

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

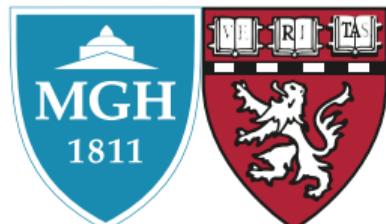
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Motivation

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

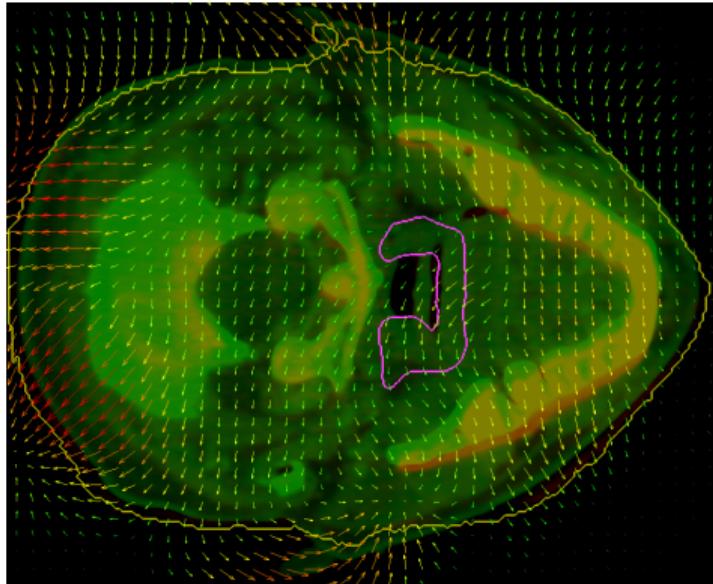


Fig: Head and neck patient geometry changes. The original CT is green, the CBCT is red, the arrows represent the vector field, the arrow color is a representation of their length.

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

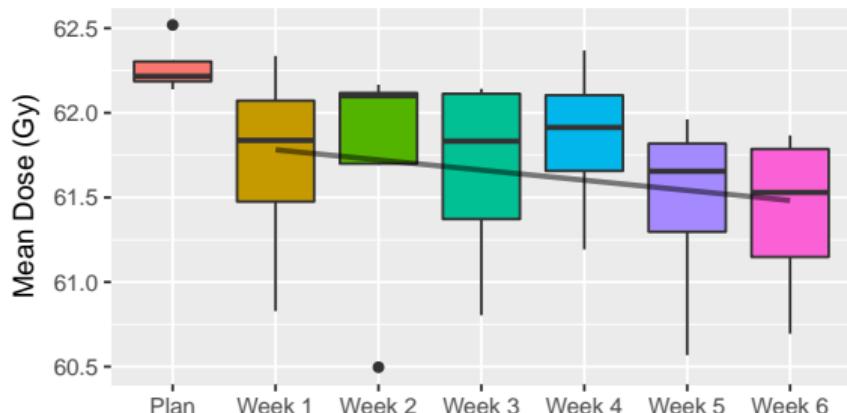


Fig: Mean CTV dose decreases: less total dose is given to the target

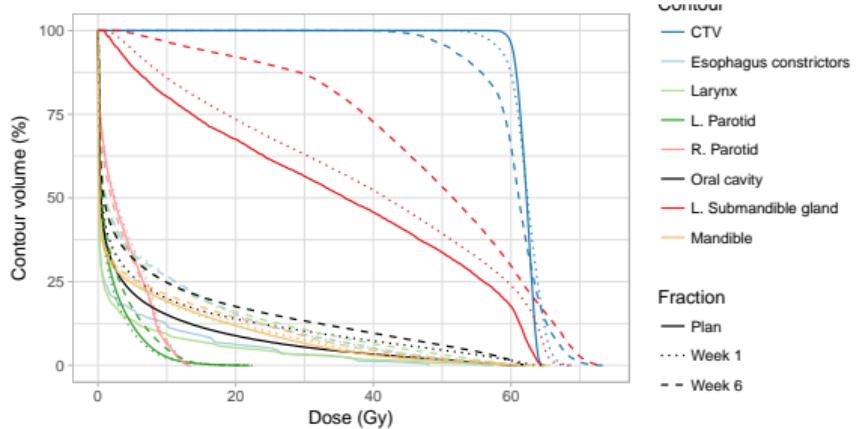


Fig: Single patient DVHs at plan, fraction 3 and 6. Target coverage is gradually lost

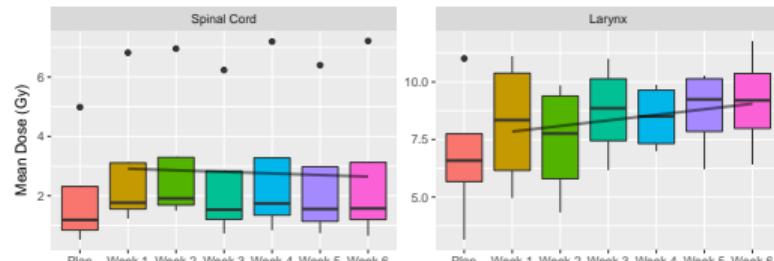
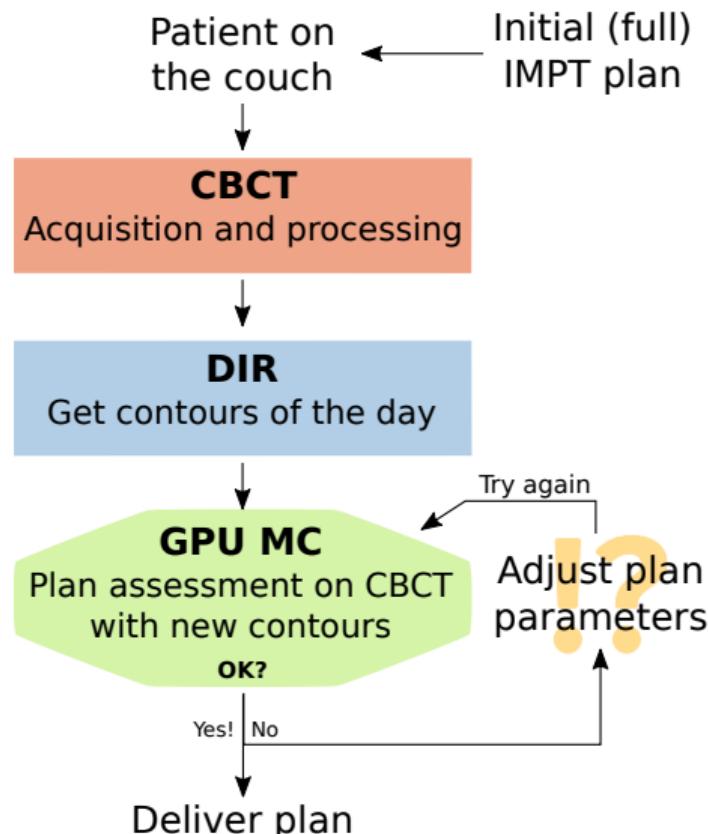


Fig: Mean dose increase of spinal cord and larynx

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

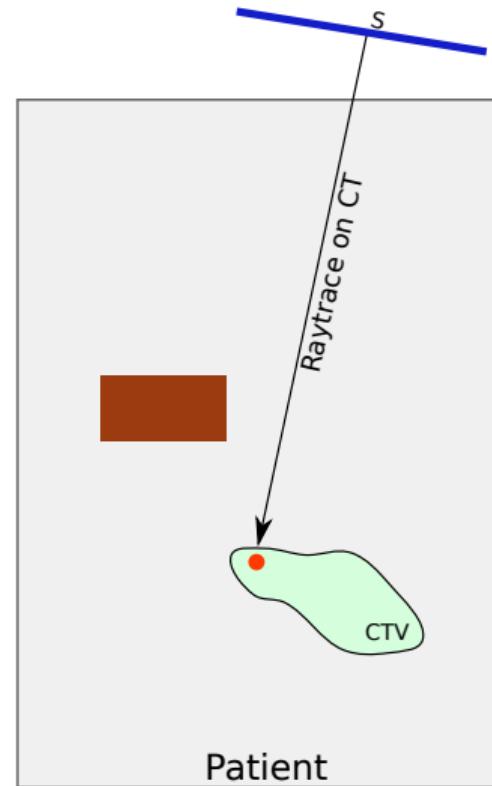
A vector field (VF) from DIR links CT and CBCT.

The VF is employed to:

- ① Transport contours to new geometry
- ② Warp IMPT plan (not dose). Per spot

$$s_i = (x_0, y_0, E_0):$$

- 1: **Raytrace** central axis of s_i in CT to end of range (r_i)



Adaptation method

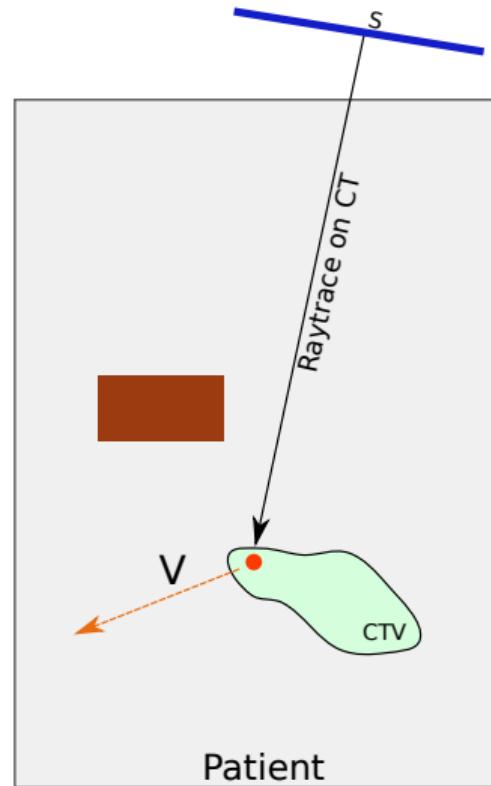
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- 1: **Raytrace** central axis of s_i in CT to end of range (r_i)
- 2: **Probe** VF at r_i coords: v_i



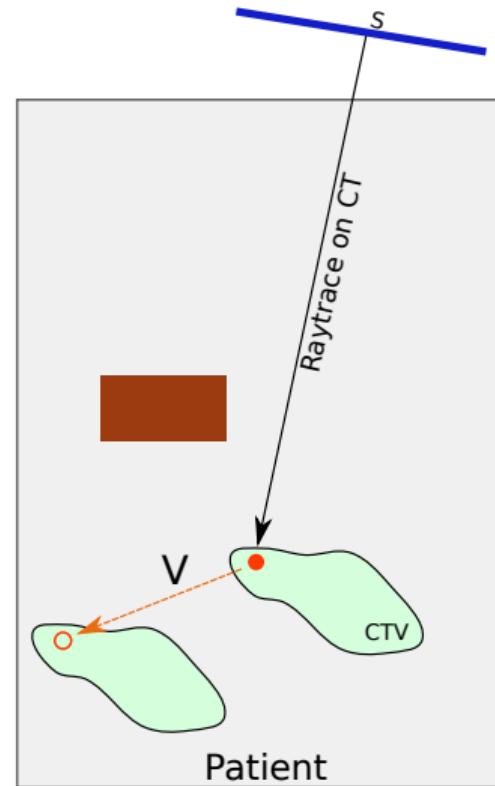
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- 1: **Raytrace** central axis of s_i in CT to end of range (r_i)
- 2: **Probe** VF at r_i coords: v_i ;
- 3: Apply v_i to r_i coords: position where the r_i should be in the CBCT



Adaptation method

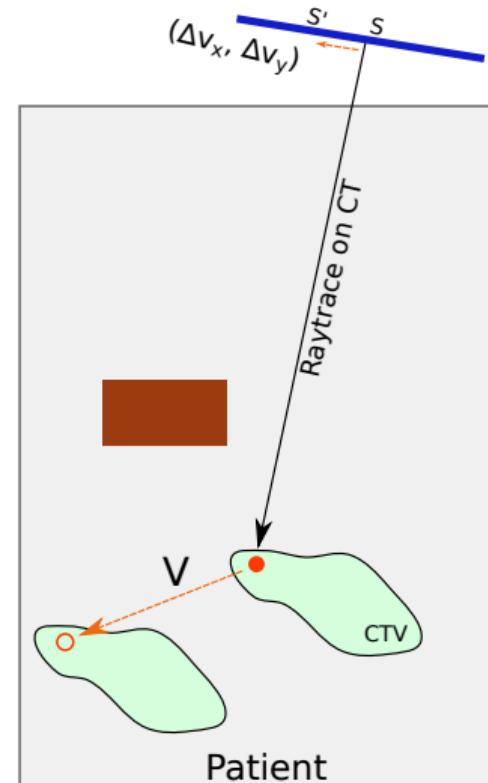
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- 3: Apply v_i to r_i coords: position where the r_i should be in the CBCT
- 4: Apply v_i to $s \rightarrow$
 $s'_i = (x_0 + \Delta v_x, y_0 + \Delta v_y, E_0)_i$



Adaptation method

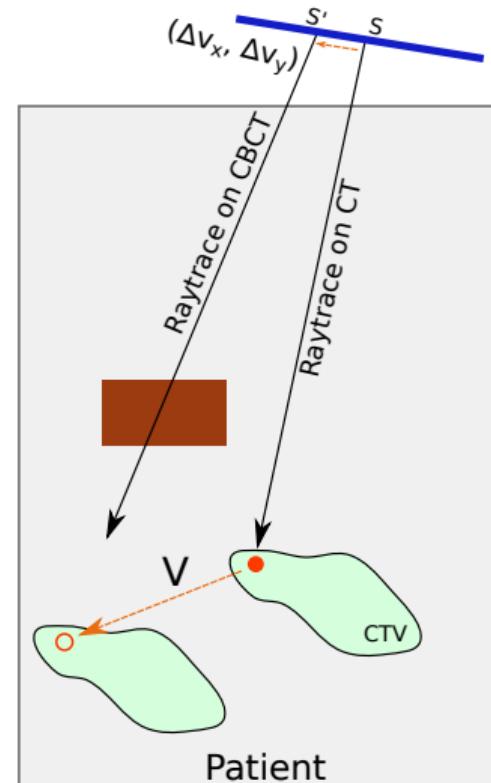
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 $s'_i = (x_0 + \Delta v_x, y_0 + \Delta v_y, E_0)_i$
- 5: **Raytrace** s'_i in CBCT



Adaptation method

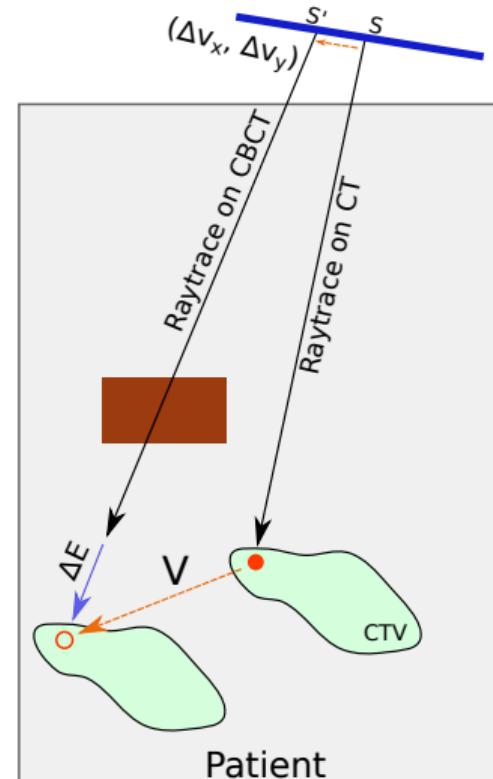
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- 4: Apply v_i to $s \rightarrow$
- $s'_i = (x_0 + \Delta v_x, y_0 + \Delta v_y, E_0)_i$
- 5: **Raytrace** s'_i in CBCT
- 6: Get ΔE_i



Adaptation method

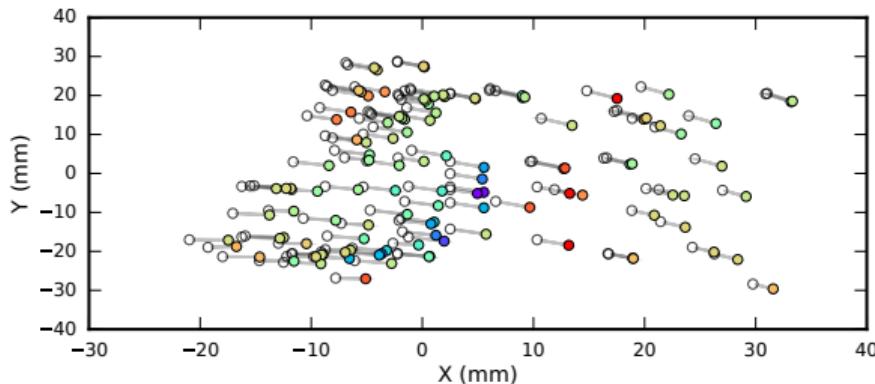


Fig: Plan positions shifted

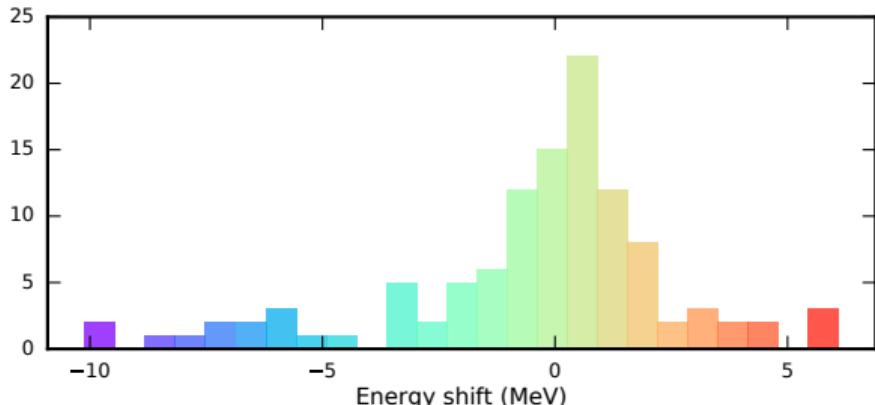
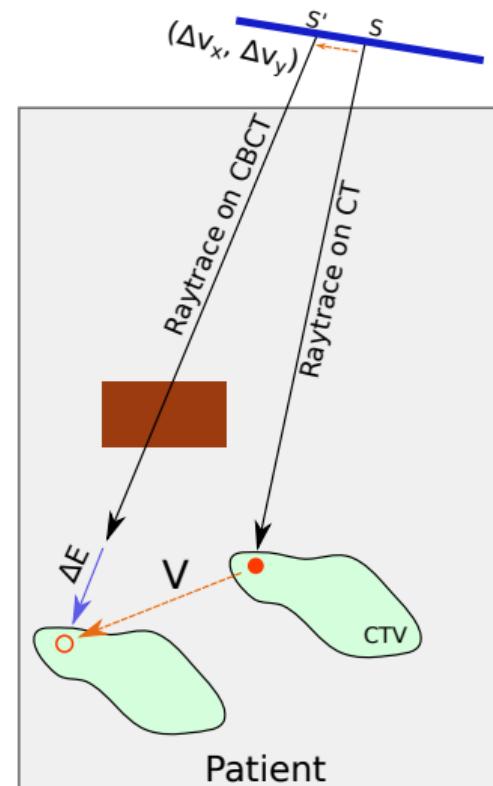


Fig: Energy shifts histogram.



Methodology

Energy layer organization is distorted by this method. Two strategies:

- **Free:** No constrains on the spots movement ($\Delta v_x, \Delta v_y, \Delta E$)
- **Rigid beams:** The average VF in the CTV is used to shift the beams, afterwards the average energy shift is applied as a *range-shifter-of-the-day*.

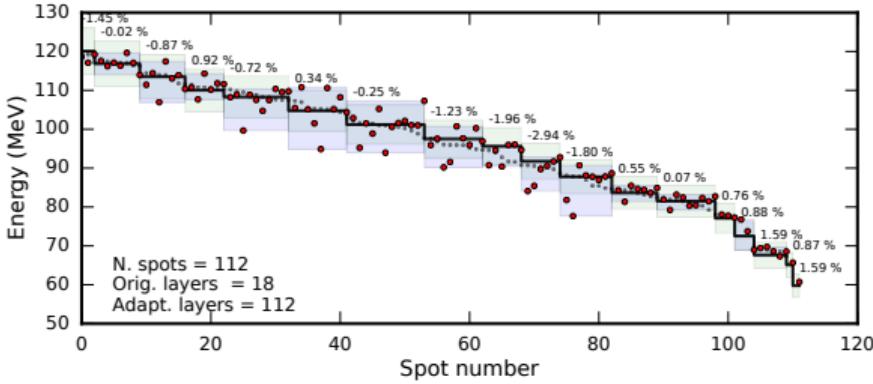


Fig: Distortion of plan energy layers.

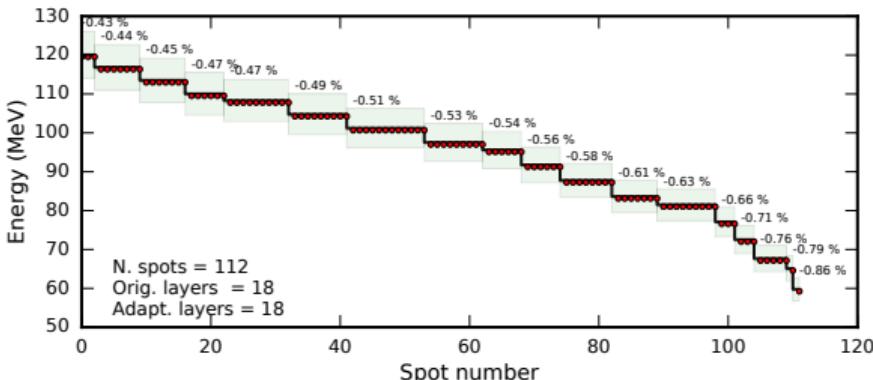


Fig: Conservation of plan energy layers.

Results

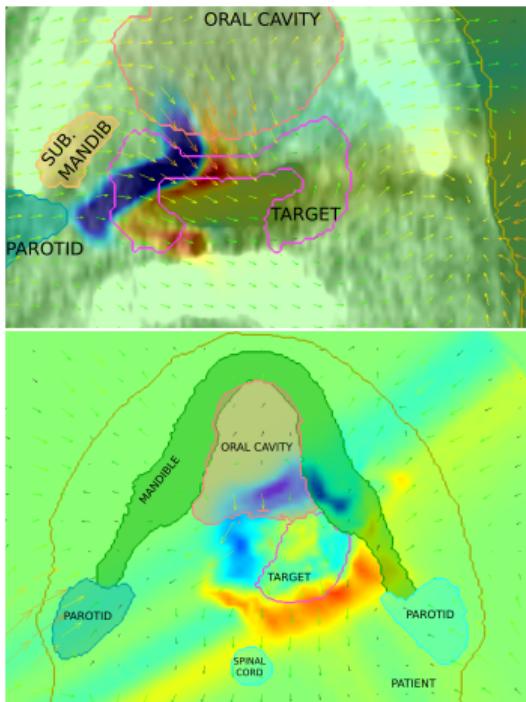


Fig: Adapted minus original dose. Red means more dose by adapted distribution. The shifts follow the VF (arrows). **Top:** a single spot. **Bottom:** 3 beams

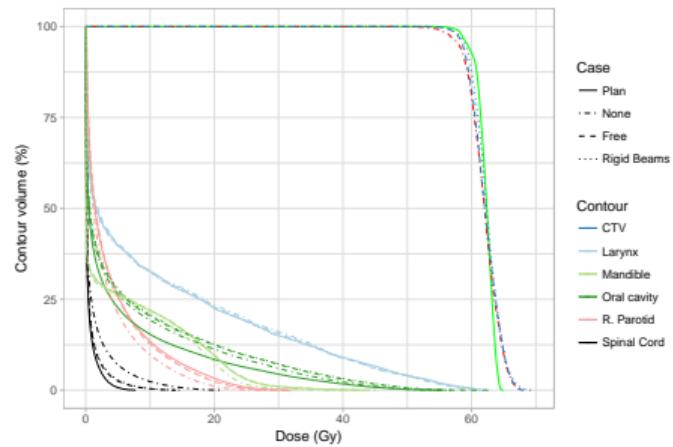
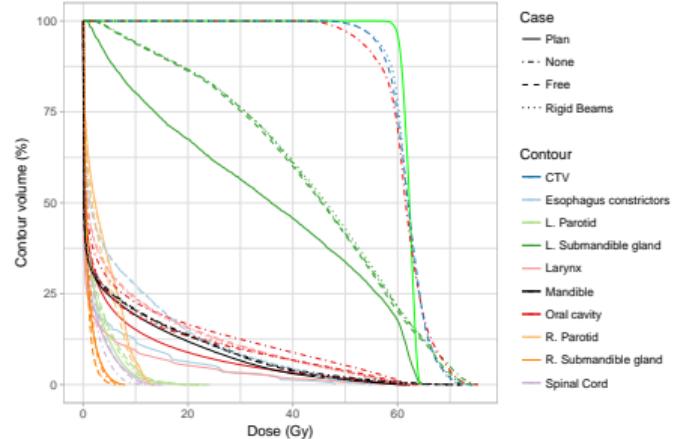


Fig: Example DVHs.
Blue target lines are adapted plans.
Top: considerable improvement, steeper DVH, but plan quality not restored
Bottom: Little improvement.

Results

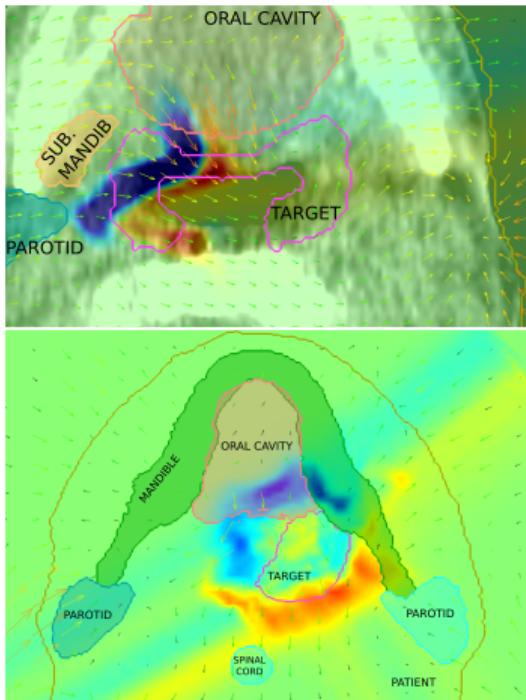


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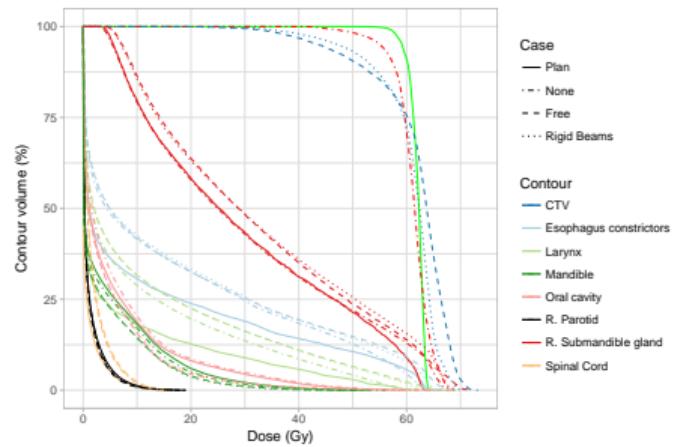
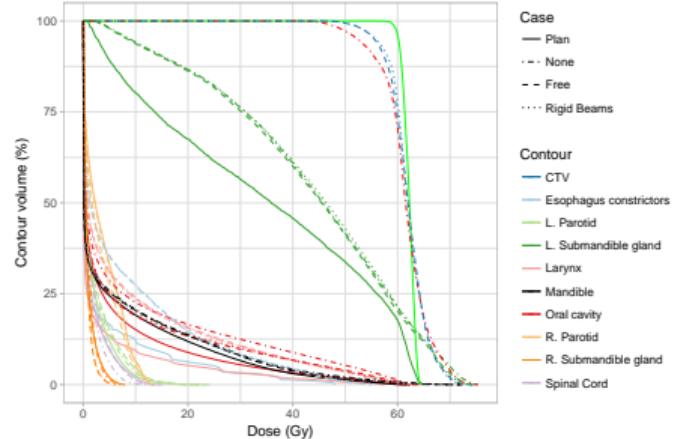


Fig: Example DVHs.
Blue target lines are adapted plans.
Top: considerable improvement, steeper DVH, but plan quality not restored
Bottom: VF divergences make adapted plan worse.

Results

- **Free** strategy usually covers the target with dose, but dose is not homogeneous → cold spots in the target
- **Rigid beams** provides more homogeneous dose, but doesn't capture the deformation that deviates from average → dose outside the target and uncovered areas
- Results depend on specific deformation

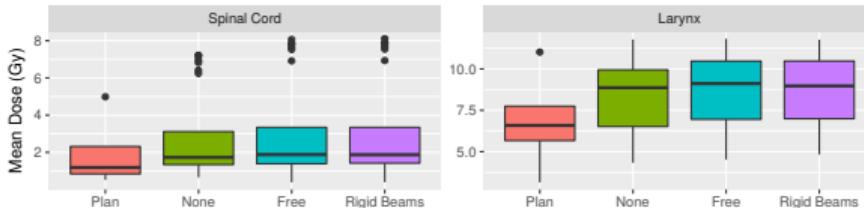


Fig: Mean dose per strategy of spinal cord and larynx.

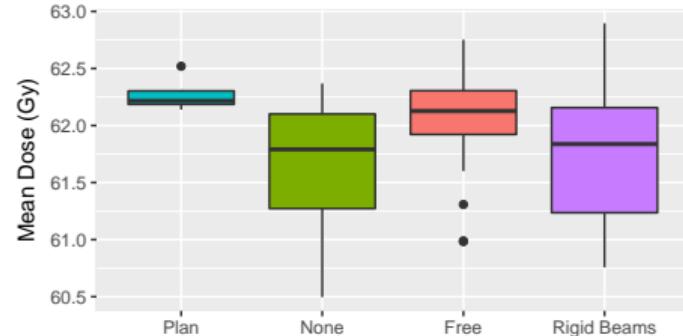


Fig: Mean dose per strategy to the target

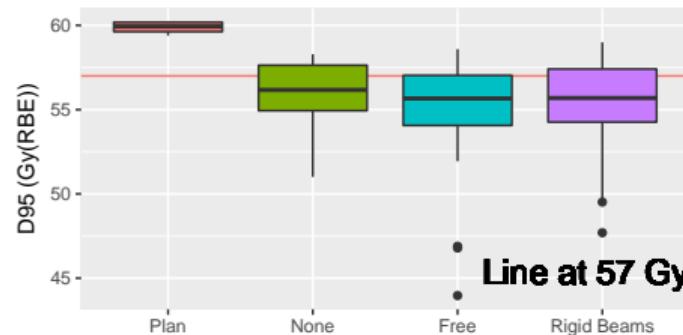


Fig: D95 per strategy in the target

Conclusions and outlook

With significant deformation and no CTV margins:

- Free spots adjusting fails to retrieve original plan quality
- Non-parallel movements changes relation between spots → hot/cold spots
- Couch shifts and *range-shifter-of-the-day* can not capture non-uniform deformations

Outlook and future steps:

- Spot weight adjustment could make the DVH steeper
- Strategies to address divergent VF should be found
- Strategies to take into account the VF in all the target, not only at the probes should be found



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