

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

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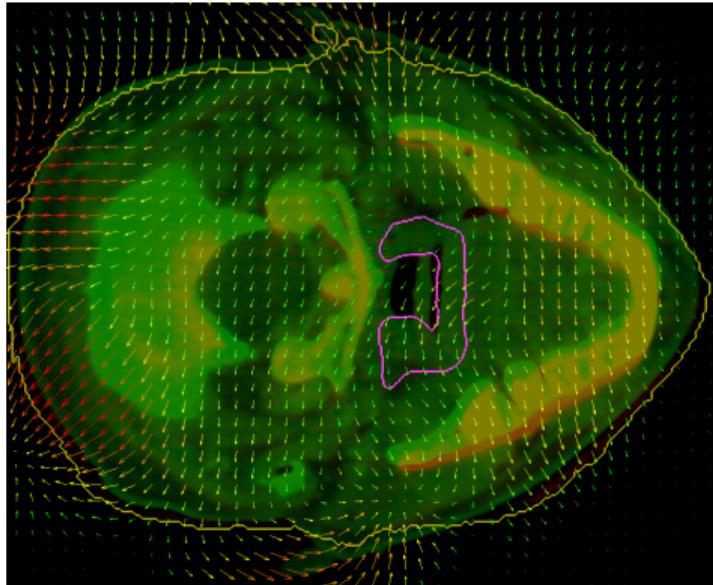
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# Motivation

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

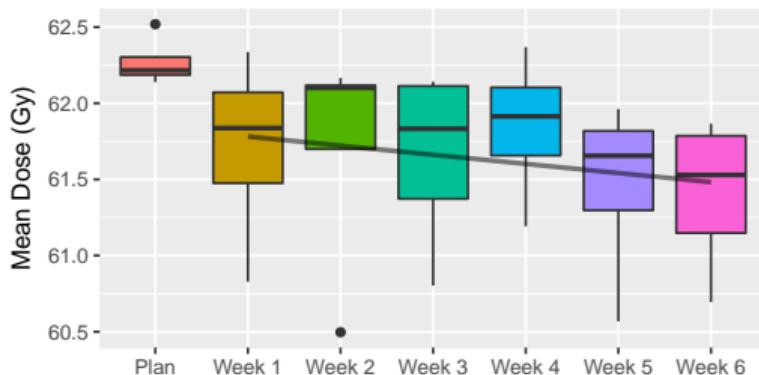


Fig: Mean CTV dose decreases

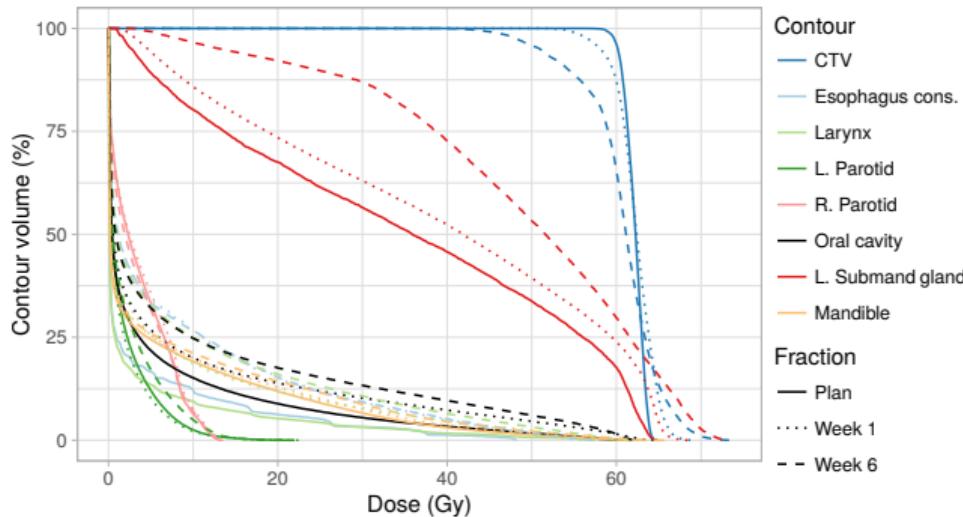
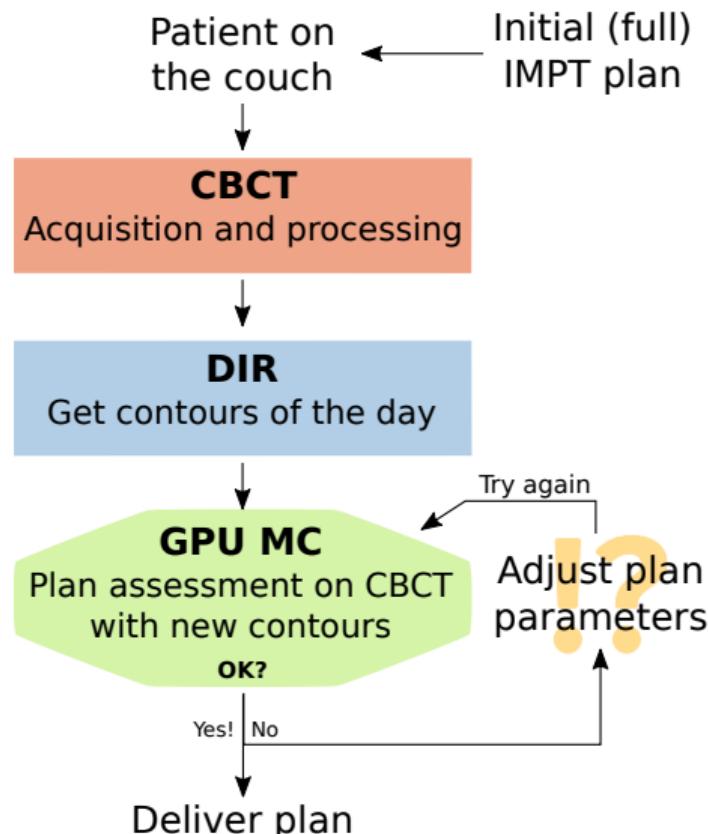


Fig: DVHs at plan, fraction 3 and 6

# 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.

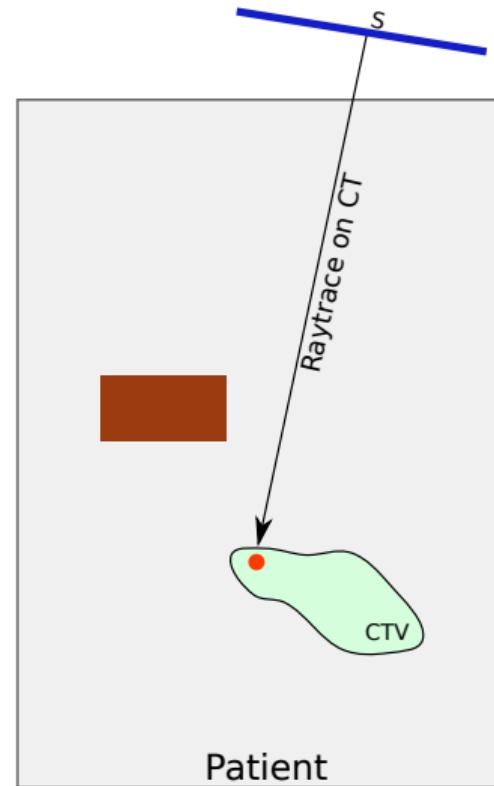
*Qin et al., Phys Med Biol. 2016;61(20)*

# Adaptation method

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

The VF is employed to:

- ① Transport contours to new geometry
- ② Warp IMPT plan (not dose). Per spot  
 $s_i = (x_0, y_0, E_0)$ :  
1: **Raytrace**  $s_i$  in CT ( $r_i$ )



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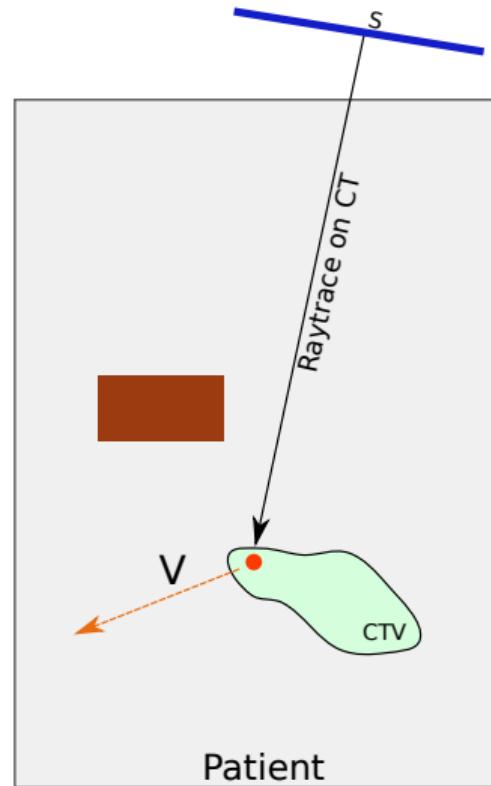
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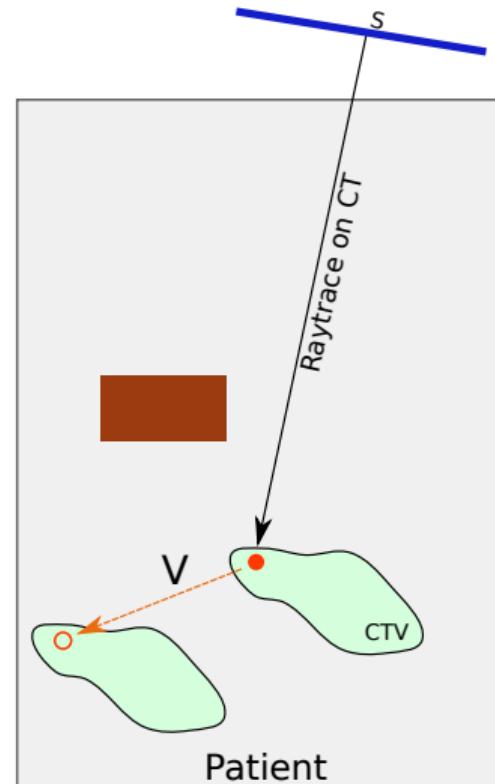
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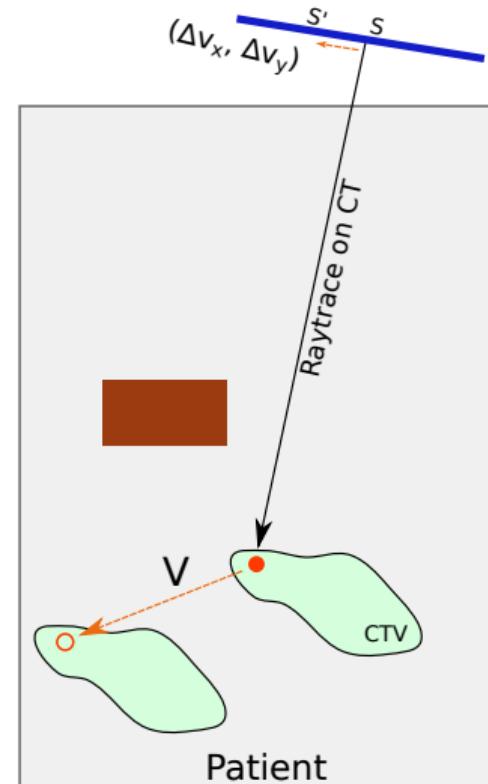
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- 4: **Apply**  $v_i$  **to**  $s \rightarrow$   
 $s'_i = (x_0 + \Delta v_x, y_0 + \Delta v_y, E_0)_i$

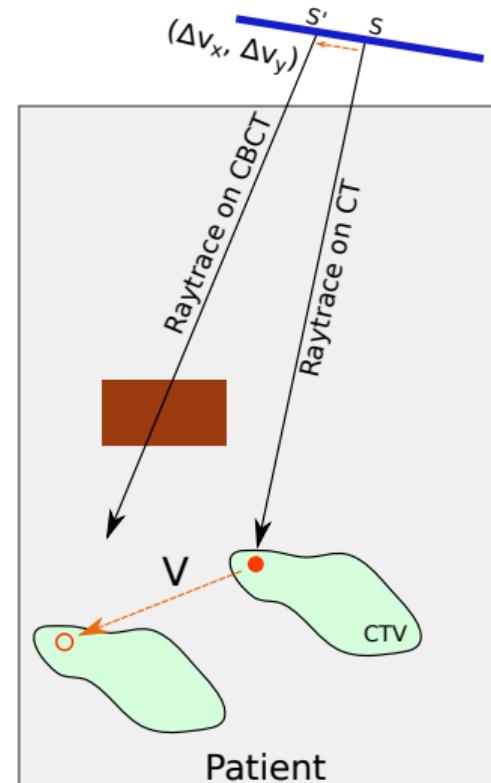


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  - 5: **Raytrace**  $s'_i$  in CBCT



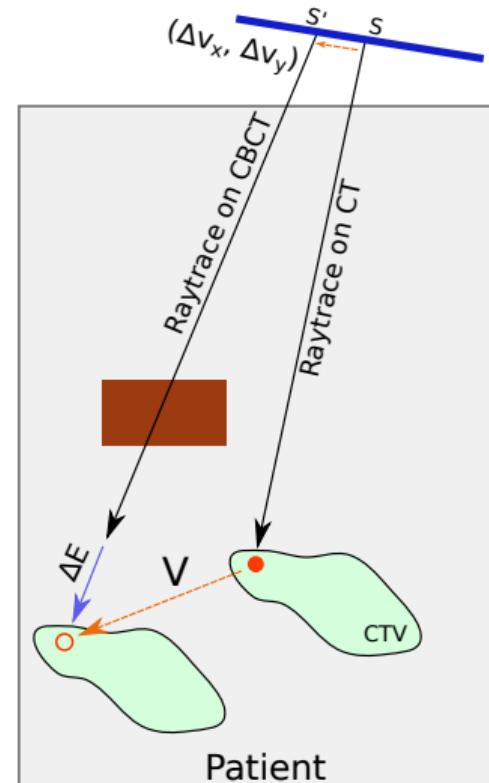
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- 6: **Get**  $\Delta E_i$



# Adaptation method

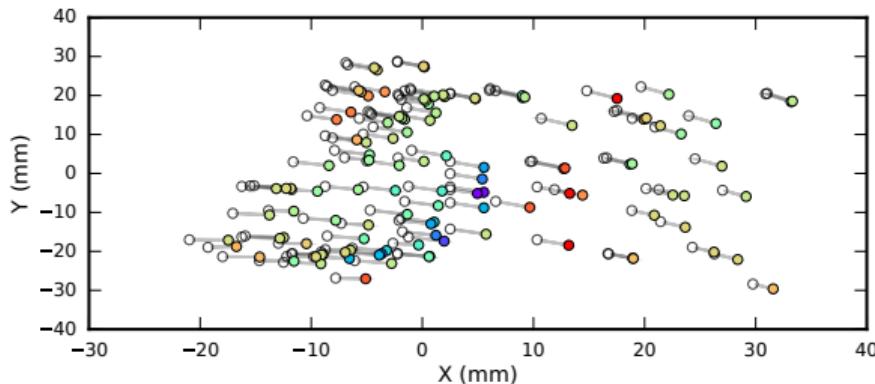


Fig: Plan positions shifted

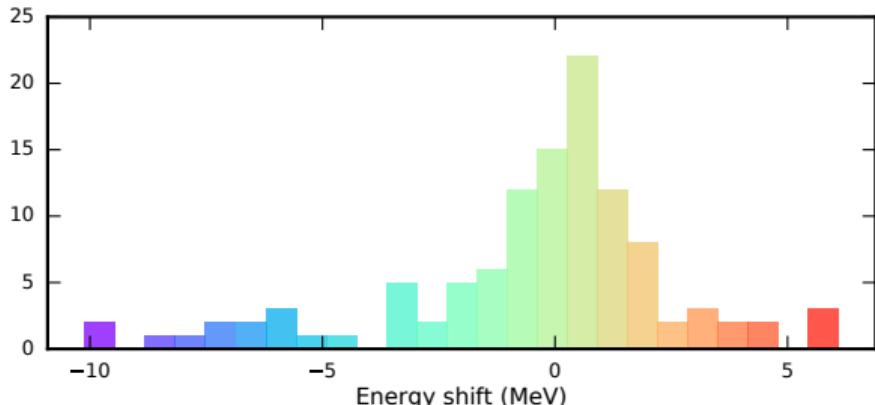
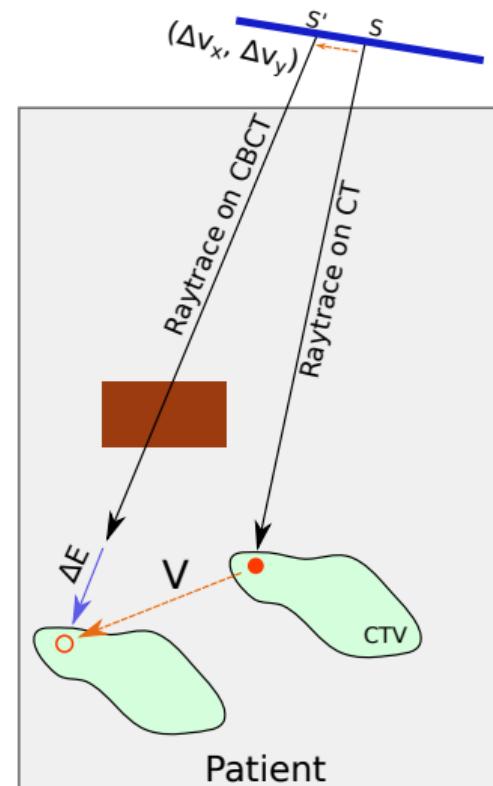


Fig: Energy shifts histogram.



# Methodology

Energy layer organization is distorted by this method.

Two strategies:

- **Free:** No constrains 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

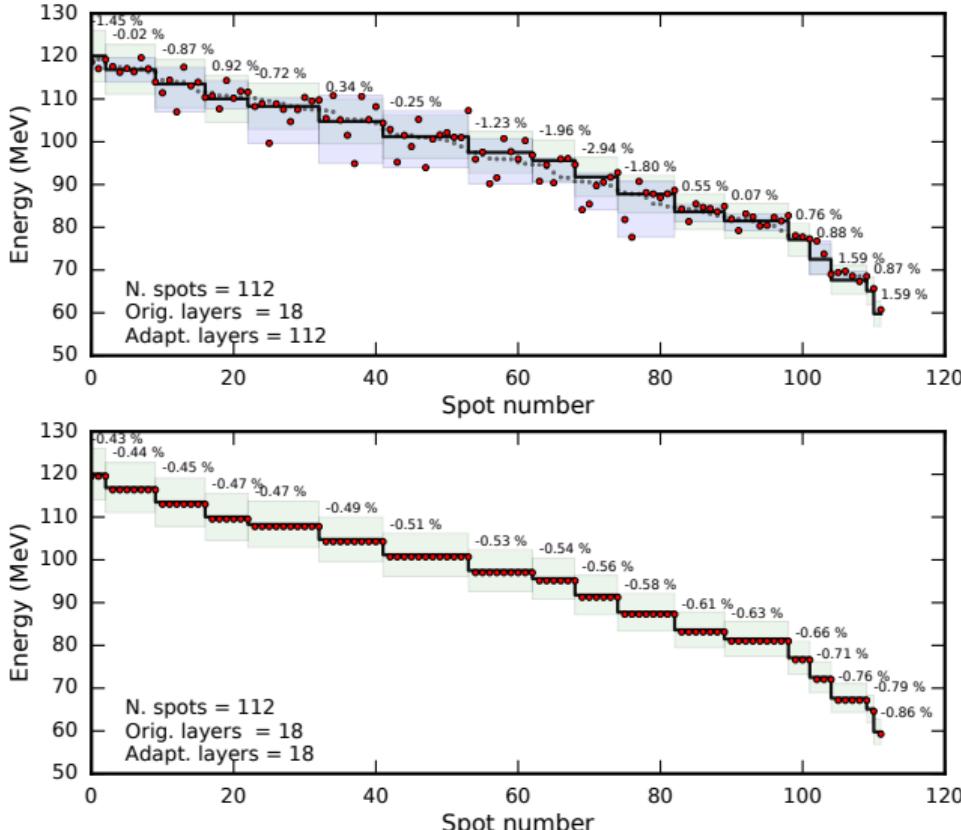


Fig: Distortion/conservation of plan energy layers.

# Results

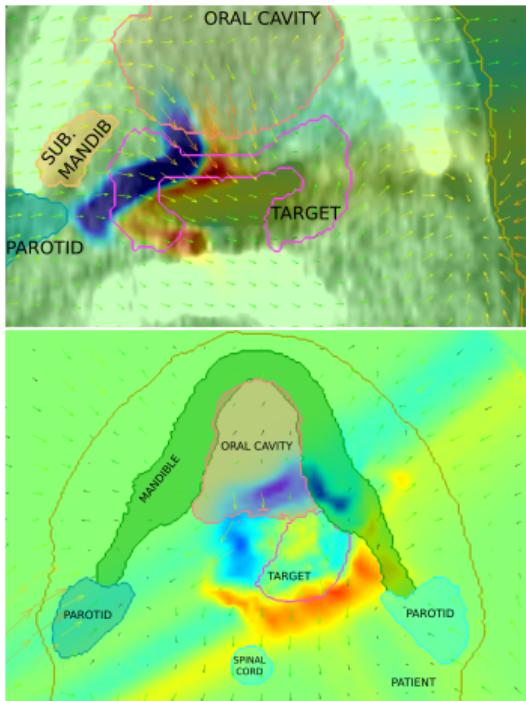


Fig: Adapted minus original dose. Red means more dose by adapted distribution. The shifts follow the VF (arrows). **Top:** a single spot. **Bottom:** 3 beams

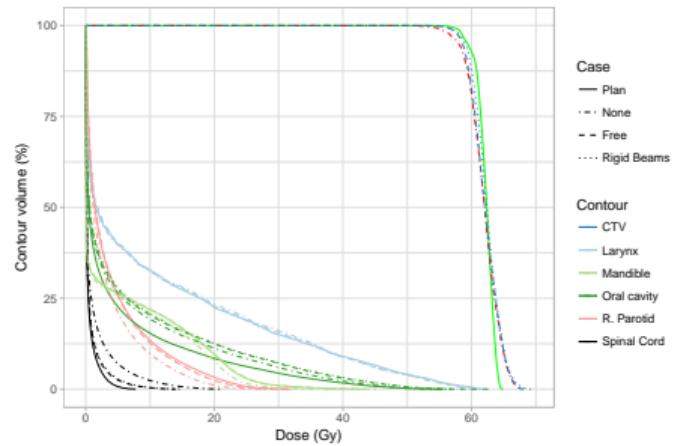
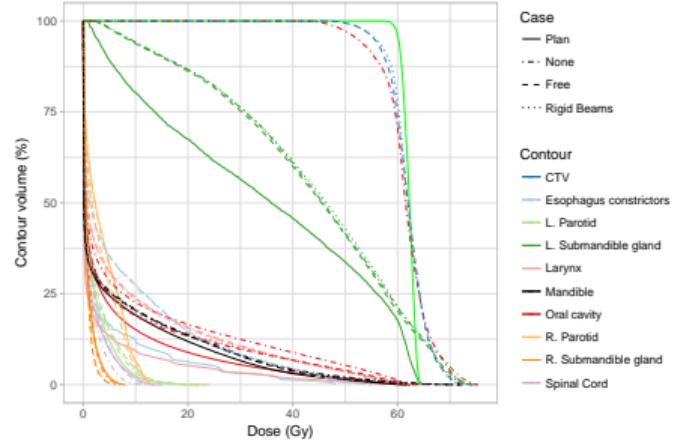


Fig: Example DVHs with original, adapted, and non-adapted plan.

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

# Results

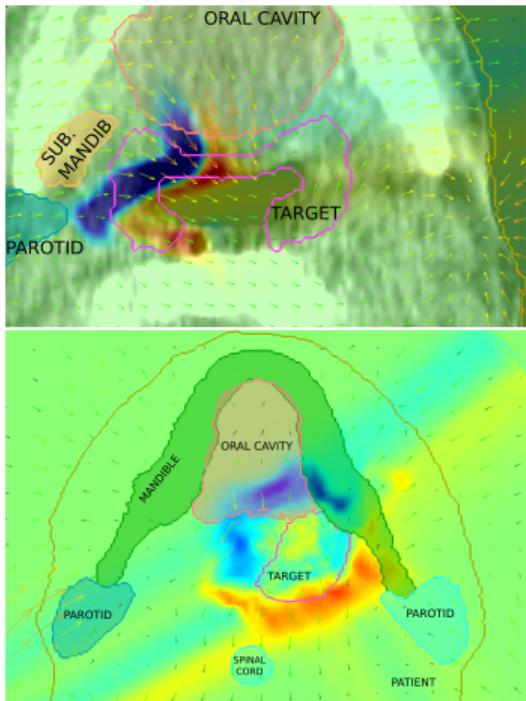


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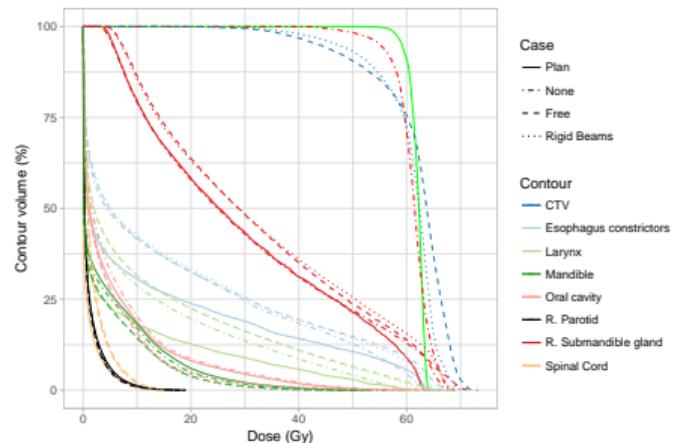
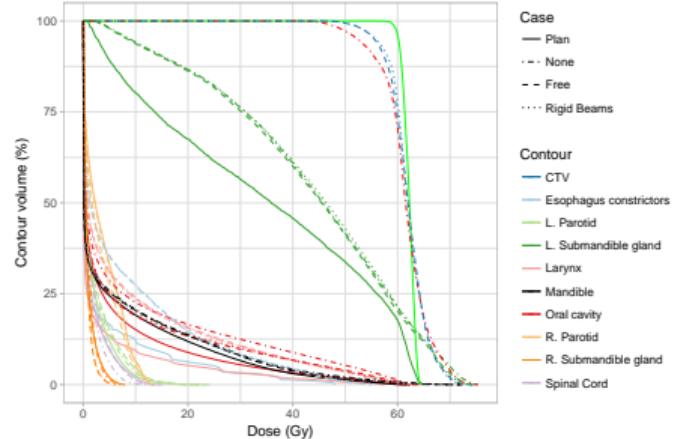


Fig: Example DVHs with original, adapted, and non-adapted plan.  
**Top:** considerable improvement, steeper DVH, but plan quality not restored  
**Bottom:** VF divergences make adapted plan worse.

# 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

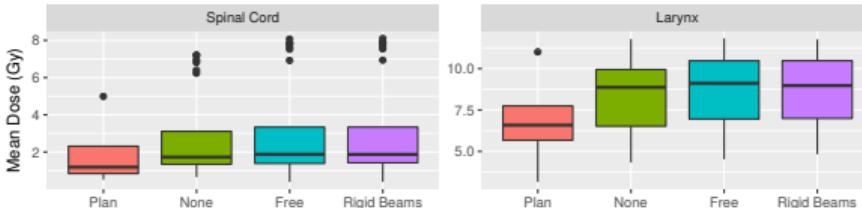


Fig: Mean dose per strategy of spinal cord and larynx.

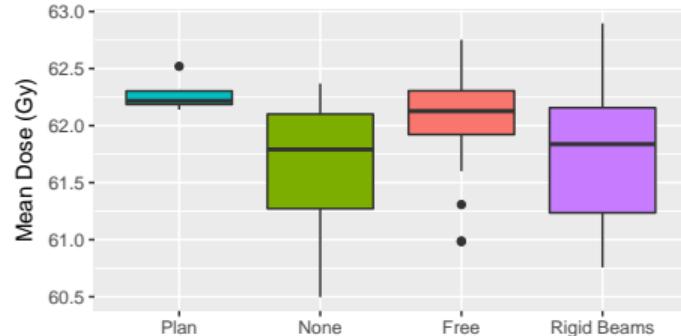


Fig: Mean dose per strategy to the target

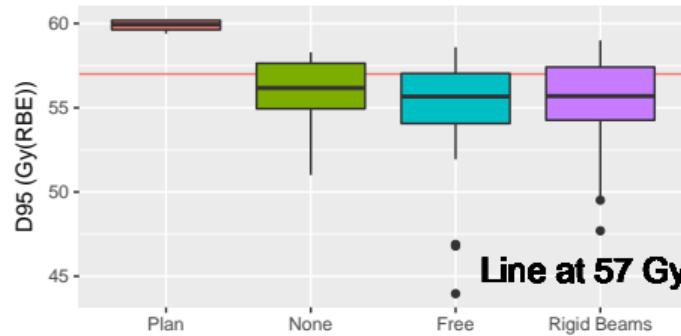


Fig: D95 per strategy in the target

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



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