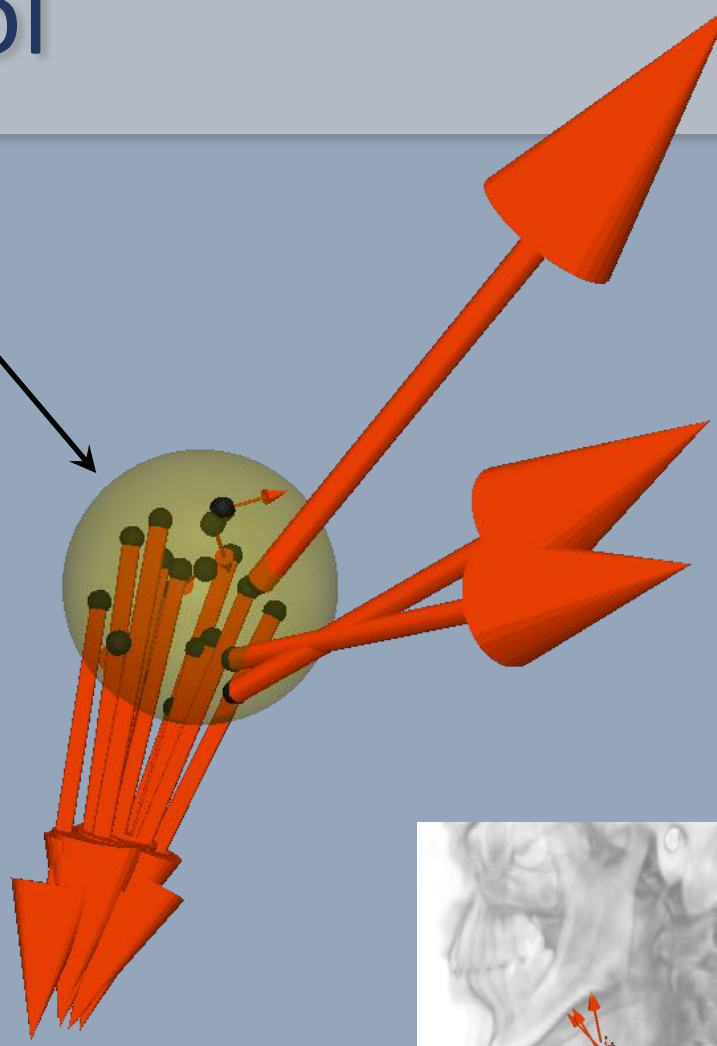


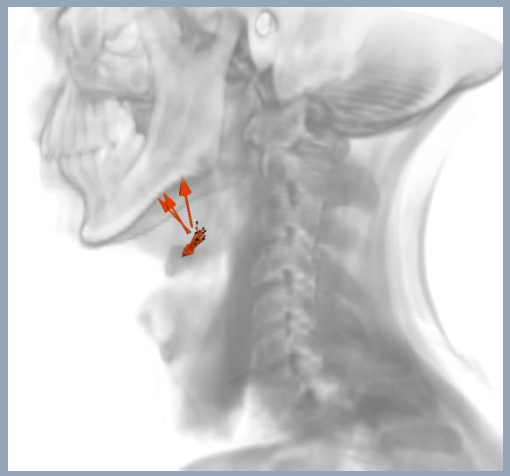


A Field Probing Tool

Random sampling points generated inside a sphere (black dots)

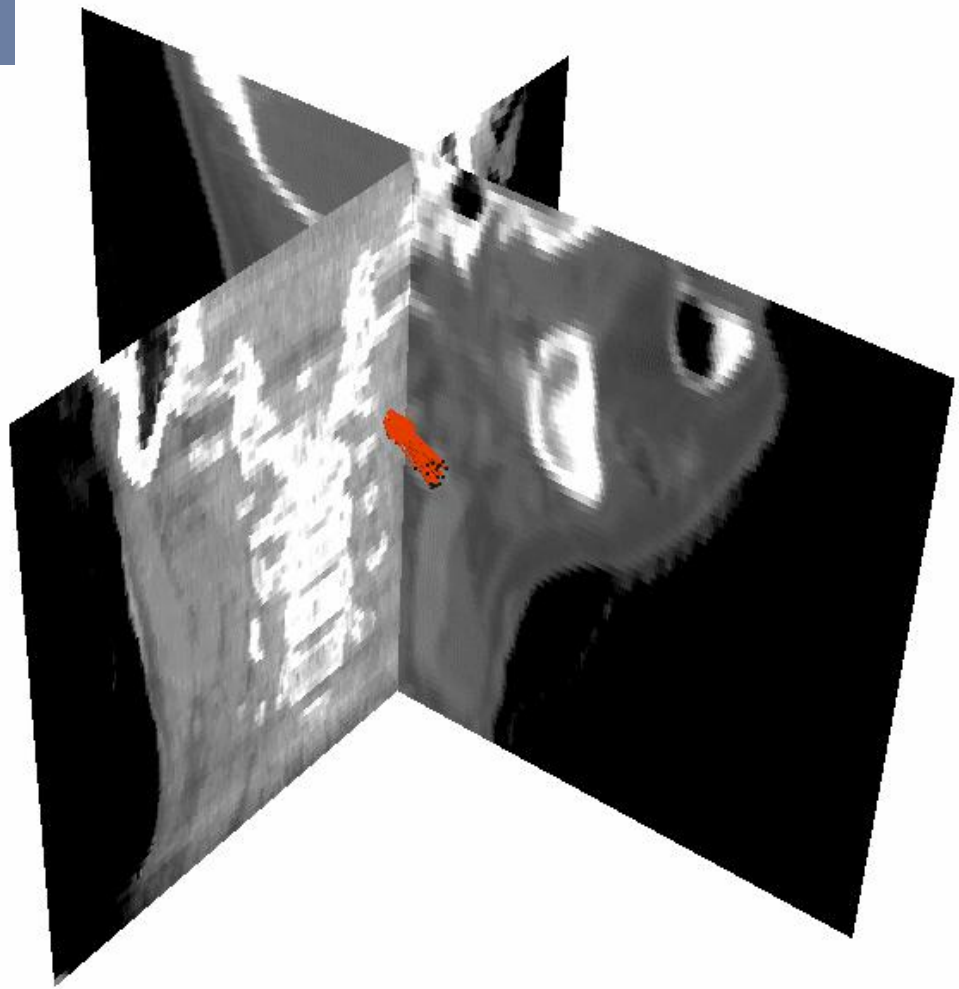
Arrows show where the displacement field would move these points



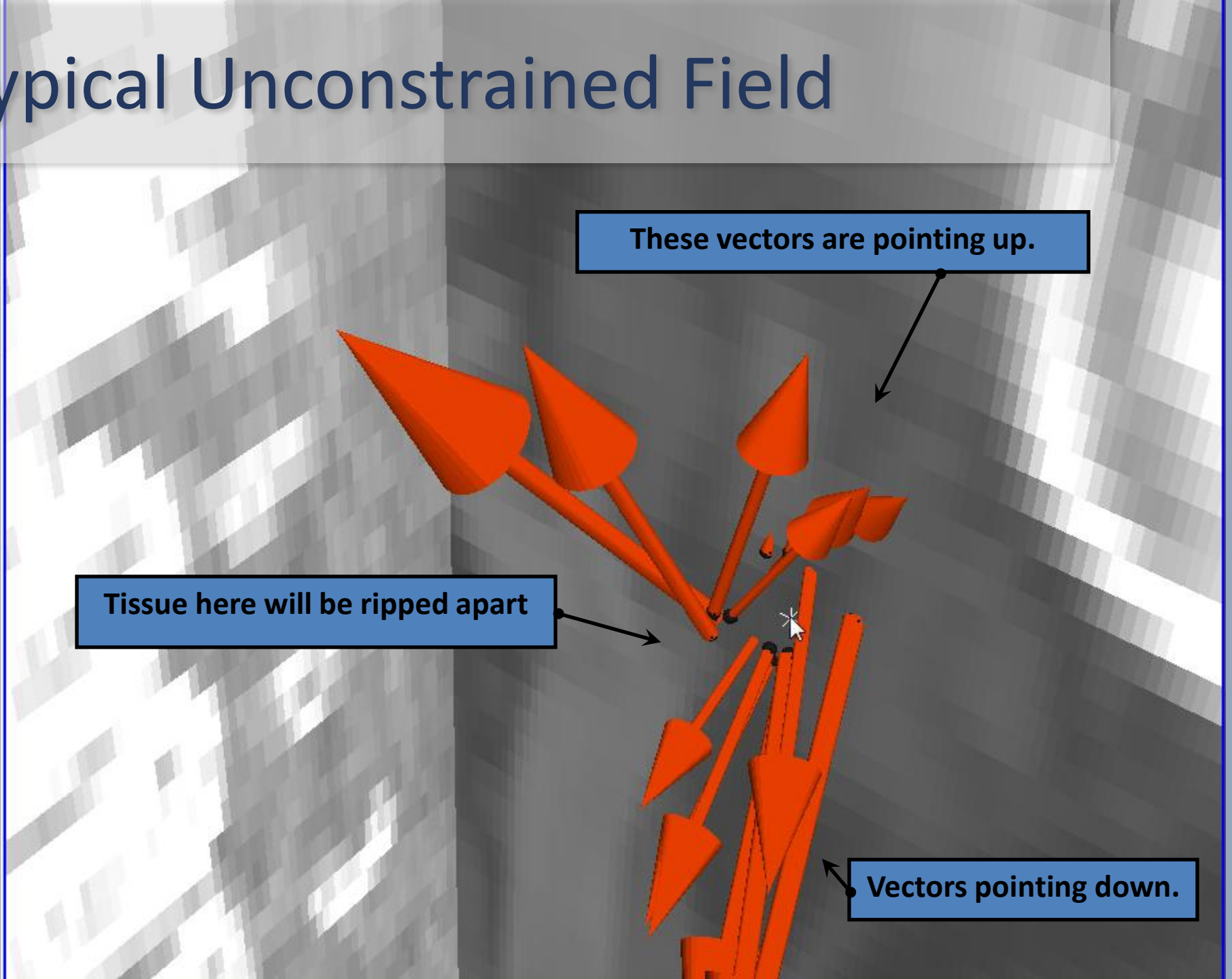


Voxel Tracking

Mono-modality field is probed

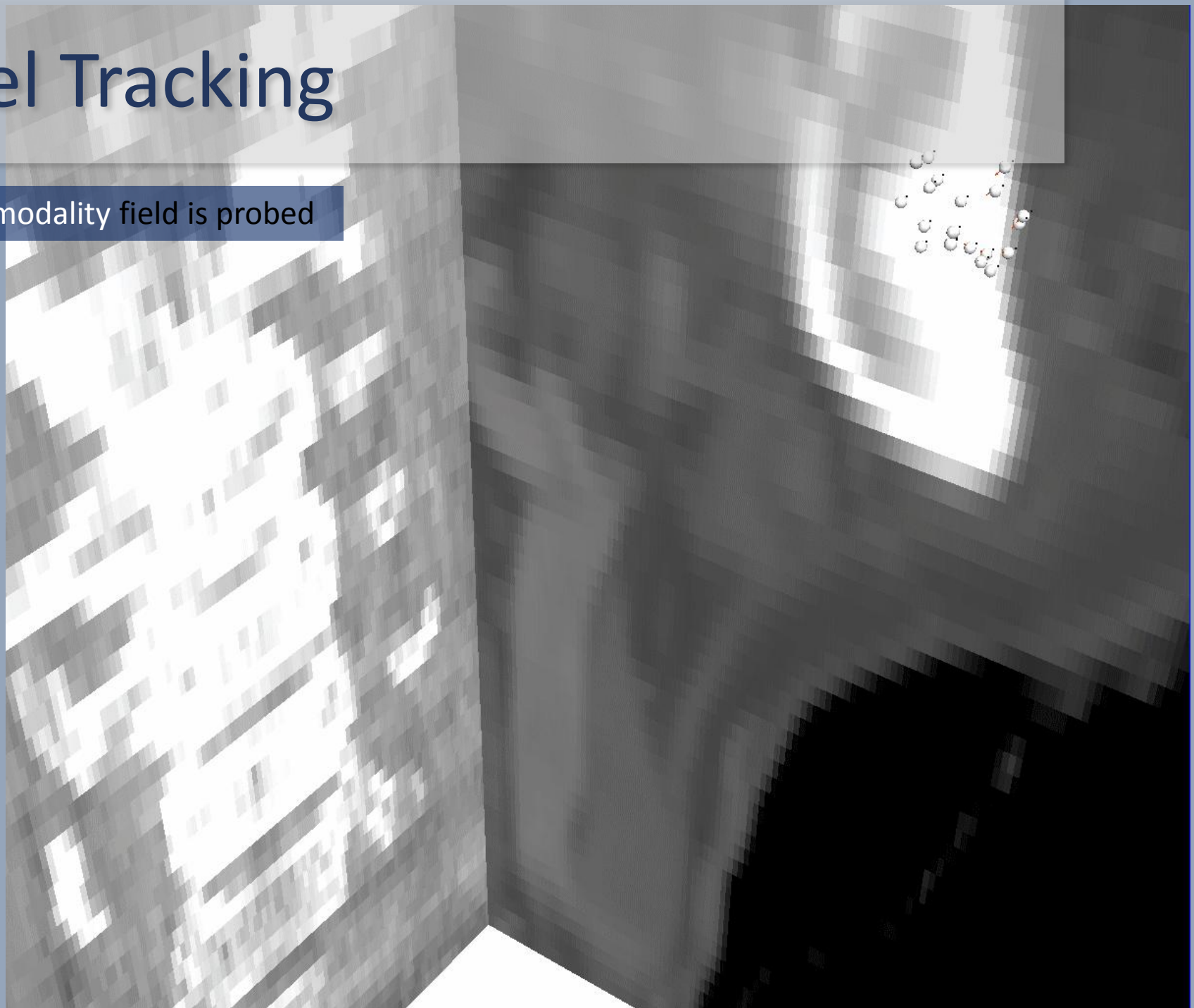


Typical Unconstrained Field

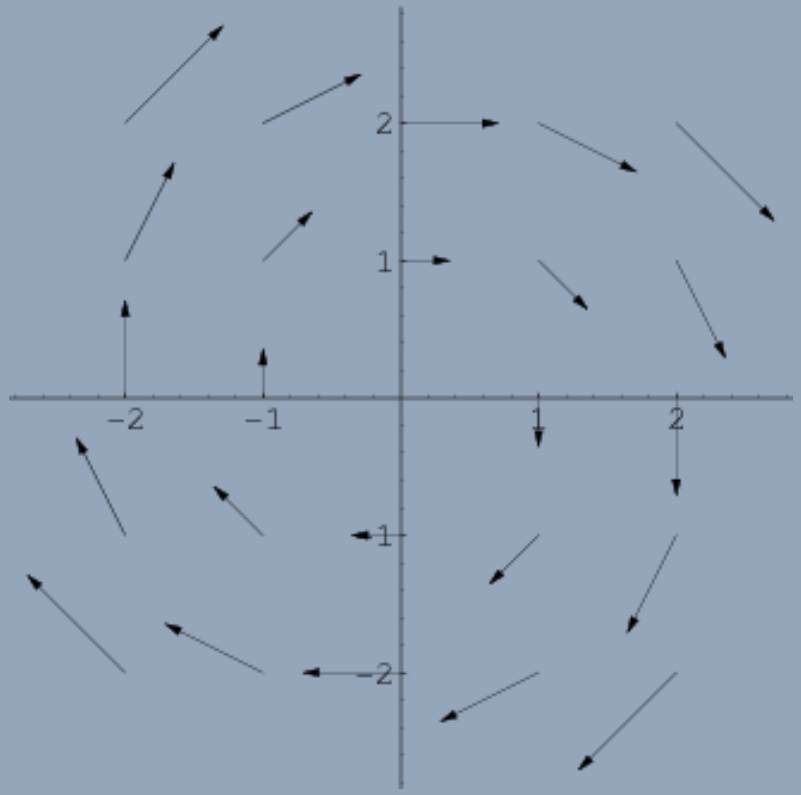


Voxel Tracking

Multi-modality field is probed



CURL Operator



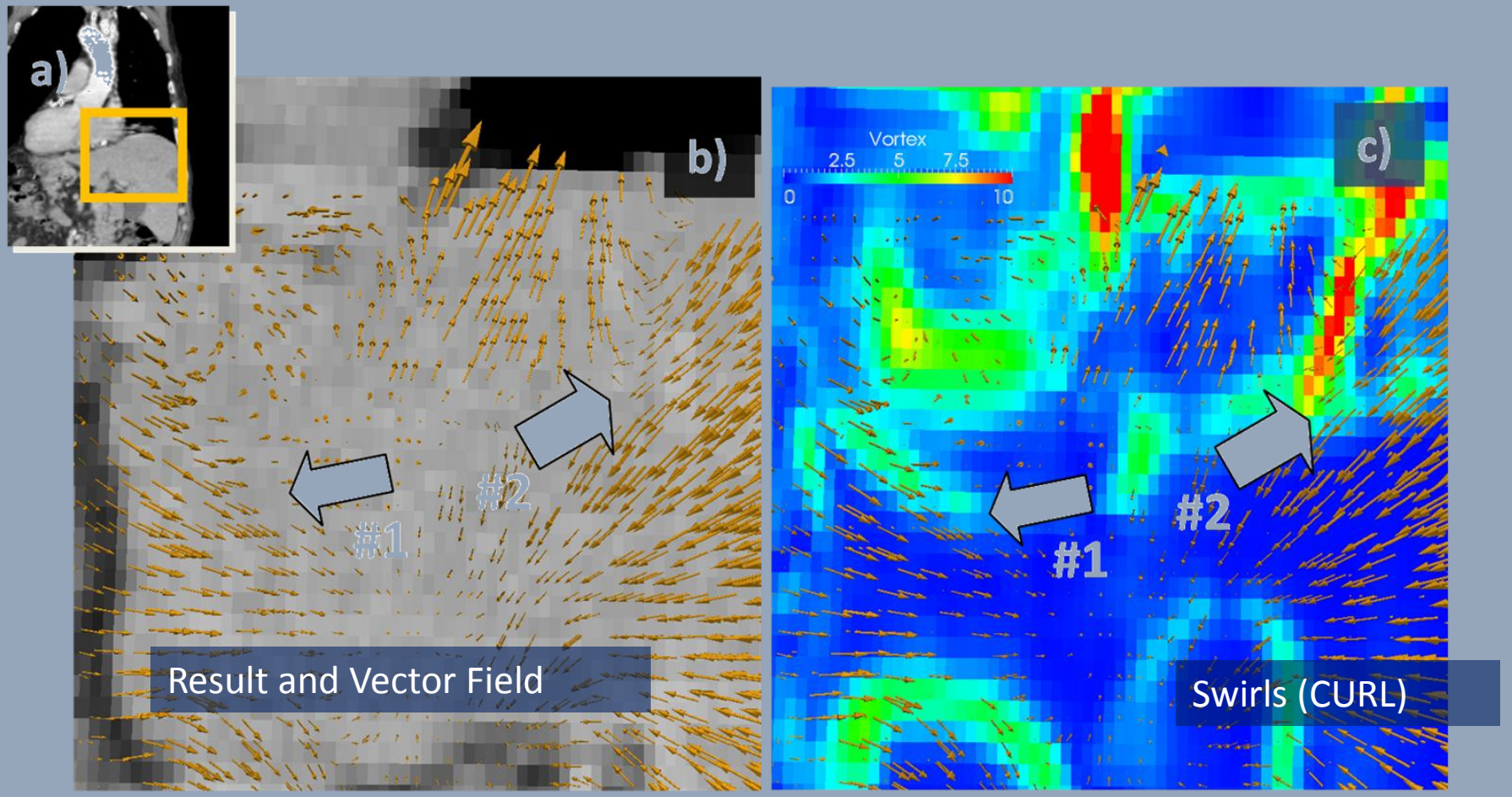
This deformation field would cause rotation of an imaginary sphere placed at origin.

Such swirls in the displacement field, uncharacteristic to natural anatomical displacements, can be characterized by the CURL operator

$$\nabla \times \mathbf{F} = \left(\frac{\partial F_z}{\partial y} - \frac{\partial F_y}{\partial z}\right)\hat{\mathbf{x}} + \left(\frac{\partial F_x}{\partial z} - \frac{\partial F_z}{\partial x}\right)\hat{\mathbf{y}} + \left(\frac{\partial F_y}{\partial x} - \frac{\partial F_x}{\partial y}\right)\hat{\mathbf{z}}.$$

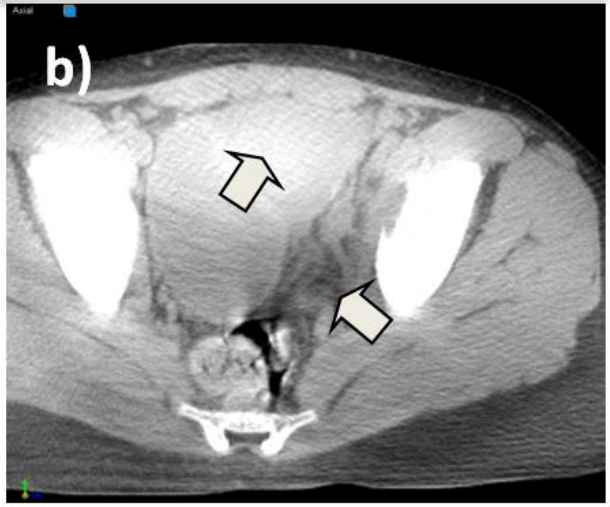
Interpretation Tool: Swirls

A measure of vector analysis (CURL) can find swirls (rotations) in the displacement field.

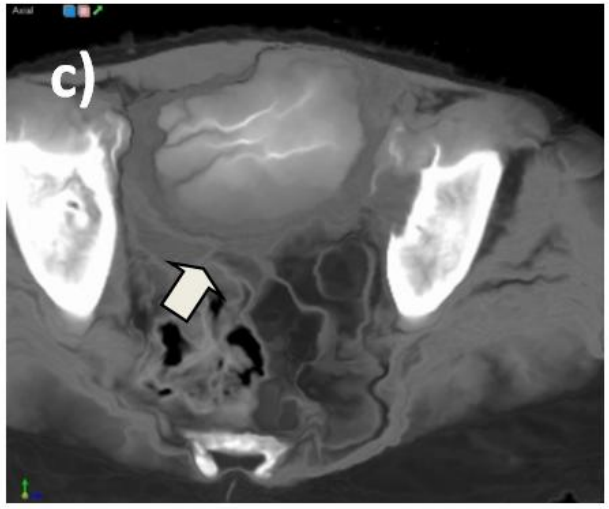


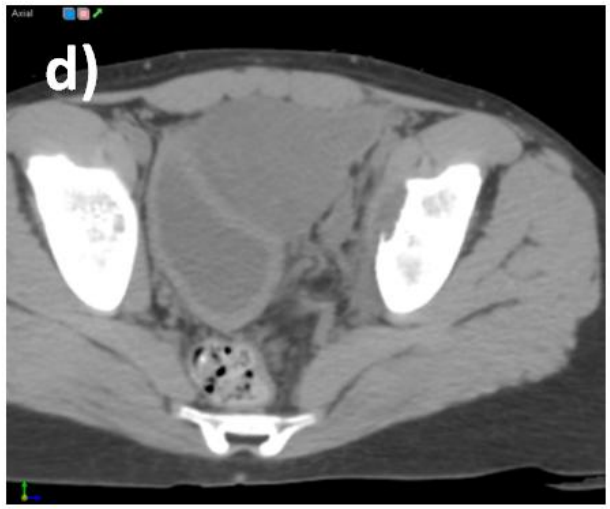
Interpretation Tool: Swirls

INPUT



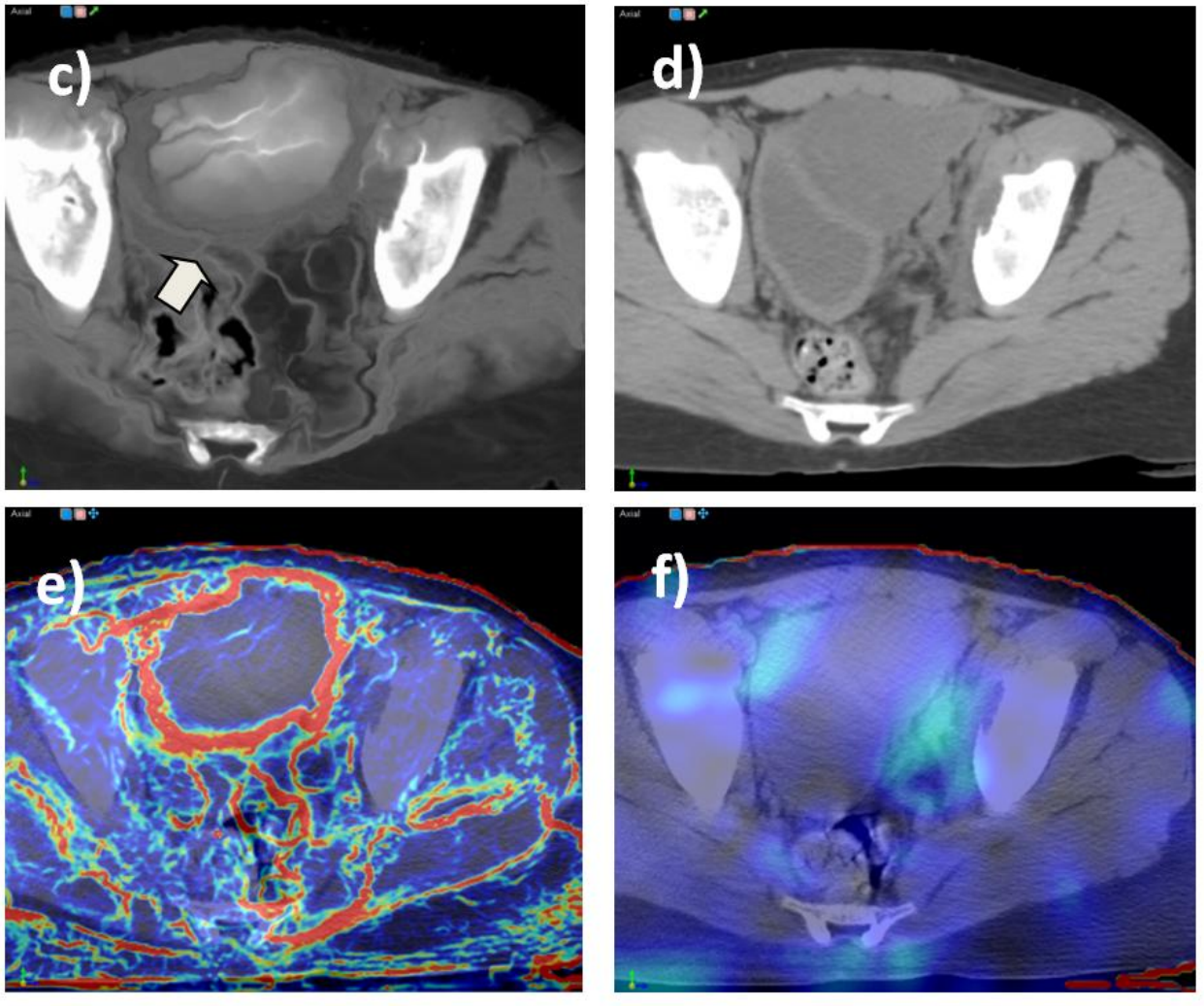
RESULTS



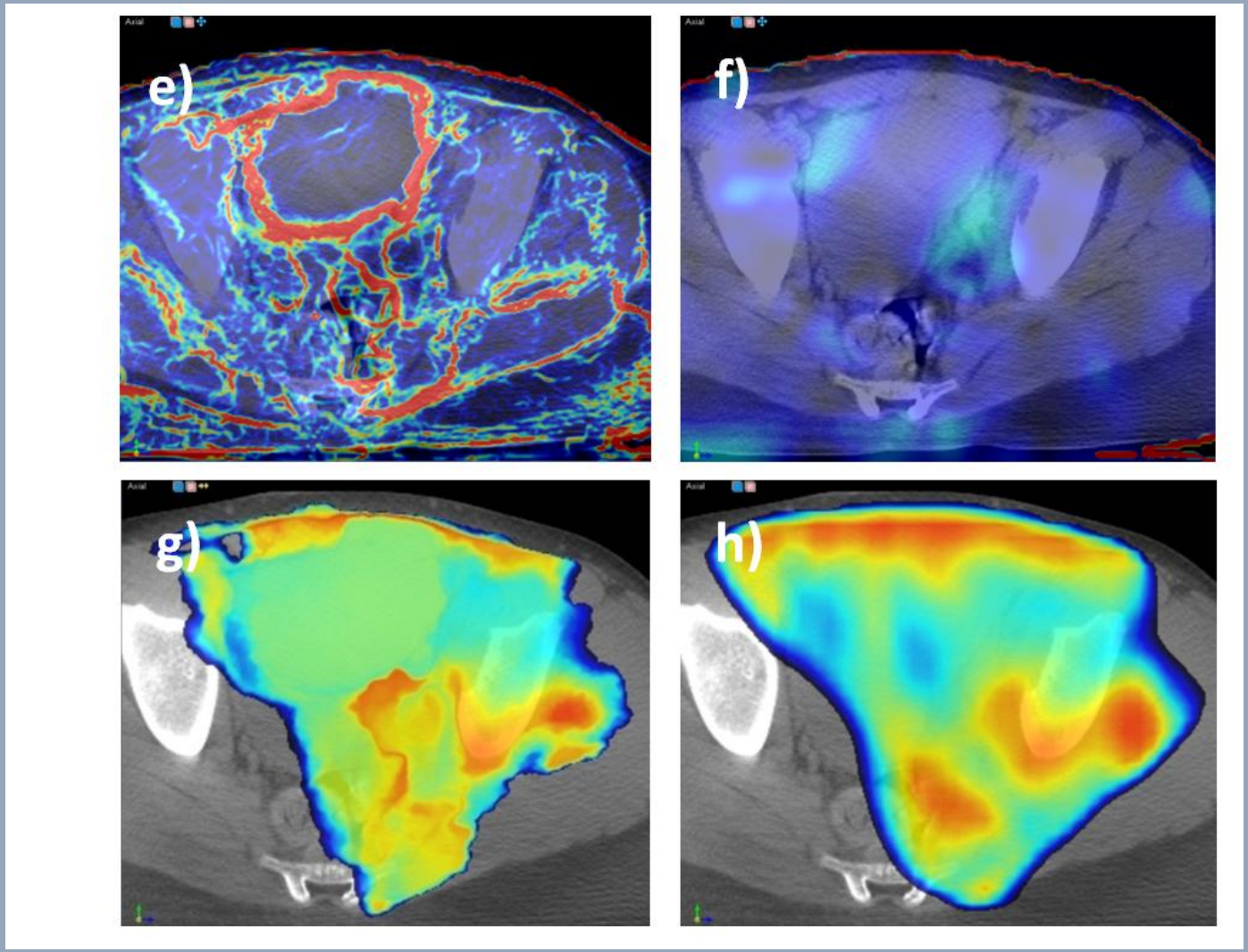


Interpretation Tool: Swirls

RESULTS



Interpretation Tool: Swirls



Conclusion

Flexible Tool– A deformable registration algorithm will give you the power to track and quantify anatomical changes

Interpretation Tools – Inspecting the displacement field directly provides valuable information.

Try it ! You'll like it.