

Assessing the need and feasibility for online plan adaptation based on daily CBCT of head and neck proton therapy treatments

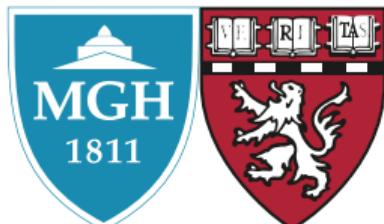
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AAPM, 59th Annual Meeting & Exhibition



Motivation

Problem and potential solution:

- Intensity modulated Proton therapy (**IMPT**) is sensitive to geometry changes
- To increase plan quality, **margins should be reduced**
- **Adaptive therapy could allow margin reduction** by correcting inter-fractional geometry changes and mispositioning
- **Head and neck patients** are perfect candidates to benefit from the technique

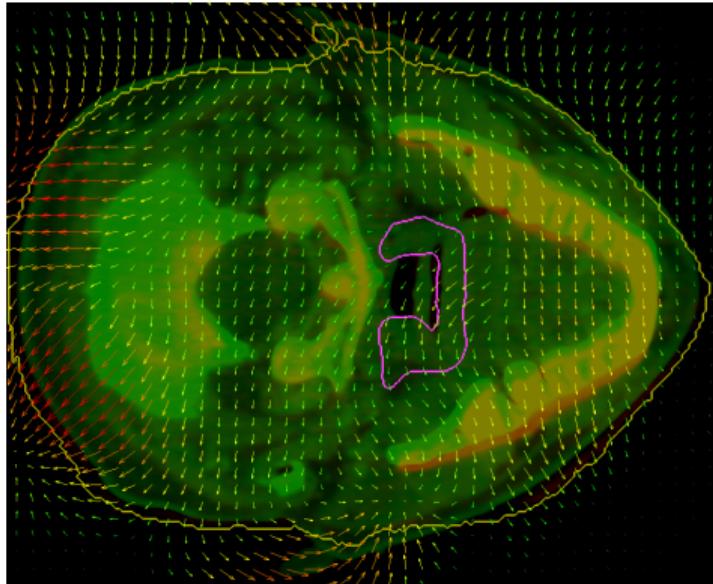


Fig: Head and neck patient geometry changes. The original CT is green, the CBCT is red, the arrows represent the vector field, the arrow color is a representation of their length.

The need for adaptive proton therapy

Head & neck patients planned without CTV margins, evaluated at different fractions:

- Reducing margins makes plans very sensitive to errors
- Adaptive proton therapy is needed

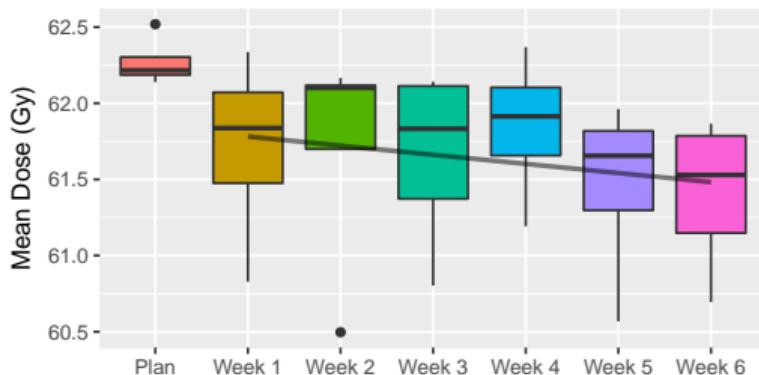


Fig: Mean CTV dose decreases

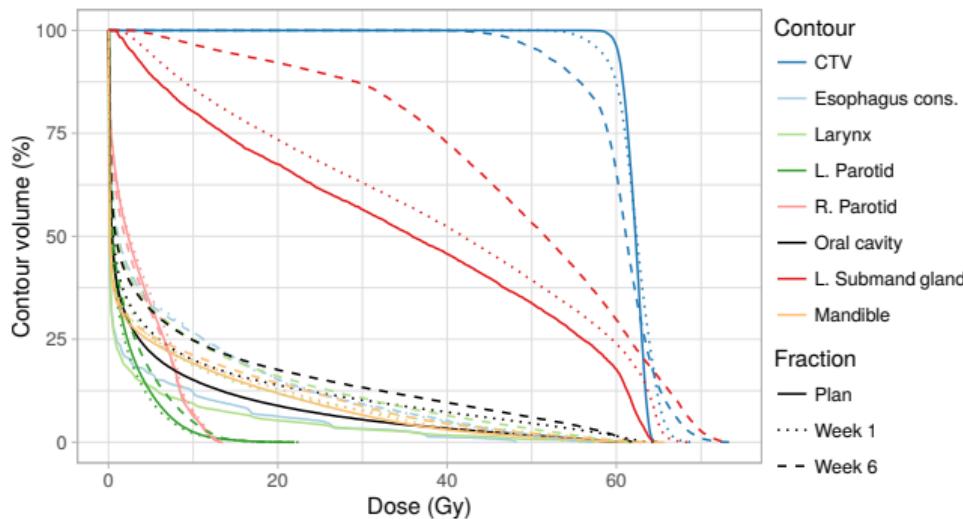


Fig: DVHs at plan, fraction 3 and 6

Adaptive proton therapy ingredients: the framework

Cone Beam CT (CBCT)

A priori CT-based scatter correction WEPL error < 2% in head cases.

Park et al., Med Phys. 2015;42(8), Kim et al., Phys Med Bio. 2017;62(1)

Image Registration: Plastimatch

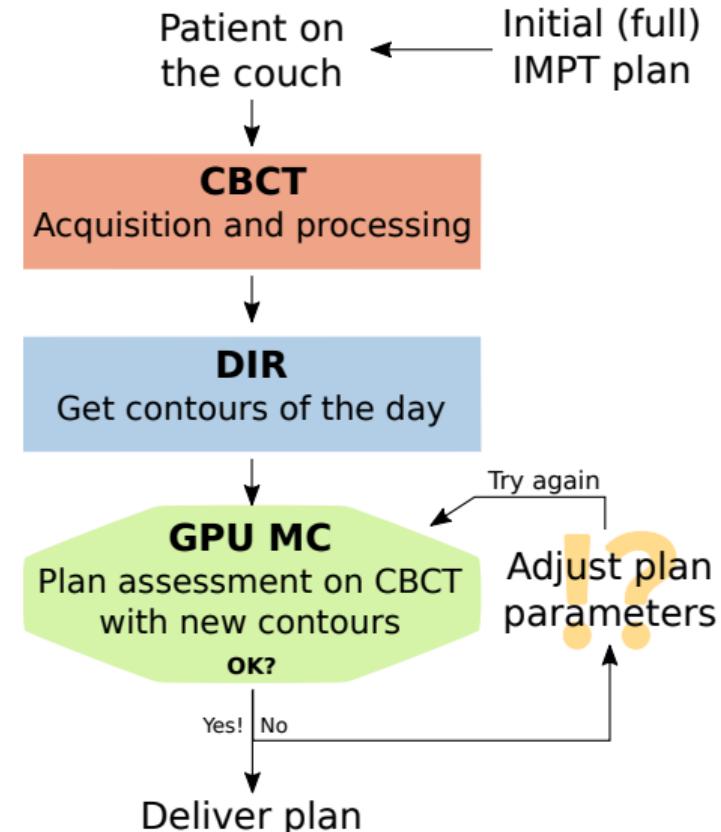
Rigid and deformable (DIR), GPU B-spline

Shackleford et al., Phys Med Biol. 2010;55(21)

Fast GPU MC: gPMC

Accurate calculation engine developed with UT Southwestern.

Qin et al., Phys Med Biol. 2016;61(20)

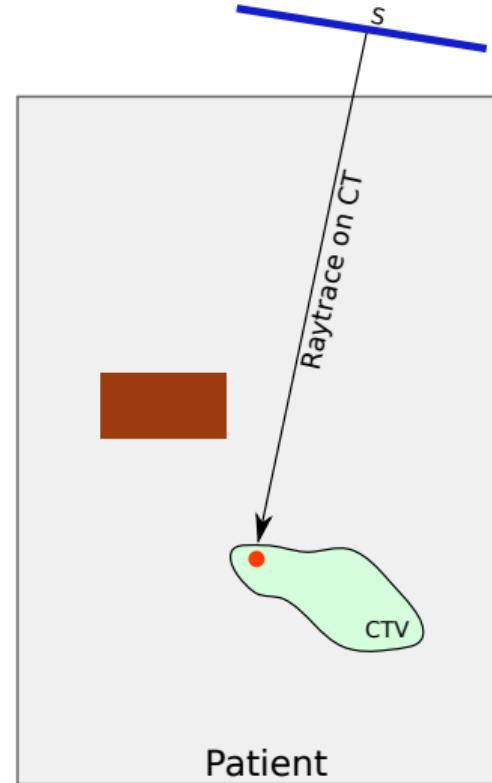


Adaptation method

A vector field (VF) from DIR links CT and CBCT.

The VF is employed to:

- ① Transport contours to new geometry

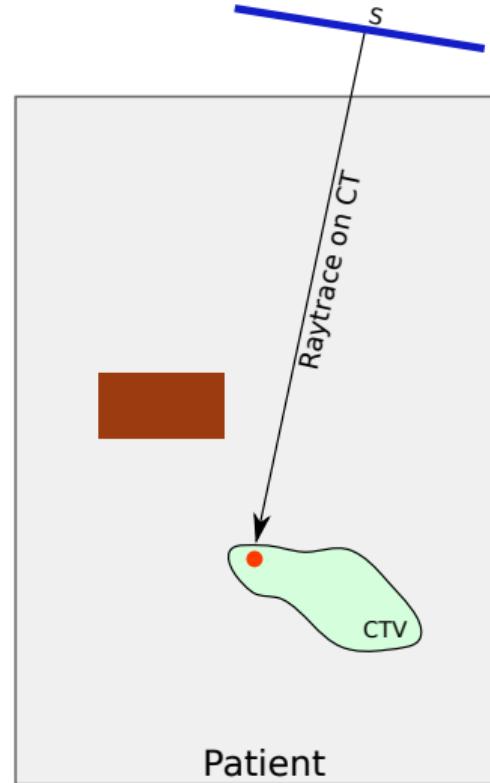


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- ② Warp IMPT plan (not dose). Per spot
 $s_i = (x_0, y_0, E_0)$:



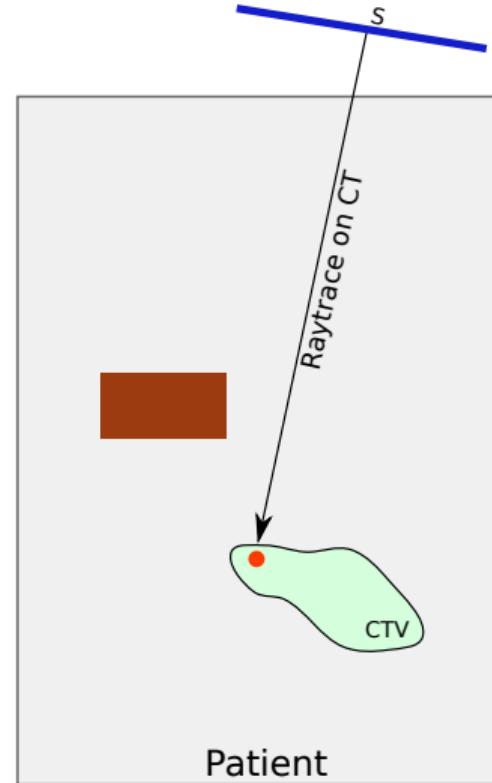
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1: **Raytrace** s_i in CT (r_i)



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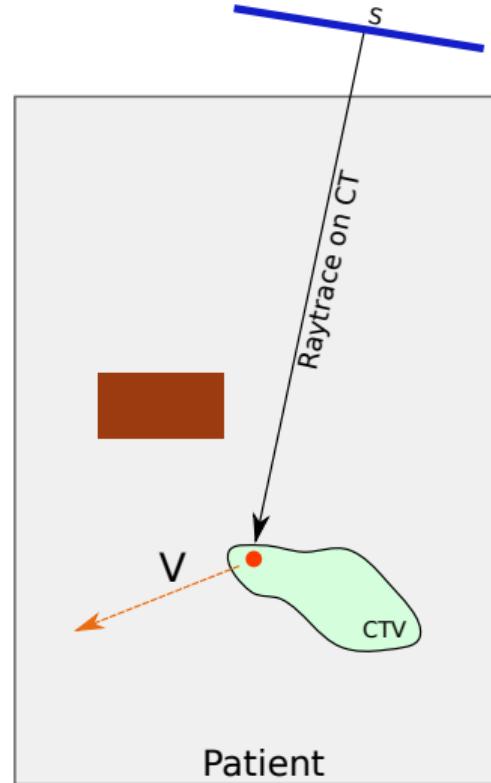
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2: **Probe** VF at r_i coords: v_i



Adaptation method

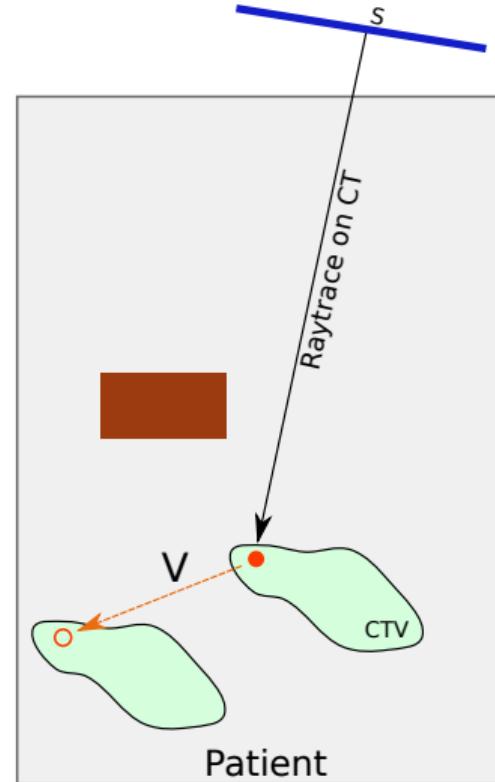
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- 3: **Apply** v_i **to** r_i coords: position where the r_i should be in the CBCT



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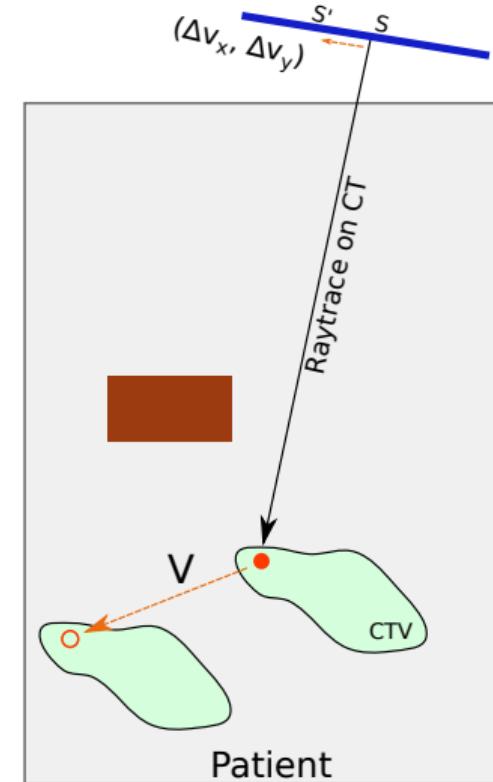
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- 4: **Apply** v_i **to** $s \rightarrow$
 $s'_i = (x_0 + \Delta v_x, y_0 + \Delta v_y, E_0)_i$



Adaptation method

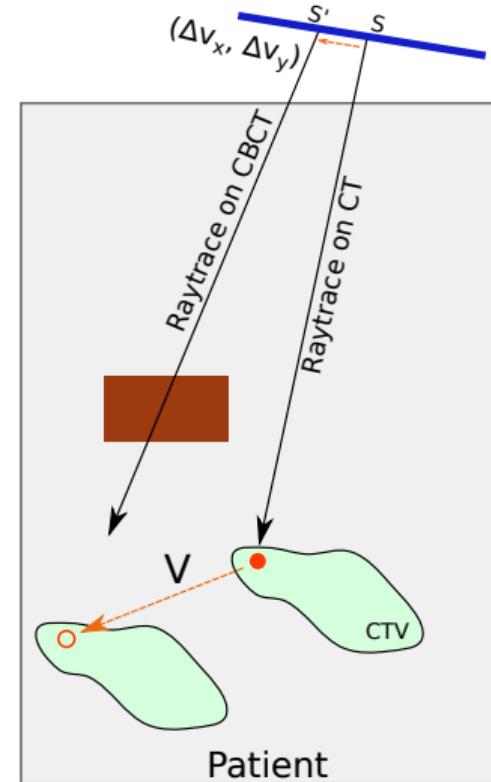
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- 5: **Raytrace** s'_i in CBCT



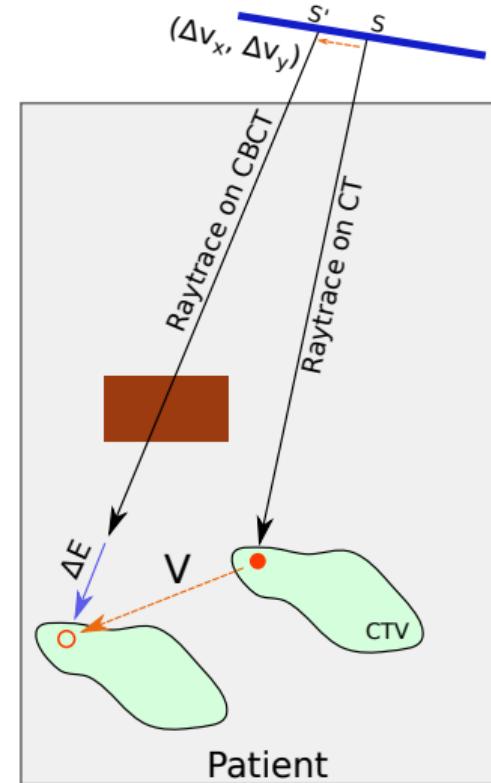
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- 5: **Raytrace** s'_i in CBCT
- 6: **Get** ΔE_i



Adaptation method

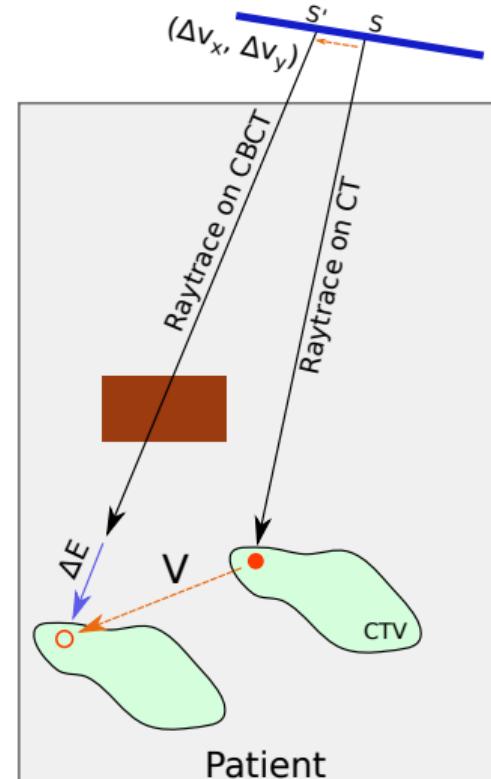
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- ③ Spot adaptation: $(\Delta v_x, \Delta v_y, \Delta E)_i$



Adaptation method

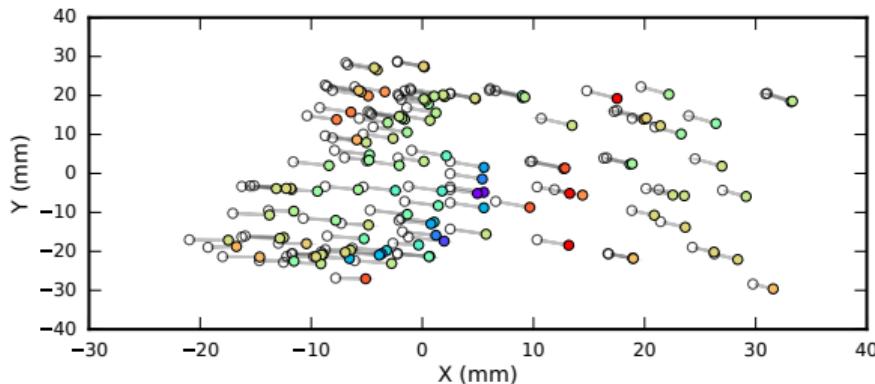


Fig: Plan positions shifted

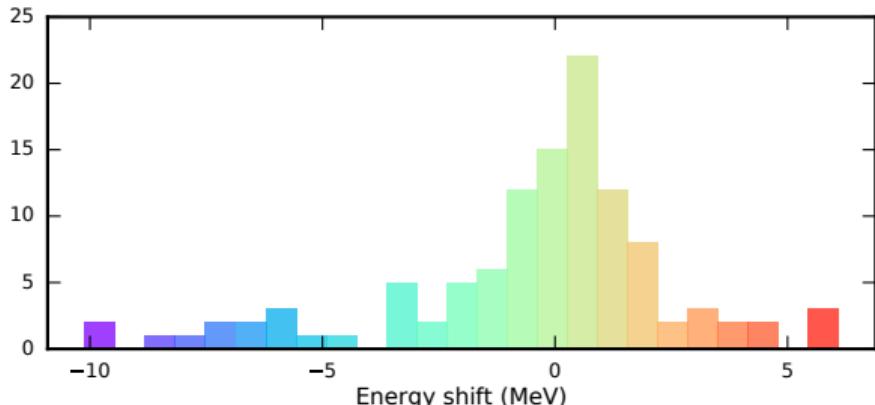
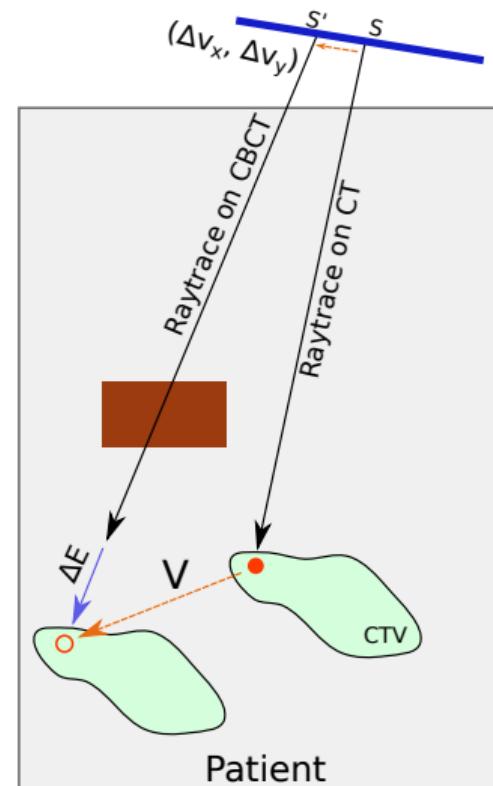


Fig: Energy shifts histogram.



Methodology

Energy layer organization is distorted by this method.

Two strategies:

- **Free:** No constraints on the spots movement ($\Delta v_x, \Delta v_y, \Delta E$);
- **Rigid beams:**
 - *Couch shift:* Average VF in the CTV
 - *Range-shifter-of-the-day:* Average energy shift

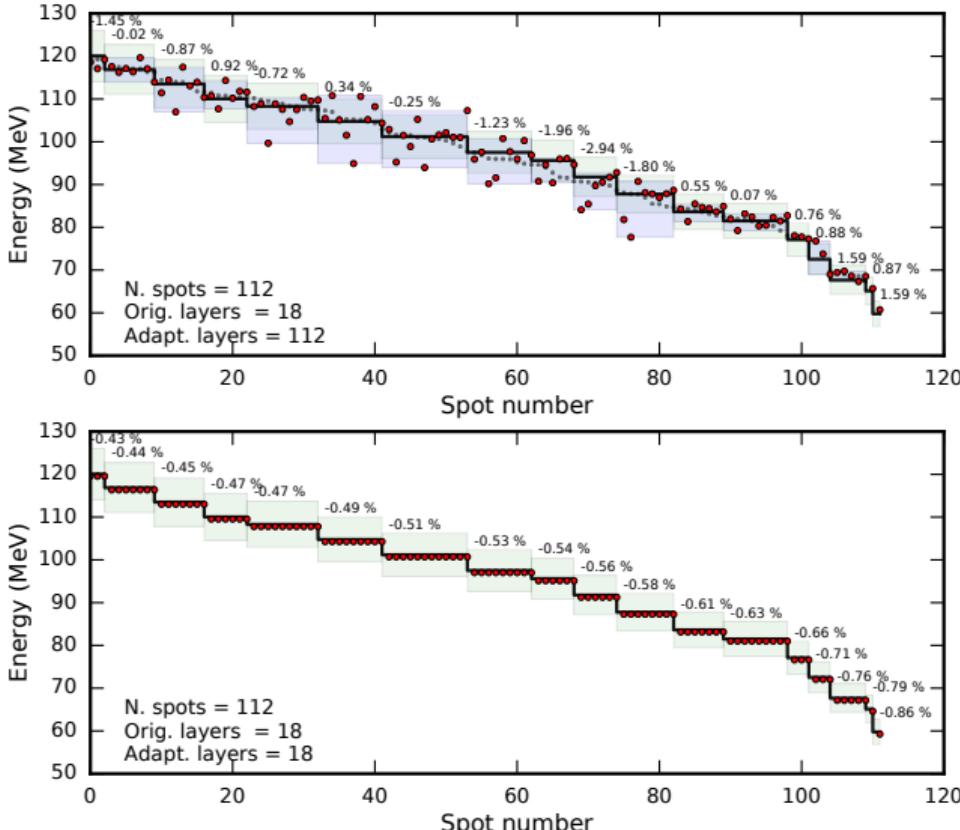


Fig: Distortion/conservation of plan energy layers

Results

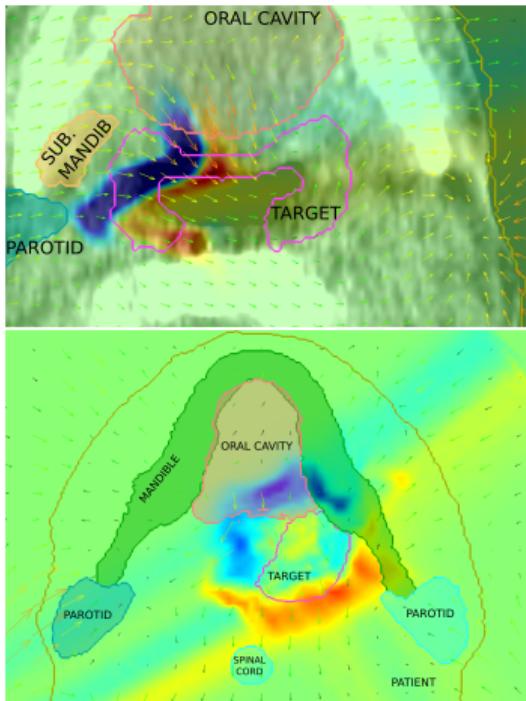


Fig: Adapted minus original dose. Red means more dose by adapted distribution. The shifts follow the VF (arrows). **Top:** a single spot. **Bottom:** 3 beams

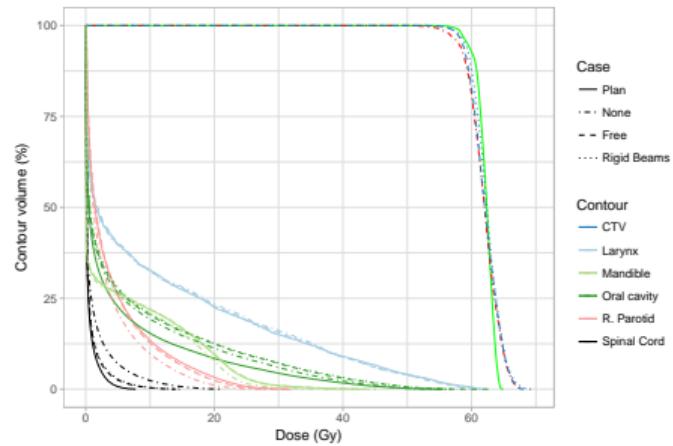
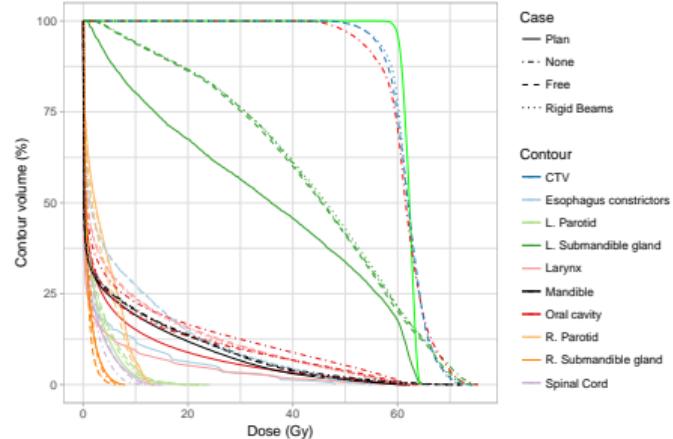


Fig: Example DVHs with original, adapted, and non-adapted plan.

Top: some improvement, steeper DVH, but plan quality not restored
Bottom: Little improvement.

Results

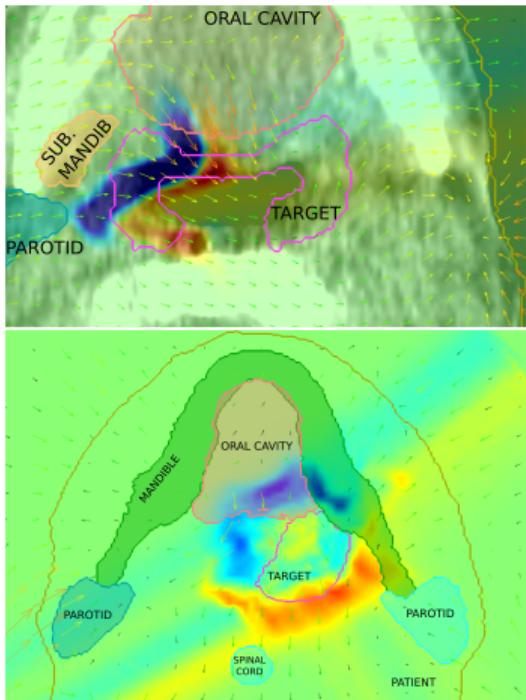


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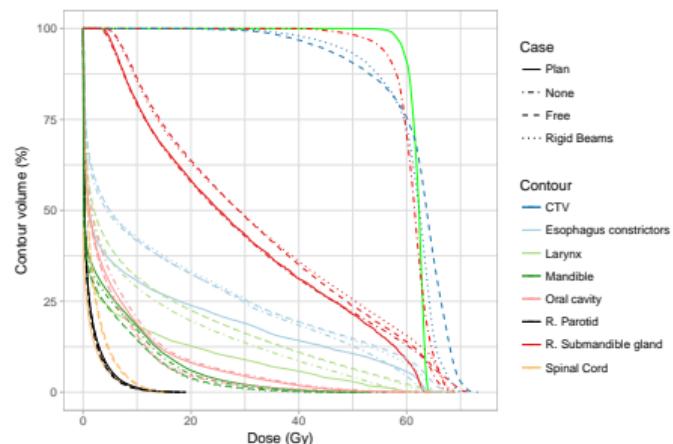
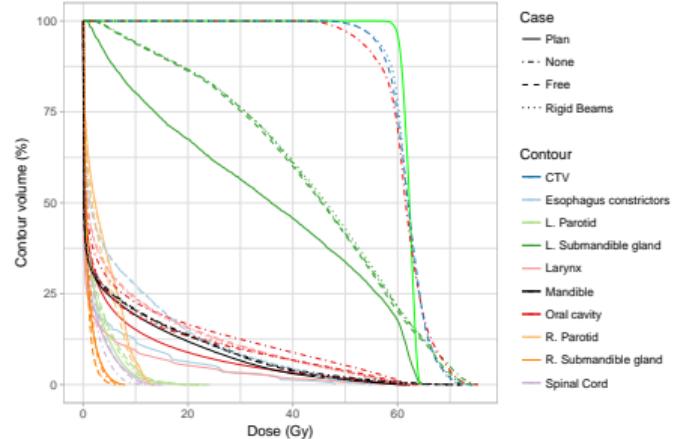


Fig: Example DVHs with original, adapted, and non-adapted plan.
Top: considerable improvement, steeper DVH, but plan quality not restored
Bottom: VF divergences make adapted plan worse.

Results

- Free:
 - Target covered by dose
 - Non homogeneous dose with cold spots
- Rigid beams:
 - More homogeneous dose
 - Dose outside the target and uncovered areas
 - Doesn't capture the deformation that deviates from average
- Results depend on specific deformation

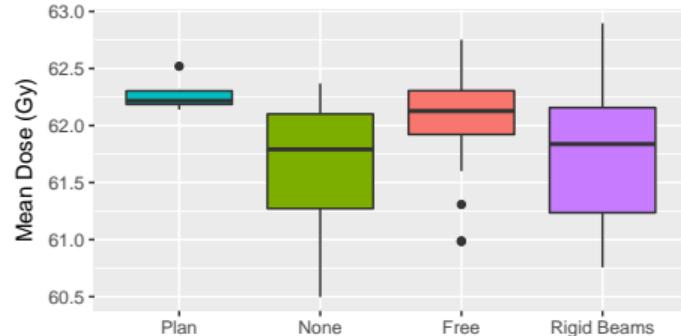


Fig: Mean dose per strategy to the target

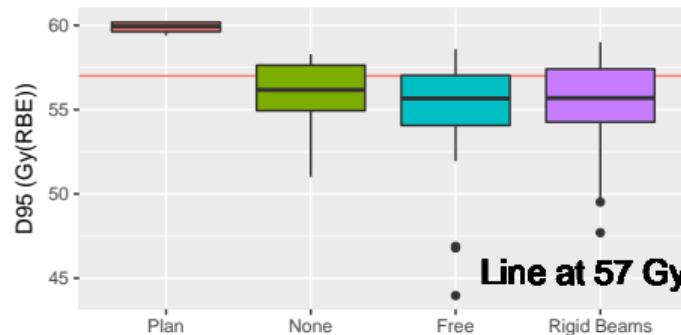


Fig: D95 per strategy in the target

Conclusions and outlook

With significant deformation and no CTV margins:

- Free spots/rigid beams fail to retrieve plan quality
- Non-parallel VF changes relation between spots → hot/cold spots

Outlook and future steps:

- Spot weight adjustment
- Divergent VF
- Take into account deformation in all the target, not only at the probes



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Backup slides

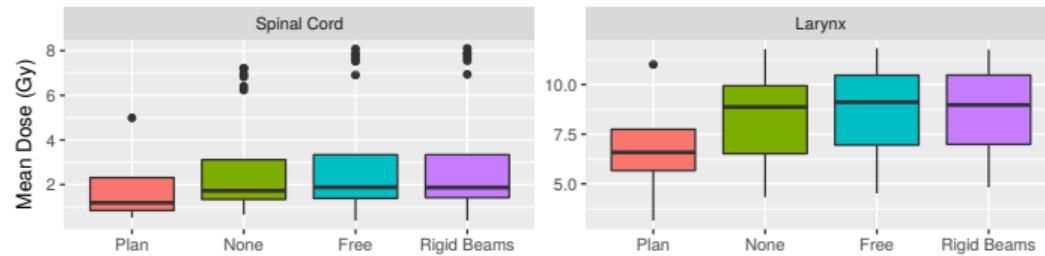


Fig: Mean dose per strategy of spinal cord and larynx.