Robust planning and margin concepts: What is the way to go?

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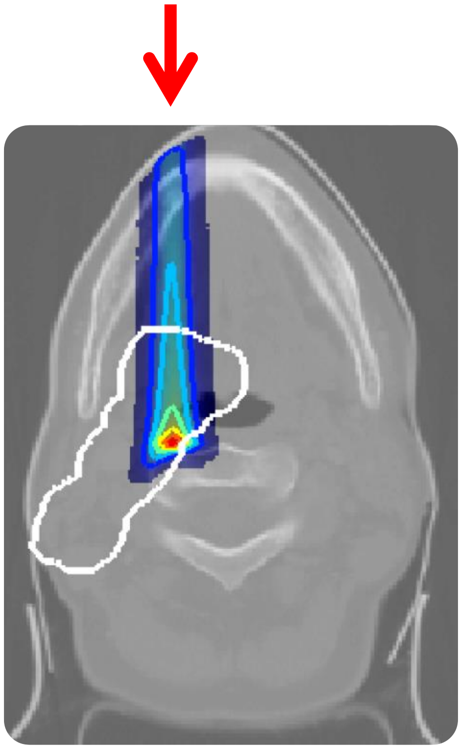
Contents

- What is the problem?
- Robust planning in IMPT
- A Robustness Recipe for IMPT
- Evaluation, approval, prescription, and reporting of robust treatment plans

WHAT IS THE PROBLEM?

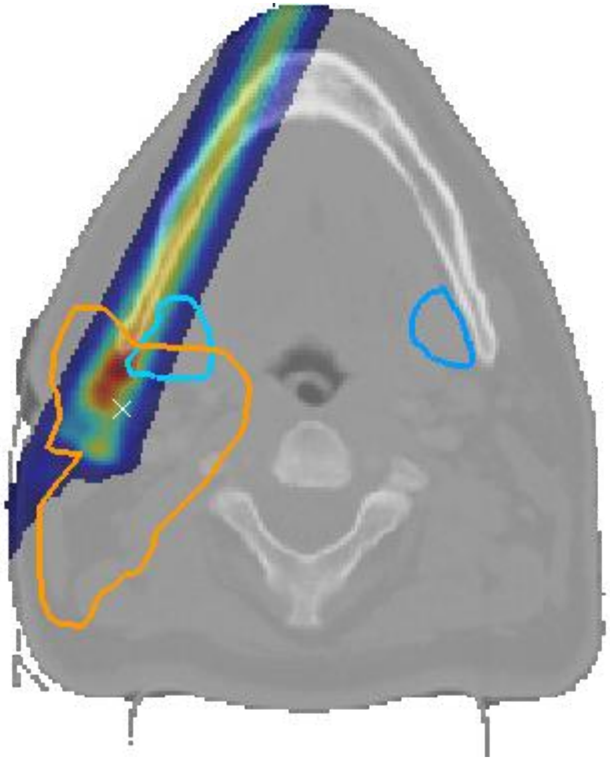
Intensity-Modulated Proton Therapy

- IMPT:
  - Discrete proton pencil beams
  - Successive delivery
  - Intensity-modulated

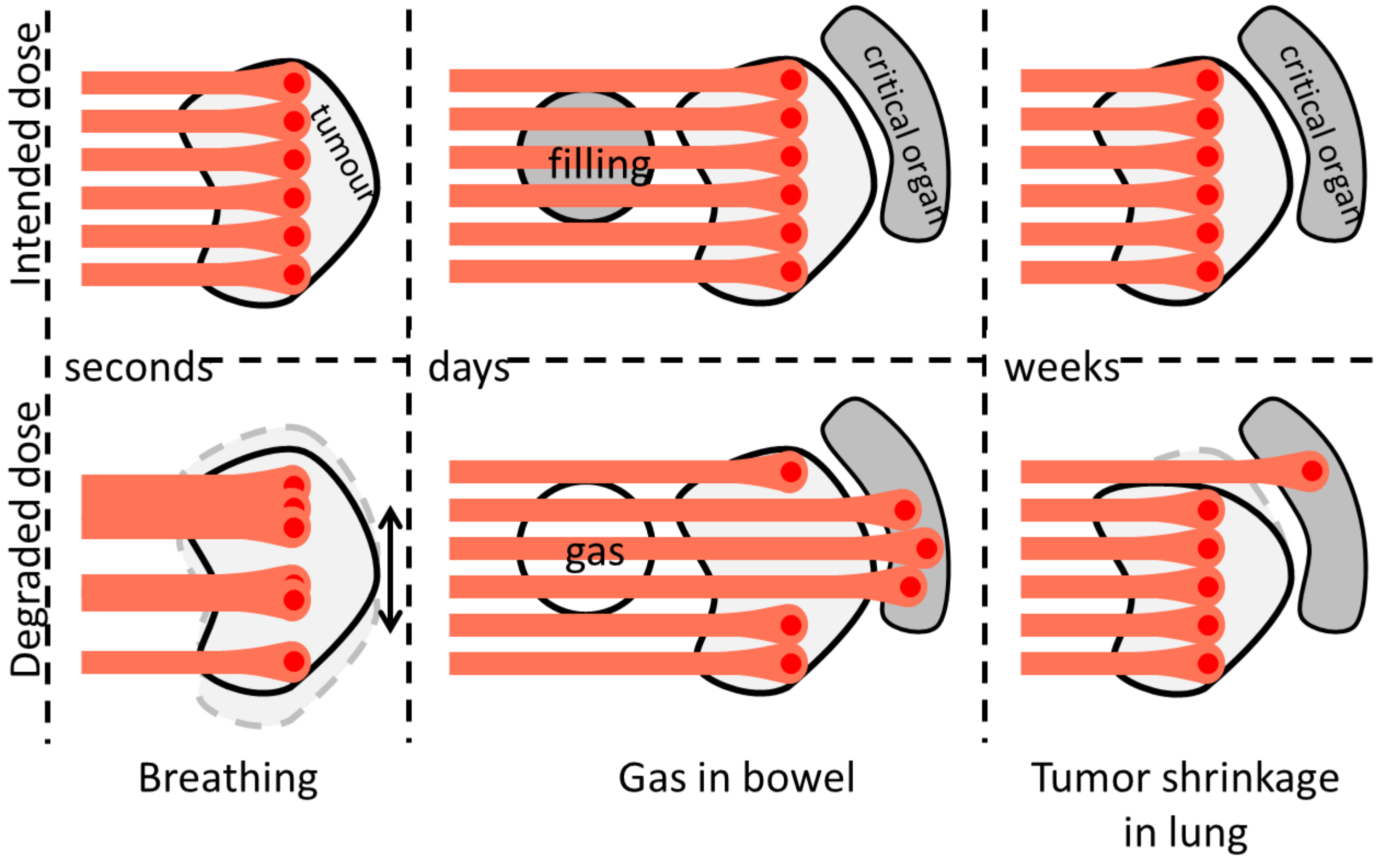


Treatment uncertainties

- IMPT is relatively sensitive to treatment uncertainties:
  - Proton range
    - Patient setup
    - Dose calculation
    - Patient anatomy
    - …



Dose Degradation in IMPT



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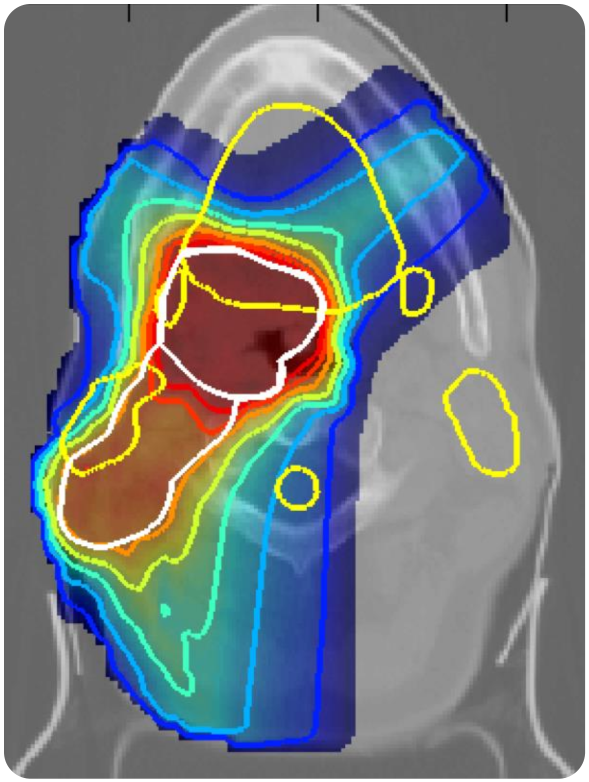
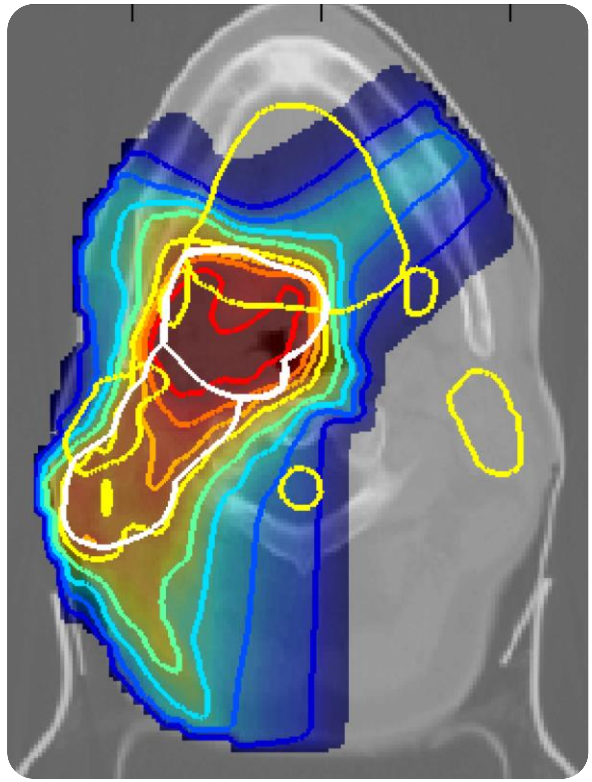
Dose Degradation



Planned dose



Delivered dose

A Kraan et al. IJROBP 2013; dx.doi.org/10.1016/j.ijrobp.2013.09.014

IMRT vs. IMPT

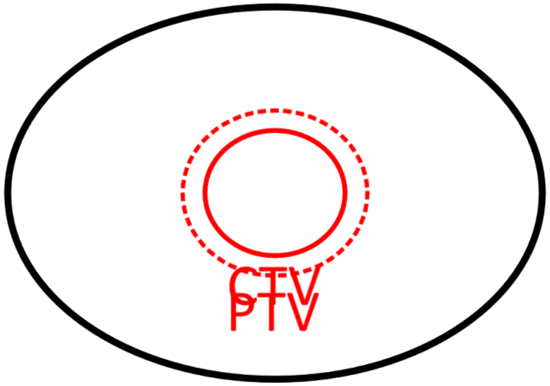
PTV margin shall not be used in PT

Uncertainty in relative stopping power

IMRT	IMPT
• **Image-guidance!**	• **Image-guidance!**
• Patient setup: in PTV	• Patient setup: **?**
• Organ motion: in PTV	• Organ motion: IM
• Dose calculation: solved	• Dose calculation: **?**
• Intra-fraction interplay: use e.g. double arcs	• Intra-fraction interplay: repainting or gating
• Anatomic changes: re-planning	• Anatomic changes: re-planning

Robust treatment planning

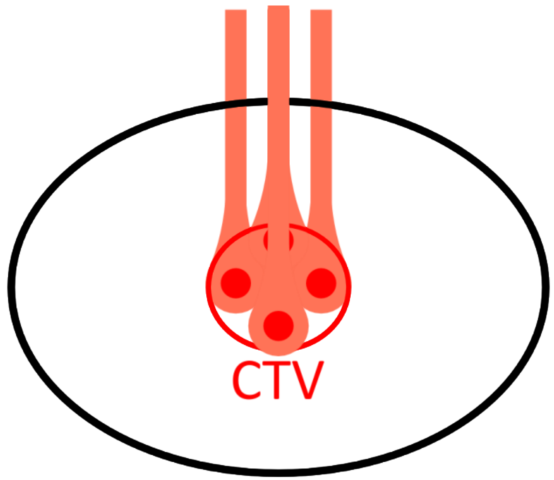
- PTV concept typically used in photons:



PTV margin

Robust treatment planning

- Robust treatment planning should be used for protons:



Robust Treatment Planning

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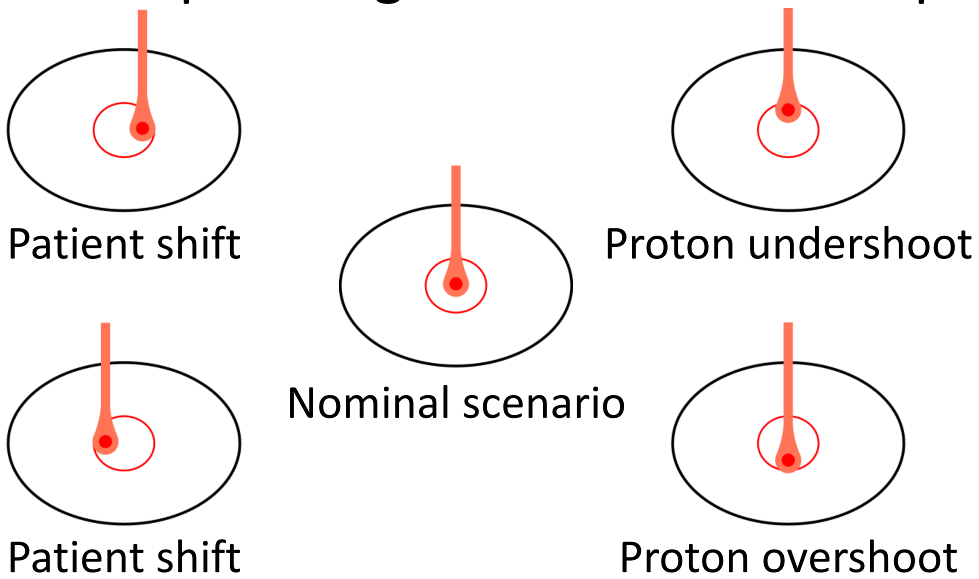

- Optimize all ‘error scenarios’ simultaneously

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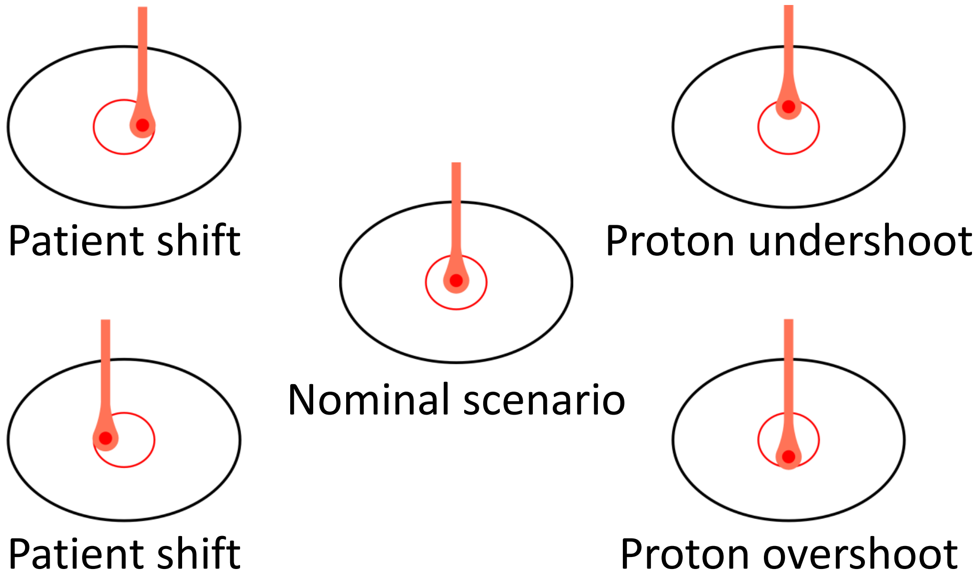
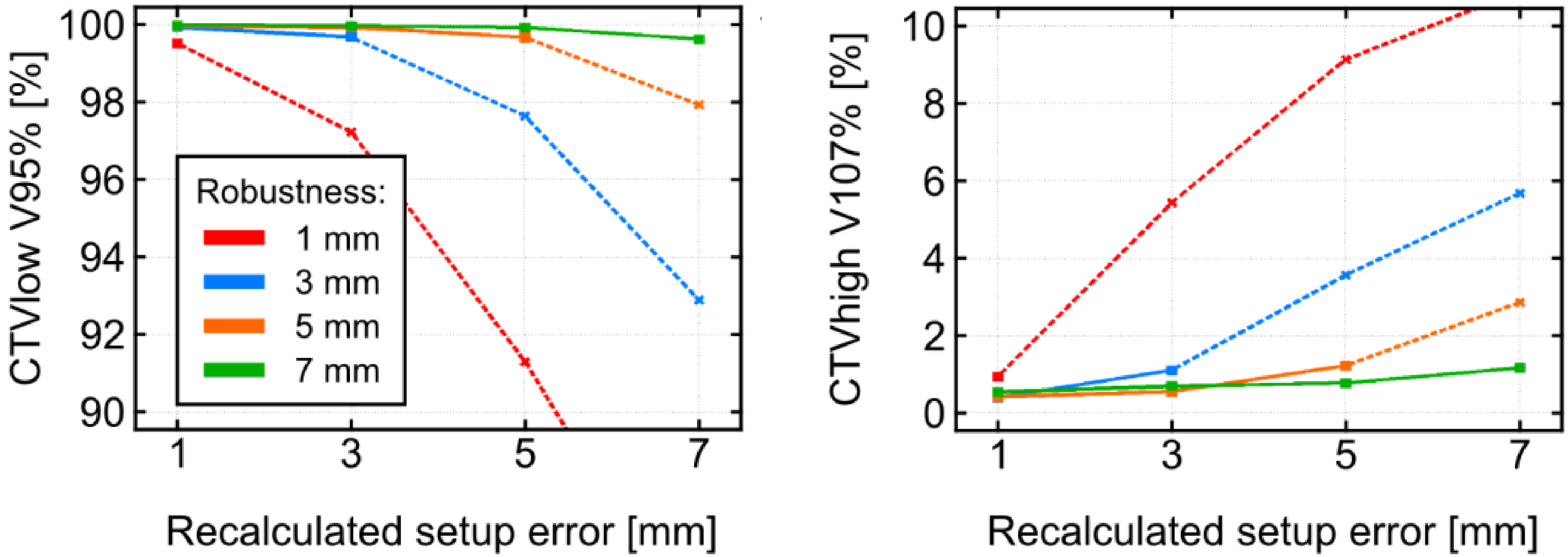
Robust Treatment Planning

- Robust treatment planning should be used for protons:



- Optimize all 'error scenarios' simultaneously
- Optimize worst-case dose values

Robust Optimization

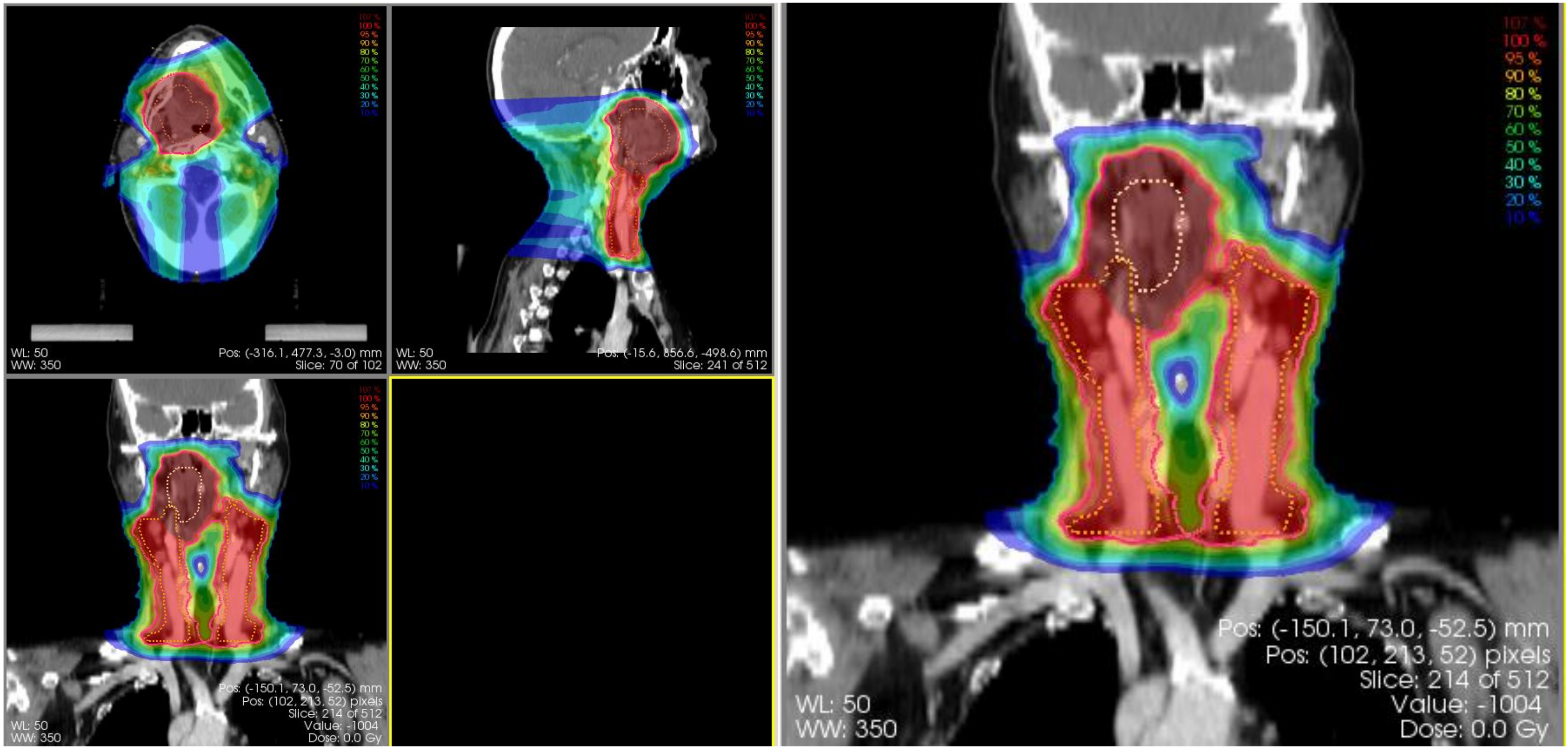


S. van de Water, I van Dam et al.

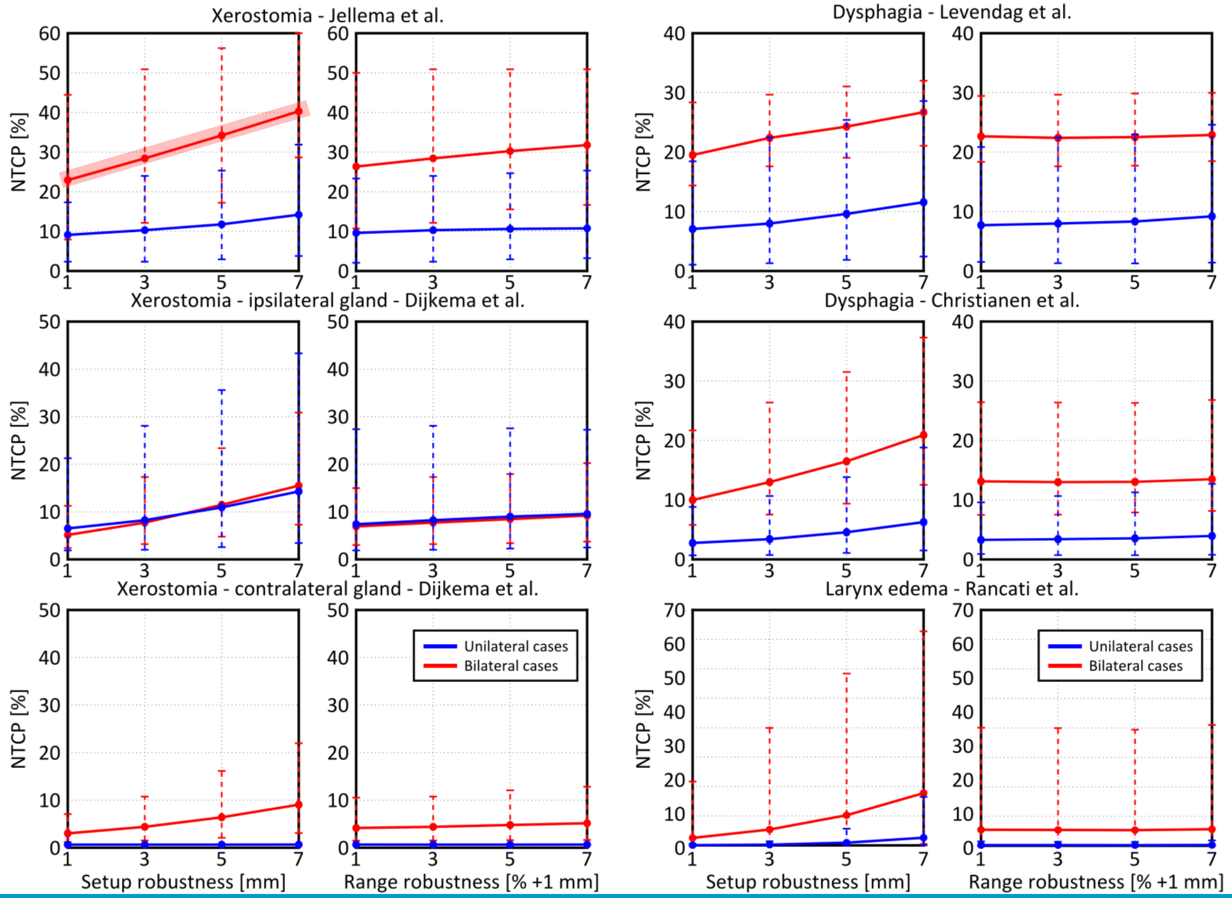
Issues

- Error scenarios are evaluated separately: no cross terms (i.e. range and setup errors combined)
- Adding more error scenarios is computational intensive
- The magnitude of the error scenario is unknown that is needed to give an adequate treatment under given setup and range error distributions

Increasingly More Robust



Prize of Robustness



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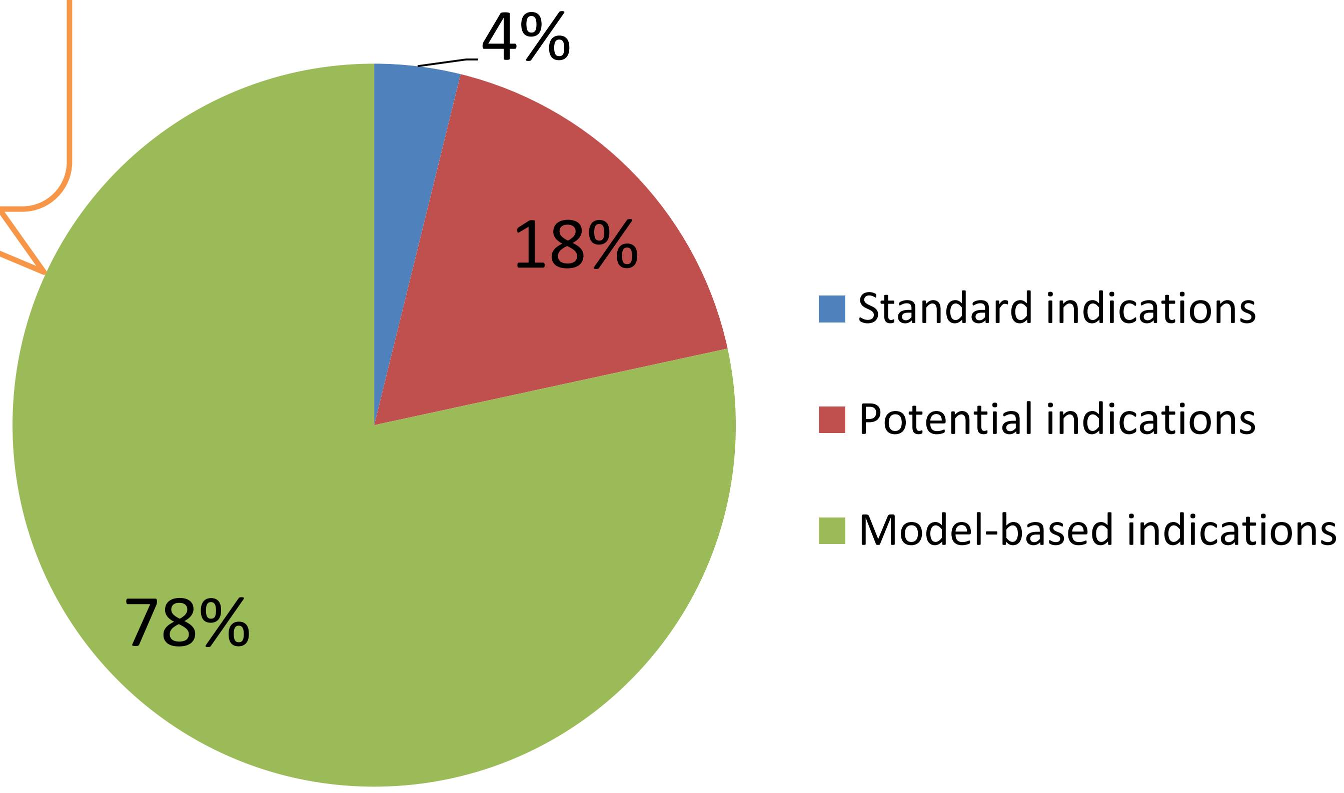
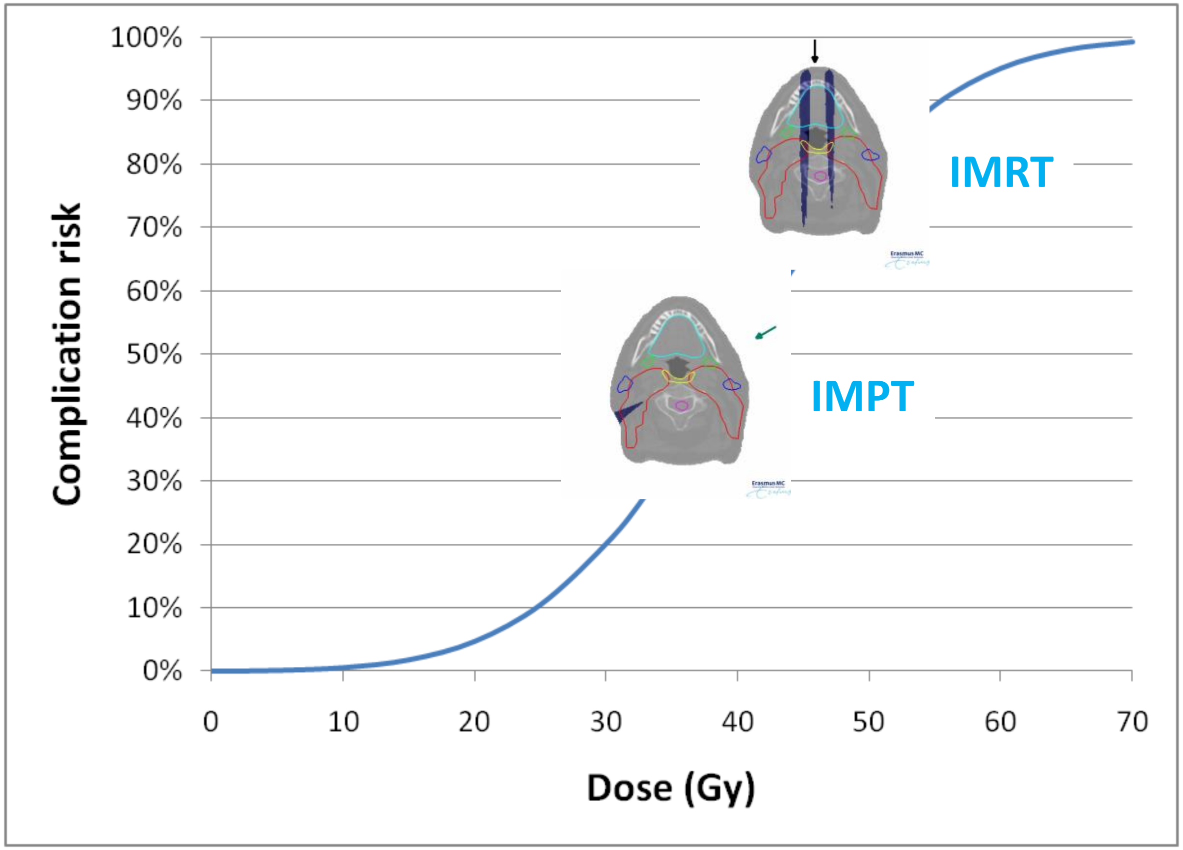
Patient Mix

"Competition" with photon therapies



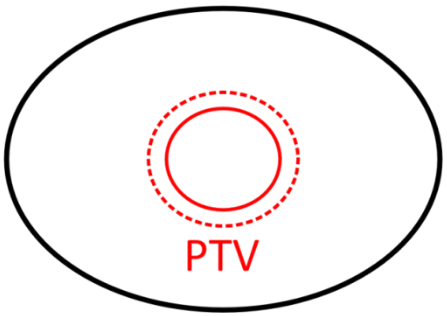
ΔNTCP Based Patient Selection



ROBUSTNESS RECIPE

Study objective

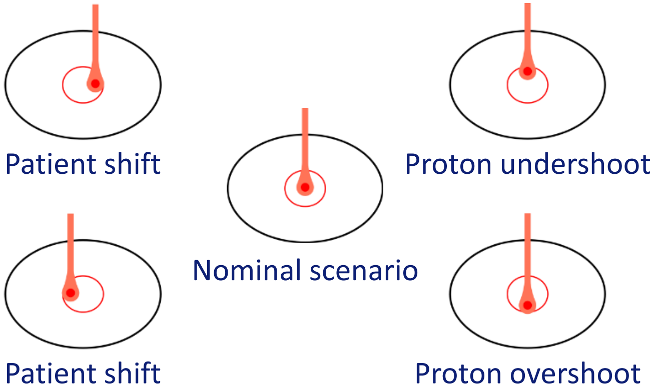
PTV margin



Margin recipe:

$M = 2.5\Sigma + 0.7\sigma$

Robust planning



Robustness recipe:

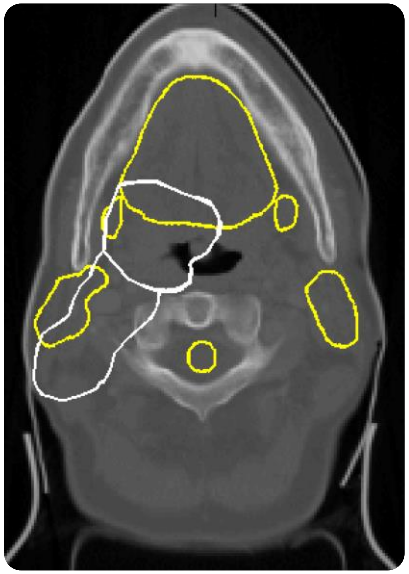
?

Study objective

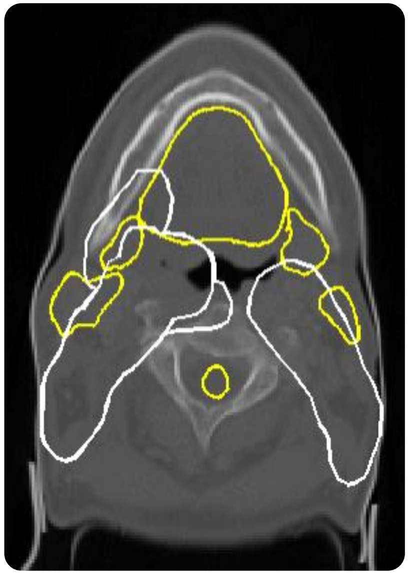
- Assuming normally distributed errors (sigma):
  - Systematic setup error (Σ)
  - Random setup error (σ)
  - Systematic range error (R)
- Obtain robustness settings that should result in adequate CTV coverage:
  - setup robustness α mm
  - range robustness β %

Patient group

Unilateral



Bilateral



- Oropharyngeal cancer patients:
  - Training: 2 cases (1 unilateral and 1 bilateral)
  - Evaluation: 12 cases (6 unilateral and 6 bilateral)

Methods

- Calculate expected CTV coverage for various robustness settings (range and setup) and treatment uncertainties (systematic range and random and systematic setup uncertainties)
- Adequate CTV coverage:
  - V95% **> 98%**
  - **> 98%** of the treatments/population

Expected Dose and Treatment Uncertainties

- Accurate estimate of expected dose requires time-consuming Monte-Carlo simulations as each iteration requires a full re-calculation of the dose distribution

- Polynomial Chaos Expansion (PCE):
  - Analytical model of the response to uncertainties

Zoltán Perkó et al. Journal of Computational Physics, 260:54–84, 2014

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Polynomial Chaos Expansion

- Multi-dimensional polynomial function:

$$\underbrace{D^i_{PCE}}_{\text{PCE dose in voxel } i}(\underline{\xi}) = \sum_{k=0}^{N} \underbrace{r^i_k}_{\text{PCE coefficients (PCCs)}} \Psi_k(\underline{\xi}) \qquad \underline{\xi} = (\underbrace{x, y, z}_{\text{setup error}}, \underbrace{r}_{\text{range error}})$$

- Expected dose for an entire fractionated treatment
  - Systematic setup (μ) and range error (r)
  - Assumes infinite number of fractions

Z. Perko, S. van der Voort et al.

Robustness Recipe

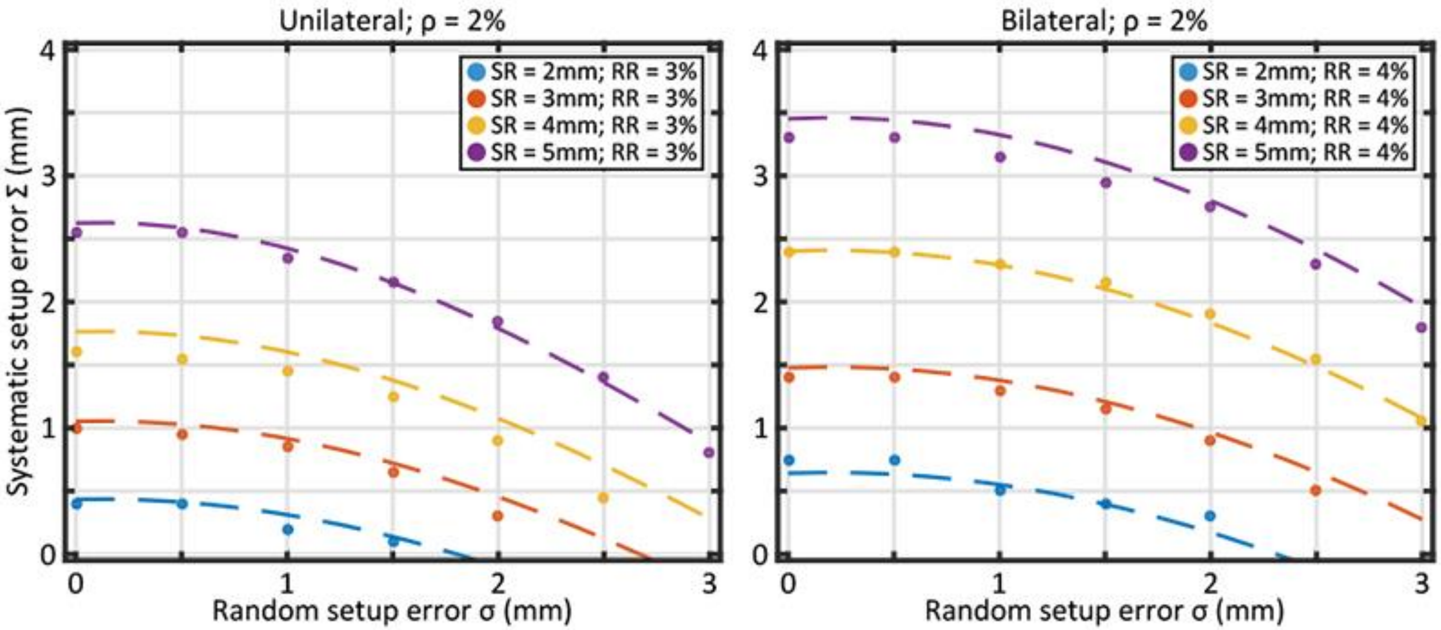

Figure 1. Combinations of systematic (Σ) and random (σ) setup errors that give adequate CTV coverage (V95% ≥ 98%) for 98% of the simulated fractionated treatments for a range error (ρ) of 2% for a unilateral and bilateral patient. In each plot different SR and RR settings are shown. The solid round markers show the obtained data, the dashed lines are a quadratic fit.

S. van der Voort et al. DOI: http://dx.doi.org/10.1016/j.ijrobp.2016.02.035

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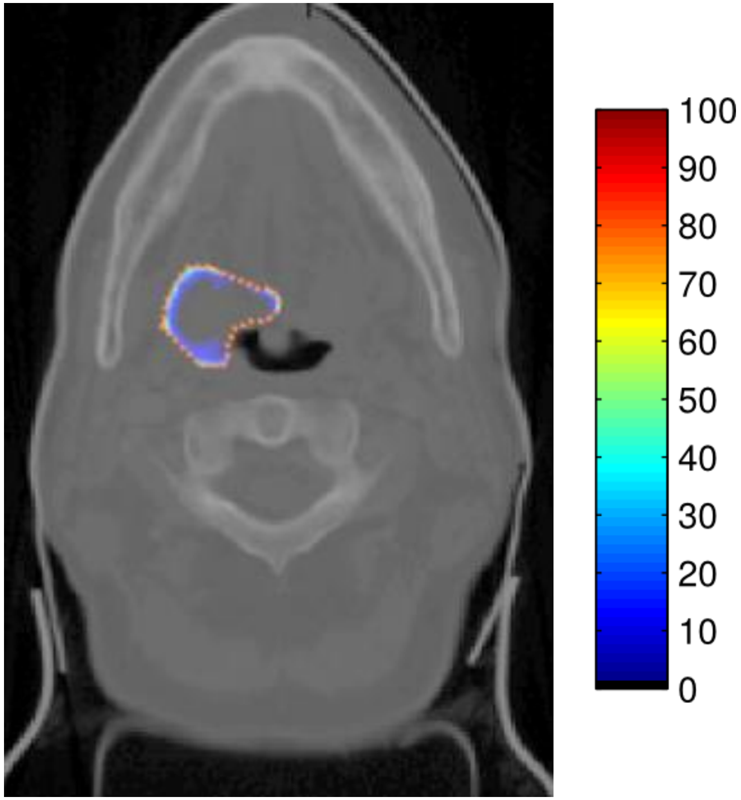
BUT ...

Location of Underdosage

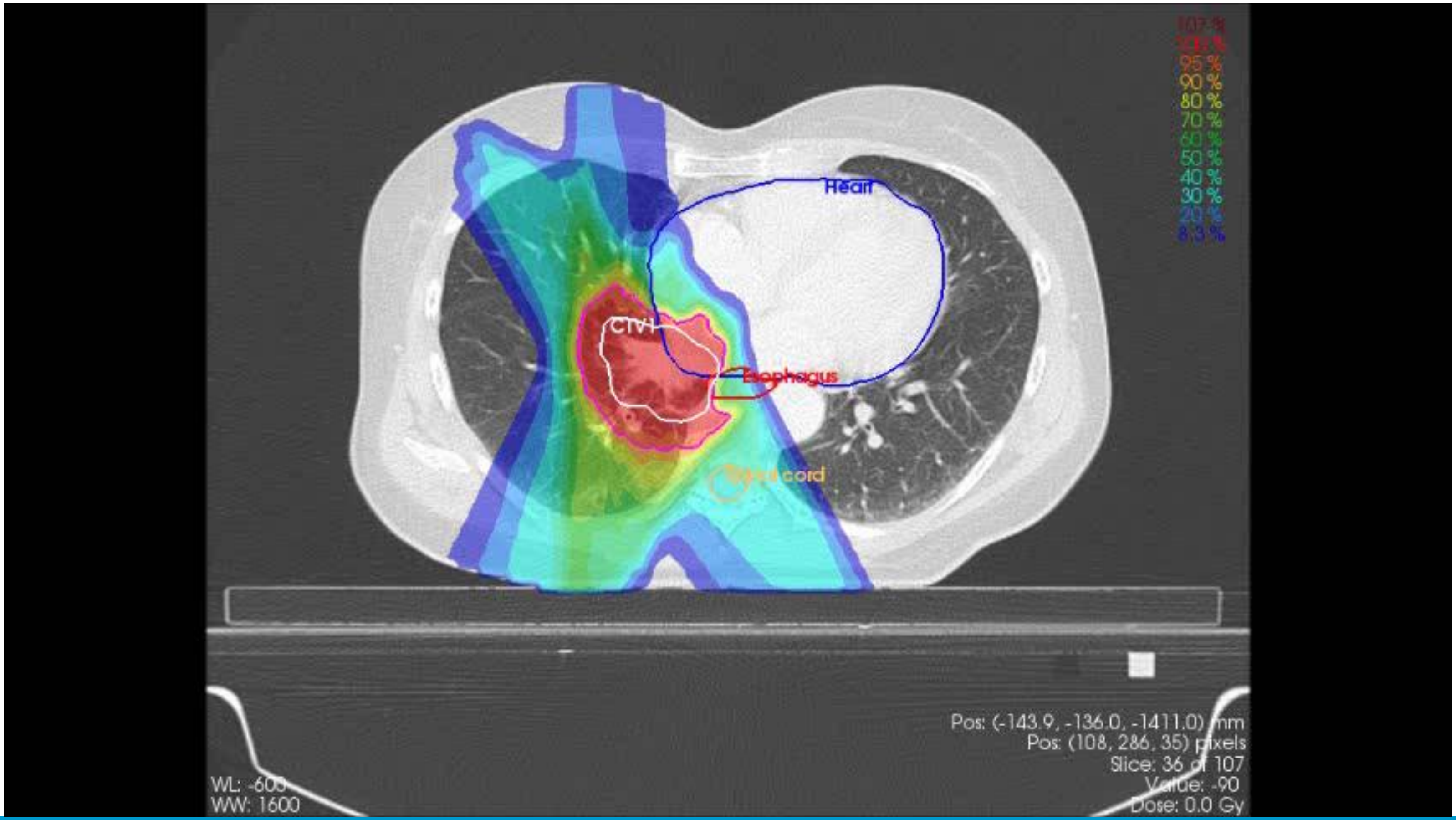
- What is the location of the underdosage in a robustly optimized treatment plan?
  - At the CTV edge or also in the center?



Robust Treatment Plans in Clinical Practice

- How to prescribe/approve/report the dose to a robustly optimized CTV and organs at risk?
  - V95%>98% for each scenario? Is this equivalent to the PTV concept?
- How to evaluate and approve a robust treatment plan?

How to Evaluate a Robust Plan?




THE WAY TO GO

Concluding Remarks

- International (ESTRO) guidelines are needed for prescribing/approving/reporting of robust treatment plans
- Those guidelines should be adopted by Treatment Planning Vendors
  - Uniformity in implemented robustness methods
- Probabilistic Planning => no robustness recipes needed

HollandPTC Construction

October 2015 - First patient mid-2017

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