Clinical online adaptive radiotherapy: optimization, dose calculation, and QA

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Disclosure

- I am not employed or a representative of Accuray and the presented opinions are my own
- Travel expenses connected to presentation
- Receives funding from regional Swedish research fund

Disclaimer

Future technology, such Online Adaptive software are technologies under development — this does not reflect a commitment to deliver products, software, features, functionality, or upgrades, and should not be relied upon in making purchasing decisions

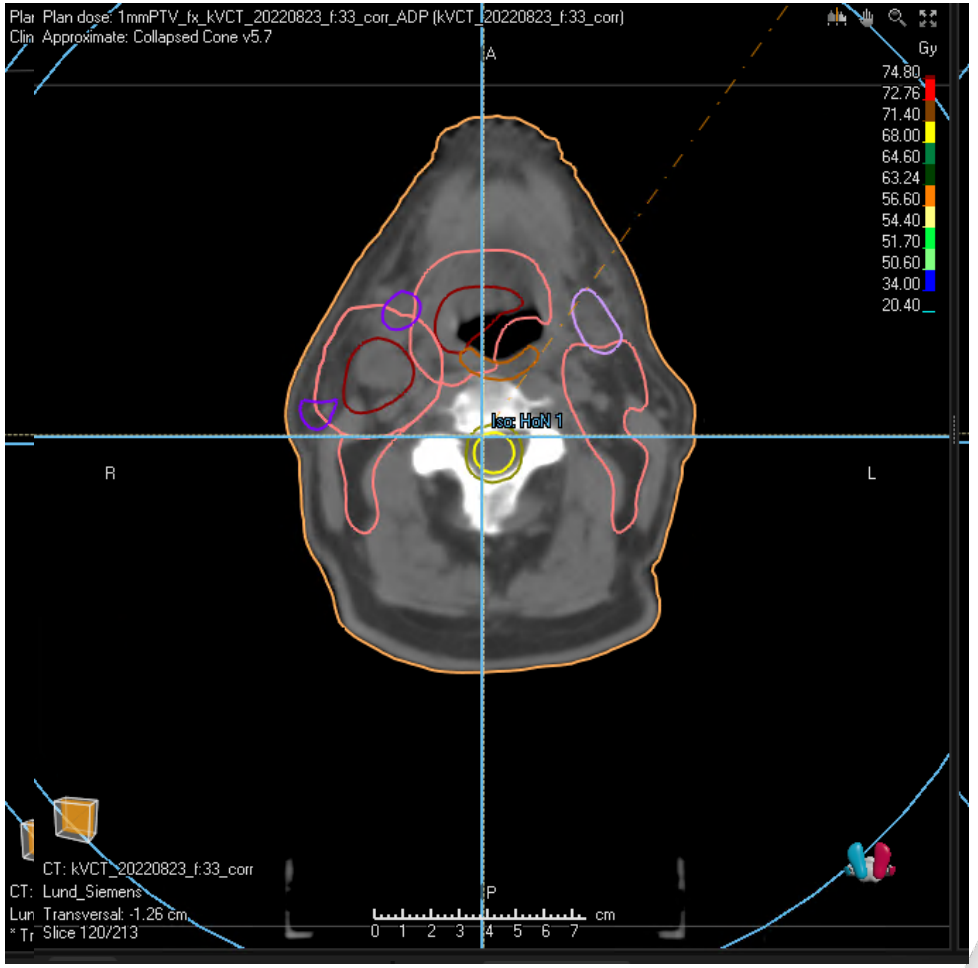
Radiotherapy - technical driven

- Multileaf collimator
- In-room (3D) imaging
- IMRT/VMAT/Helical
- Artificial intelligence

- Stereotactic radiotherapy
- Simulated integrated boost
- Motion tracking
- Adaptive radiotherapy

The daily challenge

- Fraction to fraction
  - Setup
  - Organ movement
  - Swelling
  - Weight loss
- Adaptation with standalone CT
- Adaptation with built-in imaging during or between fractions



Adaptive radiotherapy

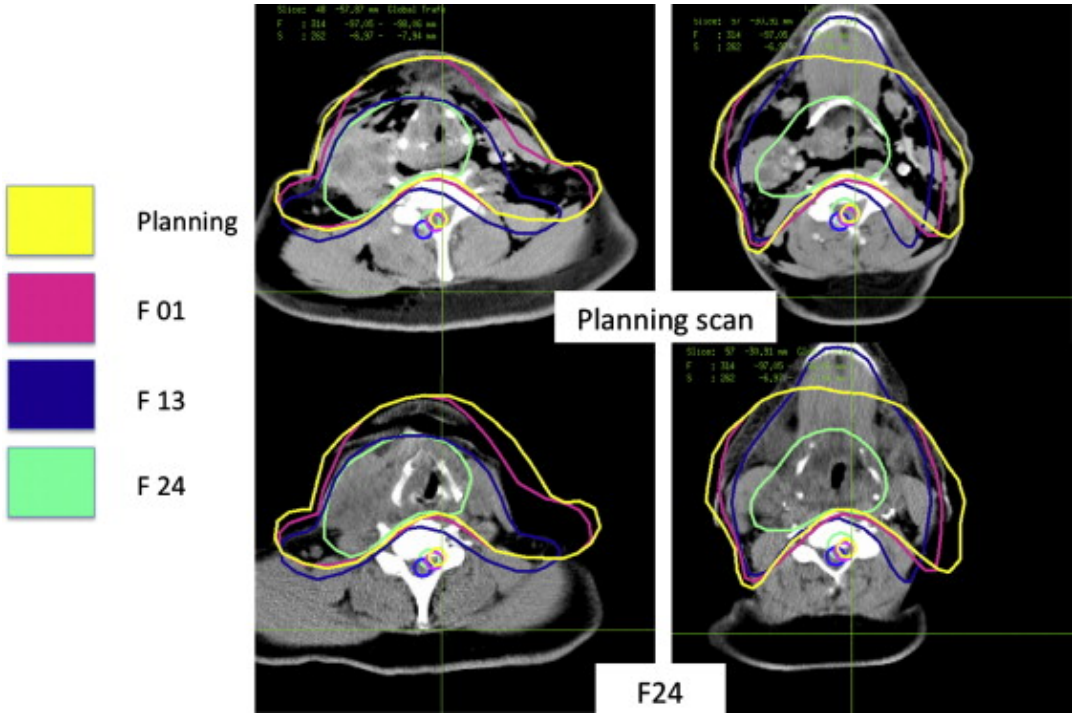
- Can change the plan to adhere to relevant variations
- Technologies:
  - imaging,
  - deformable registration,
  - contouring,
  - assessment,
  - planning,
  - quality assurance

- Challenges
  - Often slower and more resource intense then IGRT, worth the trouble?

“The key to enabling online ART into clinical mainstream practice is the maturation of a suite of synergistic technologies working in concert” - (Lim-Reinders et al. 2017)

Adaptive radiotherapy - rationale

- Jensen, Alexandra D., Simeon Nill, Peter E. Huber, Rolf Bendl, Jürgen Debus, and Marc W. Münter. 2012. 'A Clinical Concept for Interfractional Adaptive Radiation Therapy in the Treatment of Head and Neck Cancer', *International journal of radiation oncology, biology, physics*, 82: 590-96.



Adaptive radiotherapy - rationale

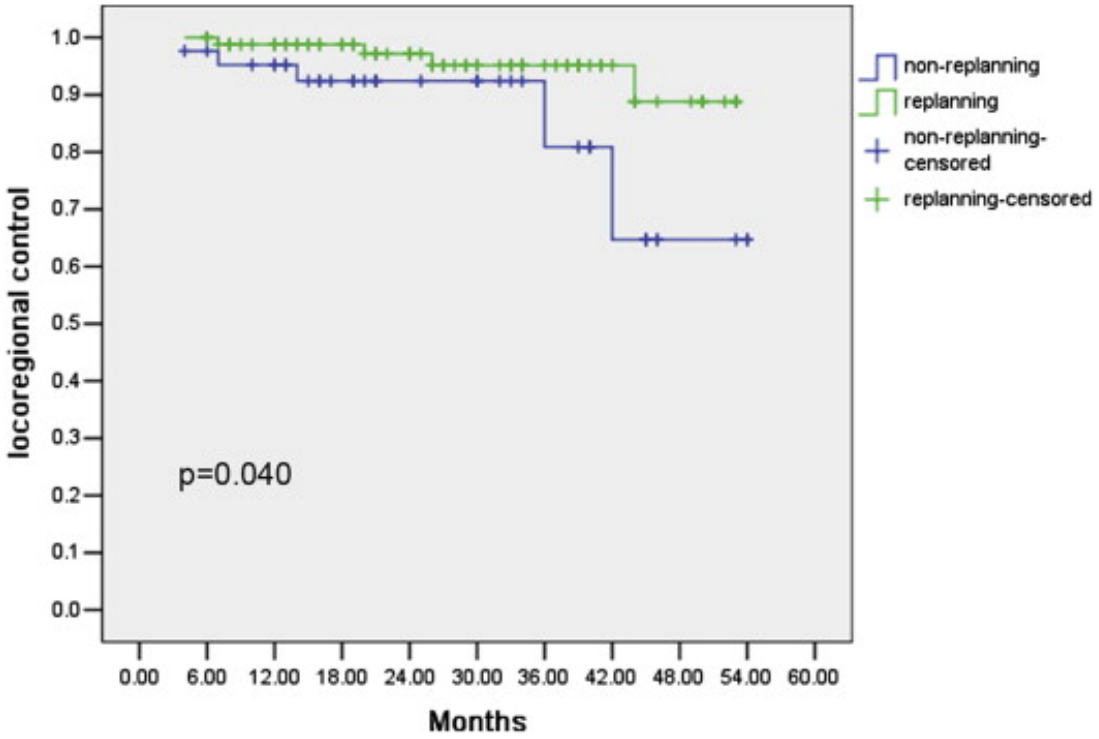
Yang, H., W. Hu, W. Wang, P. Chen, W. Ding, and W. Luo. 2013. 'Replanning during intensity modulated radiation therapy improved quality of life in patients with nasopharyngeal carcinoma', *Int J Radiat Oncol Biol Phys*, 85: e47-54. (figure)

Bertholet, J., G. Anastasi, D. Noble, A. Bel, R. van Leeuwen, T. Roggen, M. Duchateau, S. Pilskog, C. Garibaldi, N. Tilly, R. García-Mollá, J. Bonaque, U. Oelfke, M. C. Aznar, and B. Heijmen. 2020. 'Patterns of practice for adaptive and real-time radiation therapy (POP-ART RT) part II: Offline and online plan adaption for interfractional changes', *Radiother Oncol*, 153: 88-96.

Also:

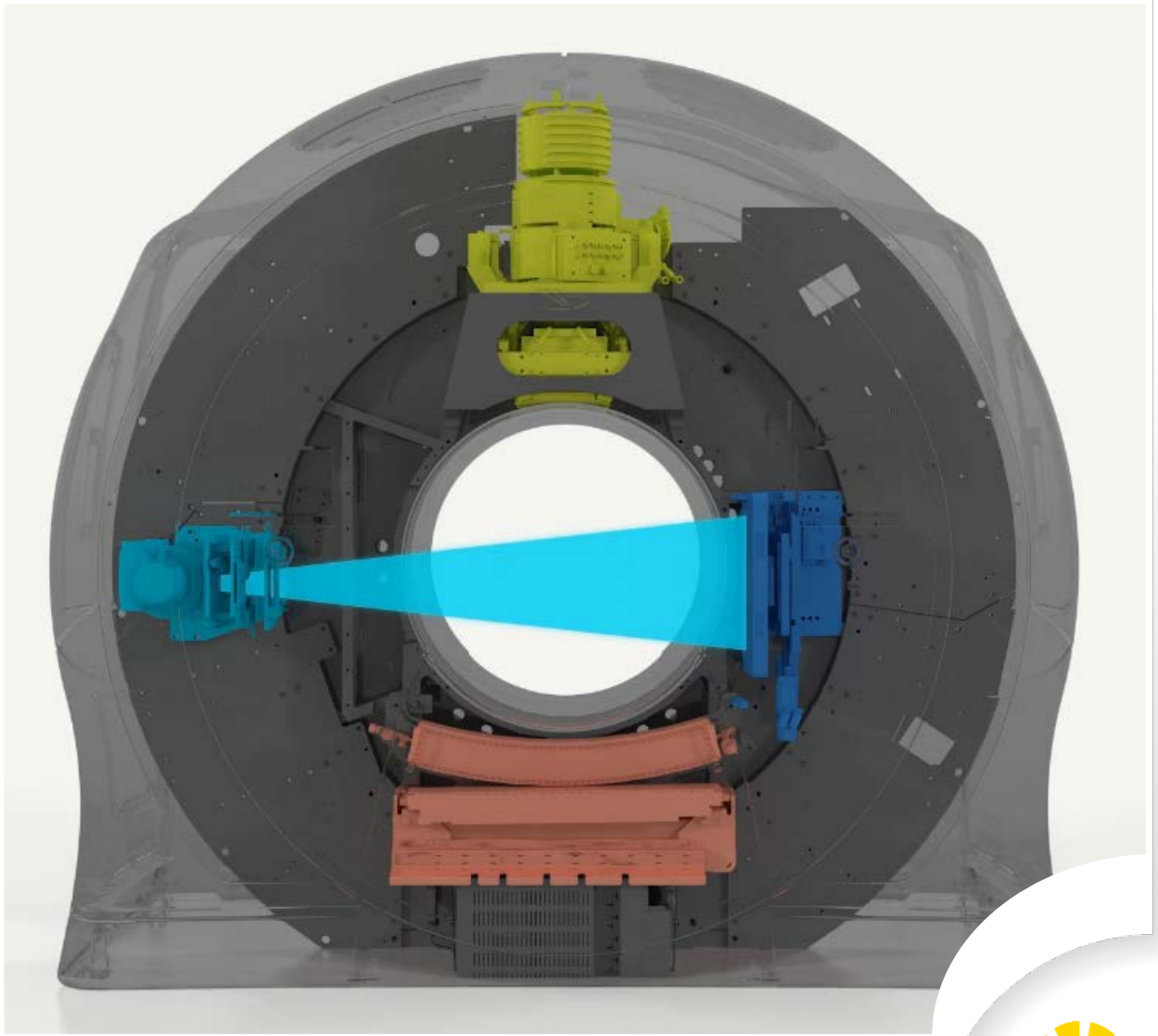
Lim-Reinders, S., B. M. Keller, S. Al-Ward, A. Sahgal, and A. Kim. 2017. 'Online Adaptive Radiation Therapy', *Int J Radiat Oncol Biol Phys*, 99: 994-1003.

Gensheimer, M. F., and Q. T. Le. 2018. 'Adaptive radiotherapy for head and neck cancer: Are we ready to put it into routine clinical practice?', *Oral Oncol*, 86: 19-24.



Online adaptive helical TomoTherapy

- Helical kilovoltage CT
- Helical high-intensity modulated radiotherapy
- Combine
  - kVCT imaging
  - helical treatment
  - state-of-the-art radiotherapy planning
  - deep learning auto-contouring
  - hybrid-intensity deformable registration



Adaptive radiotherapy helical TomoTherapy with RayStation

- Selected patients with different diseases and challenges
- Evaluated software components for online ART with:
  - Optimization of daily plans
  - Calculation on daily (corrected) kVCT images
  - QA concept
- Workflow assessment

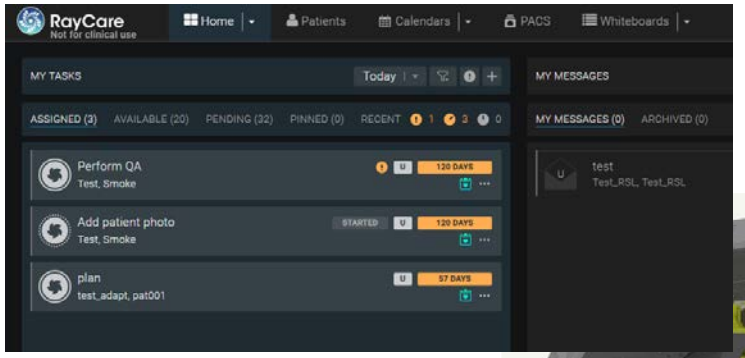
Adaptive radiotherapy helical TomoTherapy with RayStation - Cases

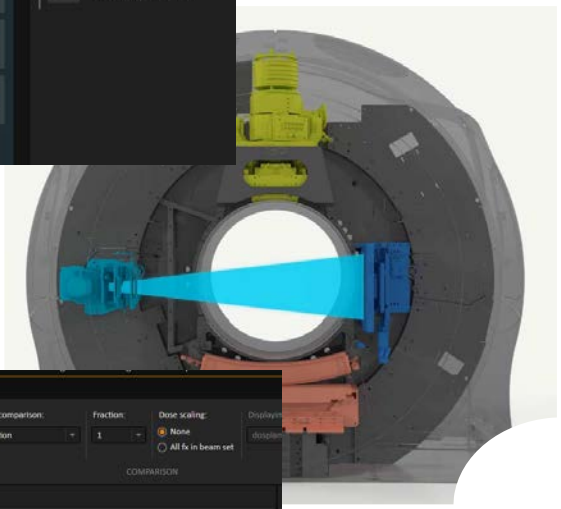
- Base of tongue
  - T2N2M0
  - 68Gy- 54.4Gy/34 fr. Billateral
- Laryngeal, supraglottic
  - T3N0M0
  - 68Gy- 54.4Gy/34 fr. Billateral

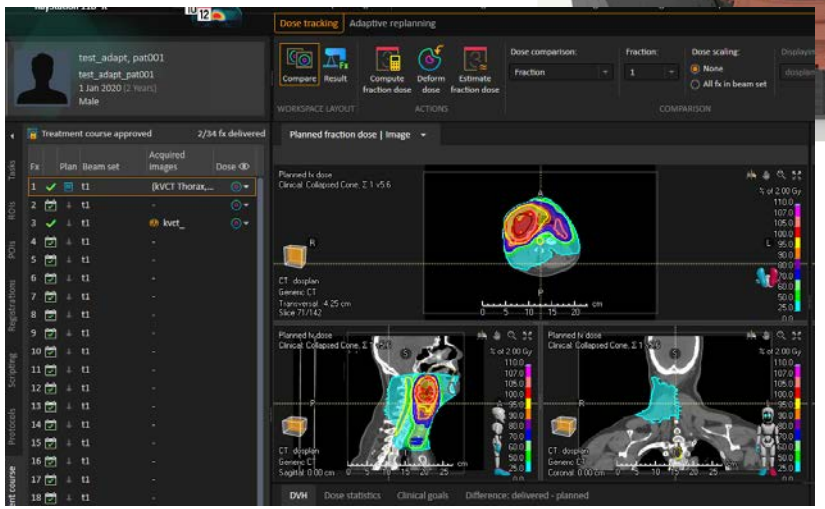
- Tonsillar fossa
  - T1N1M0
  - 68Gy- 54.4Gy/34 fr. Left
- Tonsillar fossa 2
  - T4N0M0
  - 68Gy- 54.4Gy/34 fr. Billateral

Systems

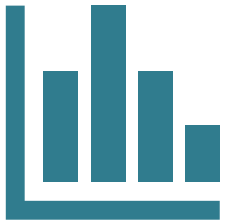
- RayStation 12-DTK
- RayCare v. 5.1
- IDMS v 3.3
- Gantry/imaging gen 1/2
- ClearRT/Radixact v. 3.0.1.1



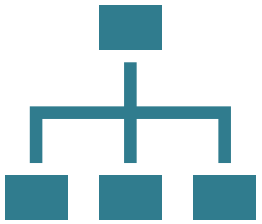




Plan optimization in adaptive radiotherapy



Optimization workflow



Daily workflow

Decision support

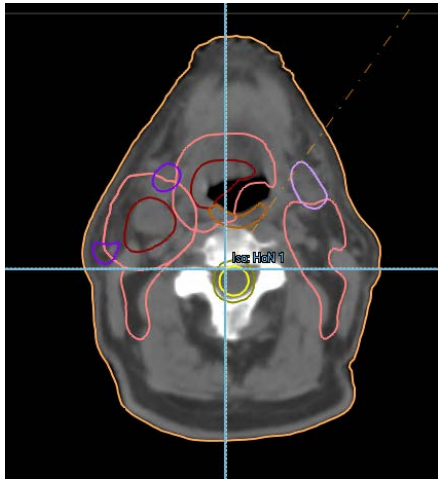
Daily workflow

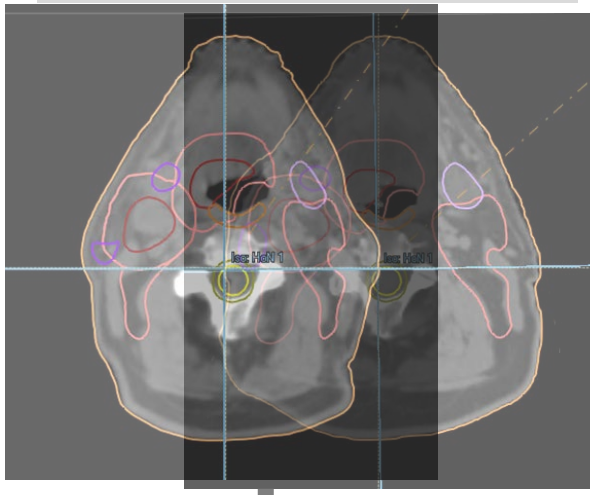
Daily imaging

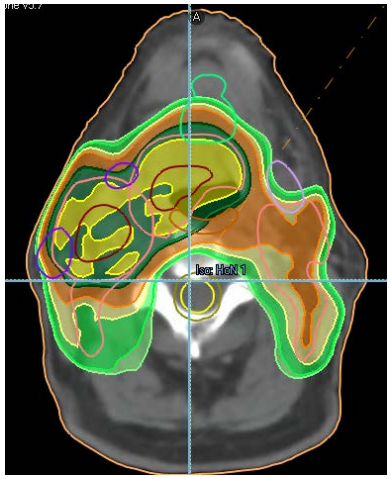
Deformable registration
Image enhancement

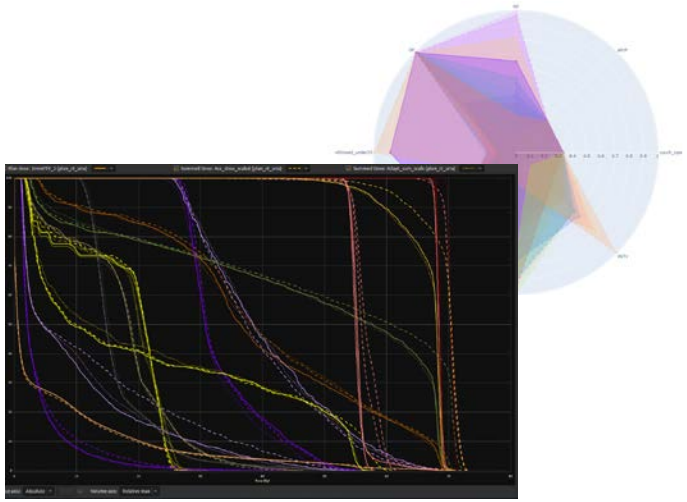
Dose planning

Evaluation/QA









Imaging

Registration

Hold for adaptive plan

Adaptive or previous plan

Treat/delivery evaluation

Machine side

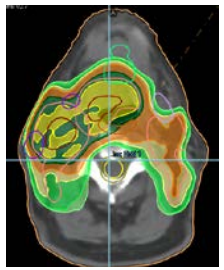
Case-based comparison of:

- Planning dose
- Accumulated plan dose
- Daily adapted planning, accumulated on planning image

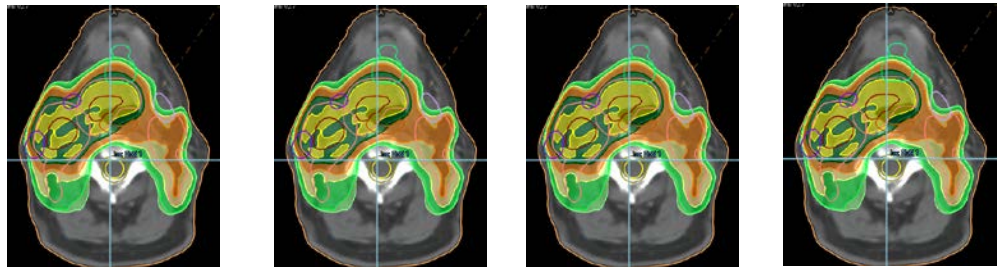
Margin

1 and 3mm PTV-CTV

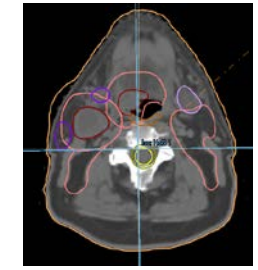
Reference plan: **PlanRef**

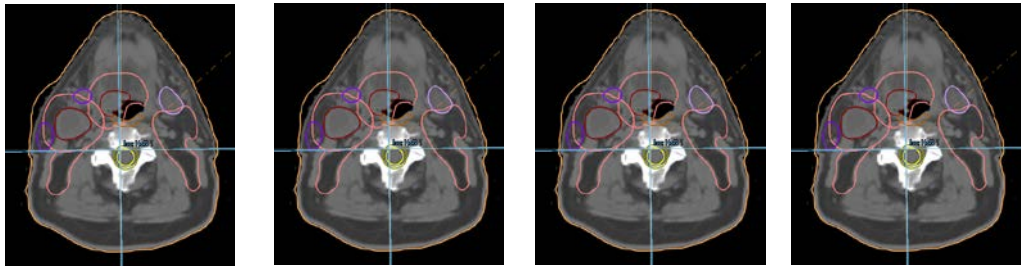


Evaluation on daily kVCT**: PlanRef$_{daily}$**



Accumulation of daily evaluation to reference CT: **PlanRef$_{acc}$**

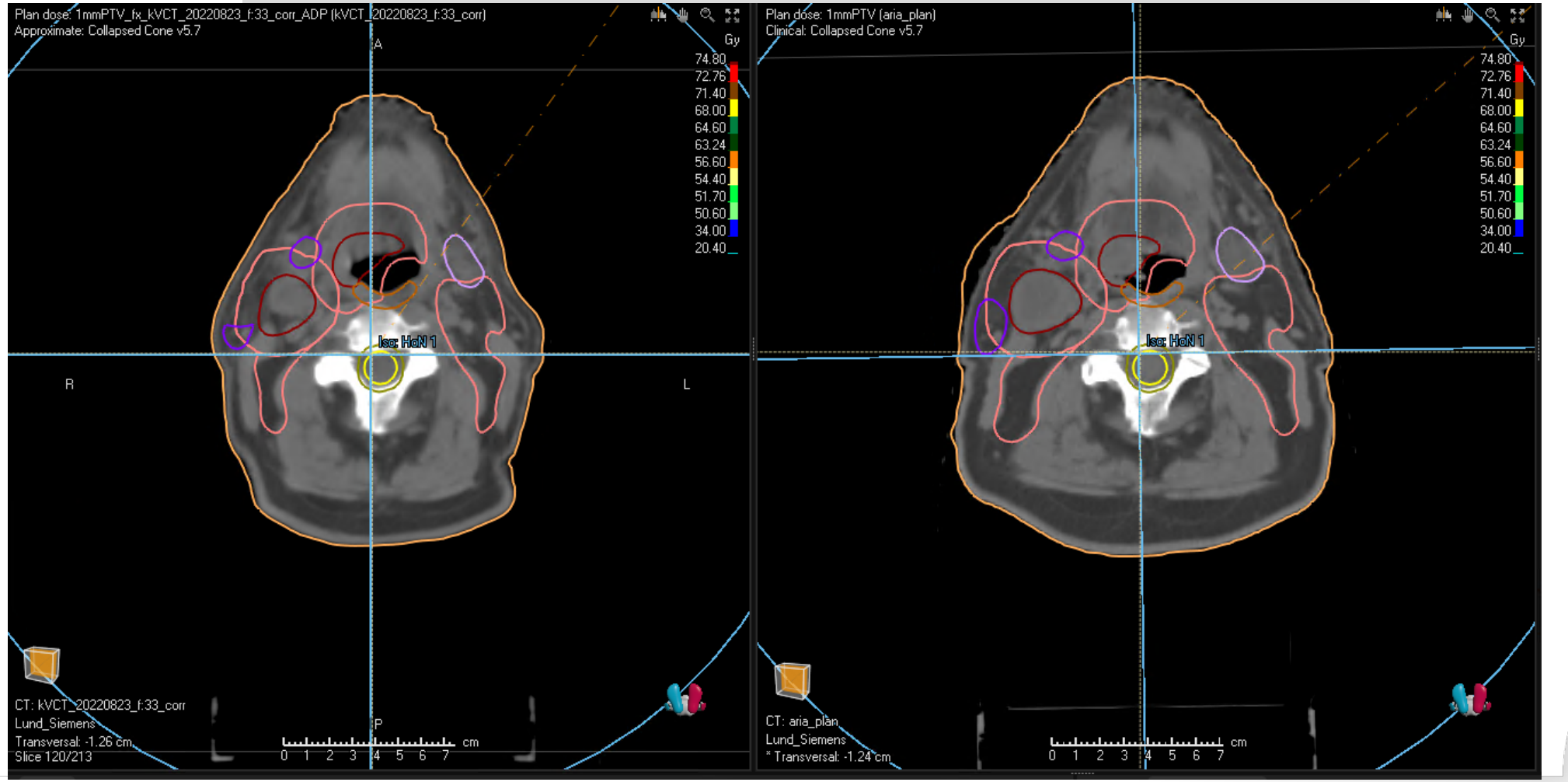




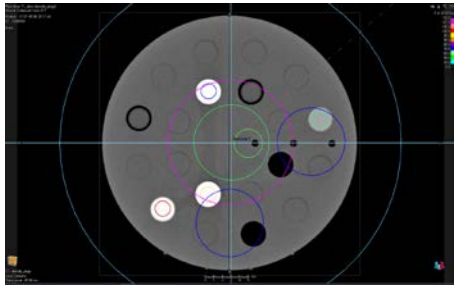
Daily adaptive planning: **PlanAdapt$_{daily}$**

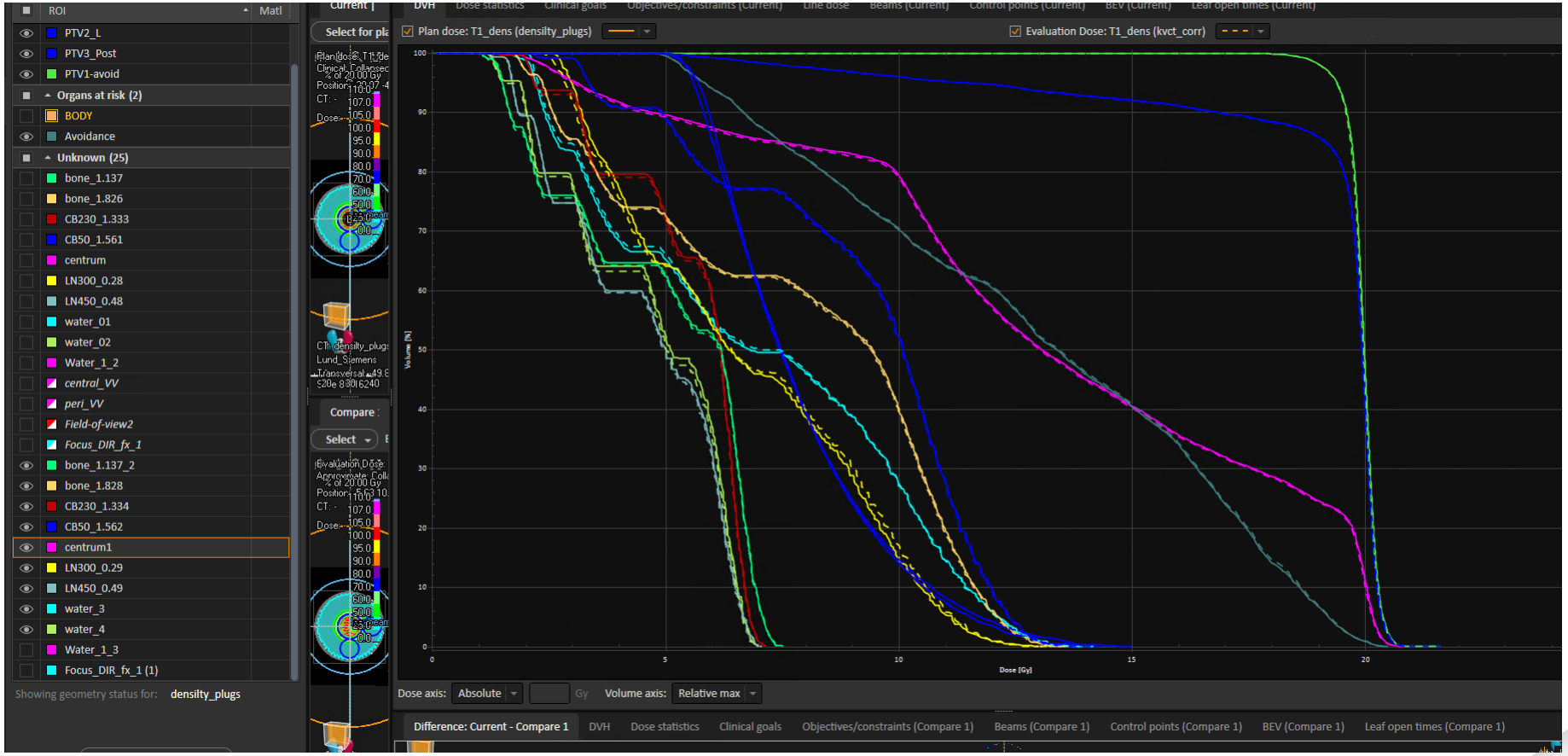
Accumulation of daily adapted to reference CT: **PlanAdapt$_{acc}$**

- Deformable registration reference CT – daily kVCT
  - Hybrid-intensity (ANACONDA)
  - Deep learning structure delineation
  - Density bulk density correction “synthetic CT”



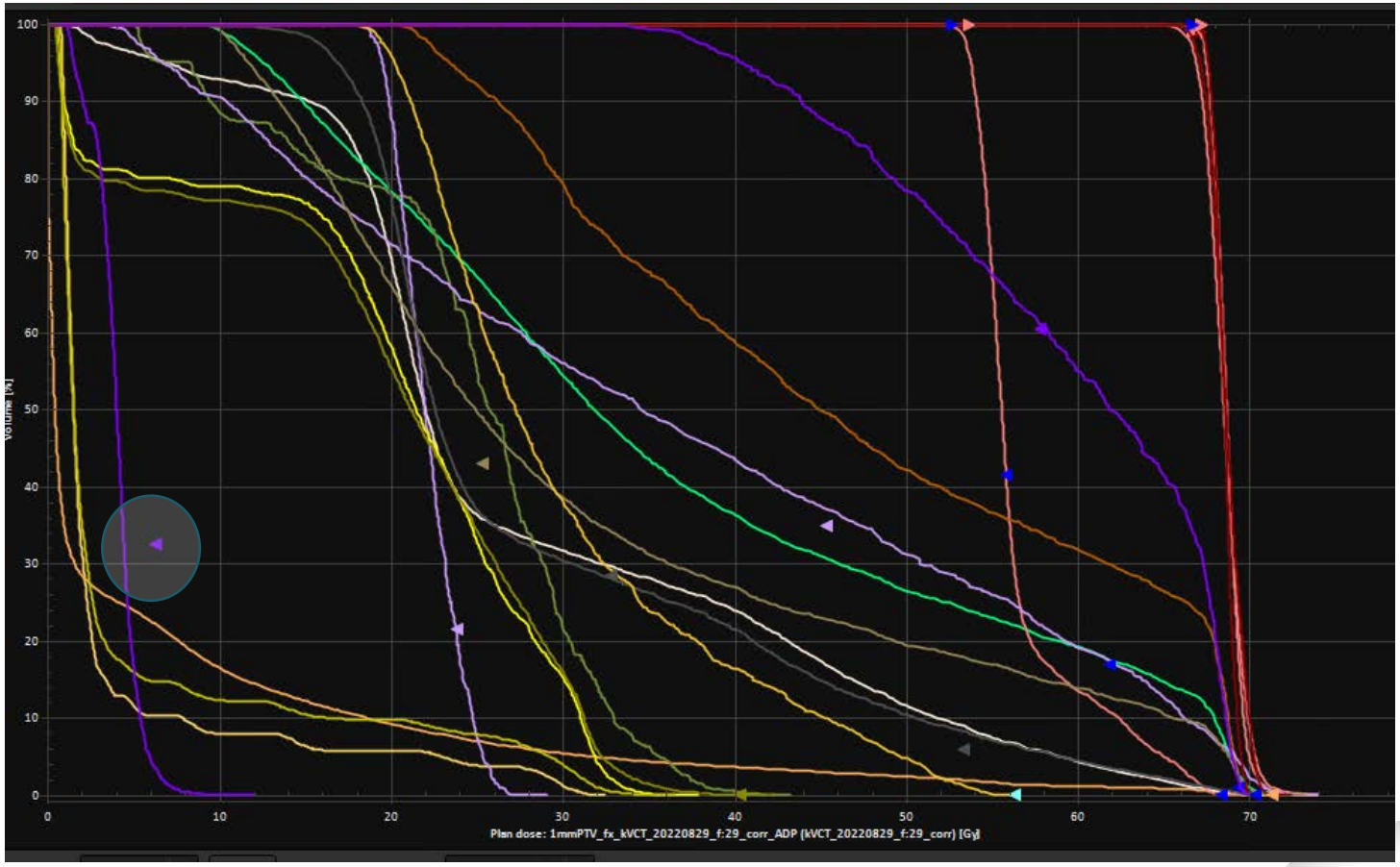
Synthetic CT / Bulk density correction





Optimization workflow

- Simulate an online workflow
- Same criteria's as reference plan
- Reoptimize 2-3 times,
- Goal= CTV/GTV coverage



Decision support

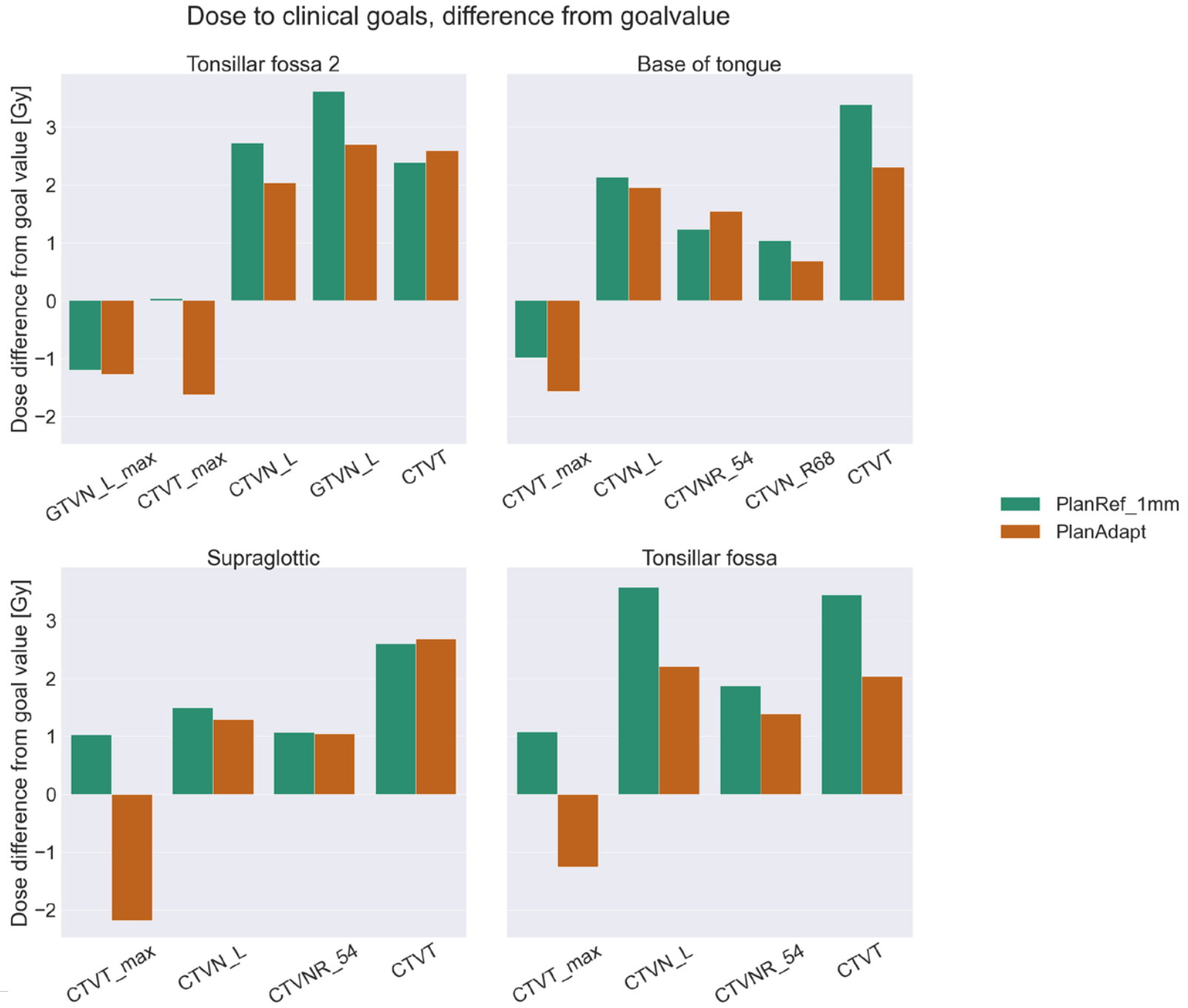
Priority	Dose	ROI/POI	Clinical goal	Value	Result	% out
1	Plan dose: 1mmPTV_2_fx_kVCT_202...	SpinalCord	At most 46.00 Gy dose at 0.00 % volume	26.57 Gy	✓	
1	Evaluation Dose: 1mmPTV_2 (kVCT_...	SpinalCord	At most 46.00 Gy dose at 0.00 % volume	26.76 Gy	✓	
1	Plan dose: 1mmPTV_2_fx_kVCT_202...	SpinalCord	At most 48.00 Gy dose at 0.00 % volume	26.57 Gy	✓	
1	Evaluation Dose: 1mmPTV_2 (kVCT_...	SpinalCord	At most 48.00 Gy dose at 0.00 % volume	26.76 Gy	✓	
2	Plan dose: 1mmPTV_2_fx_kVCT_202...	PRV_SpinalCord	At most 48.00 Gy dose at 2.00 % volume	25.50 Gy	✓	
2	Evaluation Dose: 1mmPTV_2 (kVCT_...	PRV_SpinalCord	At most 48.00 Gy dose at 2.00 % volume	25.64 Gy	✓	
2	Plan dose: 1mmPTV_2_fx_kVCT_202...	PRV_SpinalCord	At most 50.00 Gy dose at 2.00 % volume	25.50 Gy	✓	
2	Evaluation Dose: 1mmPTV_2 (kVCT_...	PRV_SpinalCord	At most 50.00 Gy dose at 2.00 % volume	25.64 Gy	✓	
9	Plan dose: 1mmPTV_2_fx_kVCT_202...	GTVT_68.0	At least 67.30 Gy dose at 98.00 % volume	67.63 Gy	✓	
9	Evaluation Dose: 1mmPTV_2 (kVCT_...	GTVT_68.0	At least 67.30 Gy dose at 98.00 % volume	71.52 Gy	✓	
10	Plan dose: 1mmPTV_2_fx_kVCT_202...	CTVN_L_54.4	At least 53.30 Gy dose at 98.00 % volume	53.40 Gy	✓	
10	Evaluation Dose: 1mmPTV_2 (kVCT_...	CTVN_L_54.4	At least 53.30 Gy dose at 98.00 % volume	41.80 Gy	!	
10	Plan dose: 1mmPTV_2_fx_kVCT_202...	CTVN_R_54.4	At least 53.30 Gy dose at 98.00 % volume	53.66 Gy	✓	
10	Evaluation Dose: 1mmPTV_2 (kVCT_...	CTVN_R_54.4	At least 53.30 Gy dose at 98.00 % volume	41.42 Gy	!	
10	Plan dose: 1mmPTV_2_fx_kVCT_202...	CTVT_68.0	At least 66.60 Gy dose at 98.00 % volume	67.24 Gy	✓	
10	Evaluation Dose: 1mmPTV_2 (kVCT_...	CTVT_68.0	At least 66.60 Gy dose at 98.00 % volume	63.86 Gy	!	
13	Plan dose: 1mmPTV_2_fx_kVCT_202...	PTV_54_1mm	At least 51.70 Gy dose at 98.00 % volume	52.72 Gy	✓	
13	Evaluation Dose: 1mmPTV_2 (kVCT_...	PTV_54_1mm	At least 51.70 Gy dose at 98.00 % volume	39.66 Gy	!	
13	Plan dose: 1mmPTV_2_fx_kVCT_202...	PTV_68_1mm	At least 64.60 Gy dose at 98.00 % volume	66.50 Gy	✓	
13	Plan dose: 1mmPTV_2_fx_kVCT_202...	PTV_68_1mm	At least 64.60 Gy dose at 98.00 % volume	66.50 Gy	✓	
13	Evaluation Dose: 1mmPTV_2 (kVCT_...	PTV_68_1mm	At least 64.60 Gy dose at 98.00 % volume	61.28 Gy	!	
13	Evaluation Dose: 1mmPTV_2 (kVCT_...	PTV_68_1mm	At least 64.60 Gy dose at 98.00 % volume	61.28 Gy	!	
14	Plan dose: 1mmPTV_2_fx_kVCT_202...	PTV_68_1mm	At most 71.40 Gy dose at 2.00 % volume	69.88 Gy	✓	
14	Plan dose: 1mmPTV_2_fx_kVCT_202...	PTV_68_1mm	At most 71.40 Gy dose at 2.00 % volume	69.88 Gy	✓	
14	Evaluation Dose: 1mmPTV_2 (kVCT_...	PTV_68_1mm	At most 71.40 Gy dose at 2.00 % volume	74.87 Gy	!	
14	Evaluation Dose: 1mmPTV_2 (kVCT_...	PTV_68_1mm	At most 71.40 Gy dose at 2.00 % volume	74.87 Gy	!	
15	Plan dose: 1mmPTV_2_fx_kVCT_202...	Parotid_L	At most 20.00 Gy average dose	9.24 Gy	✓	
15	Evaluation Dose: 1mmPTV_2 (kVCT_...	Parotid_L	At most 20.00 Gy average dose	13.19 Gy	✓	
15	Plan dose: 1mmPTV_2_fx_kVCT_202...	Parotid_L	At most 25.00 Gy average dose	9.24 Gy	✓	
15	Evaluation Dose: 1mmPTV_2 (kVCT_...	Parotid_L	At most 25.00 Gy average dose	13.19 Gy	✓	

REGION SKÅNE

Summed doses

-Selected dose coverage criterias and target structures.

Difference from goal value

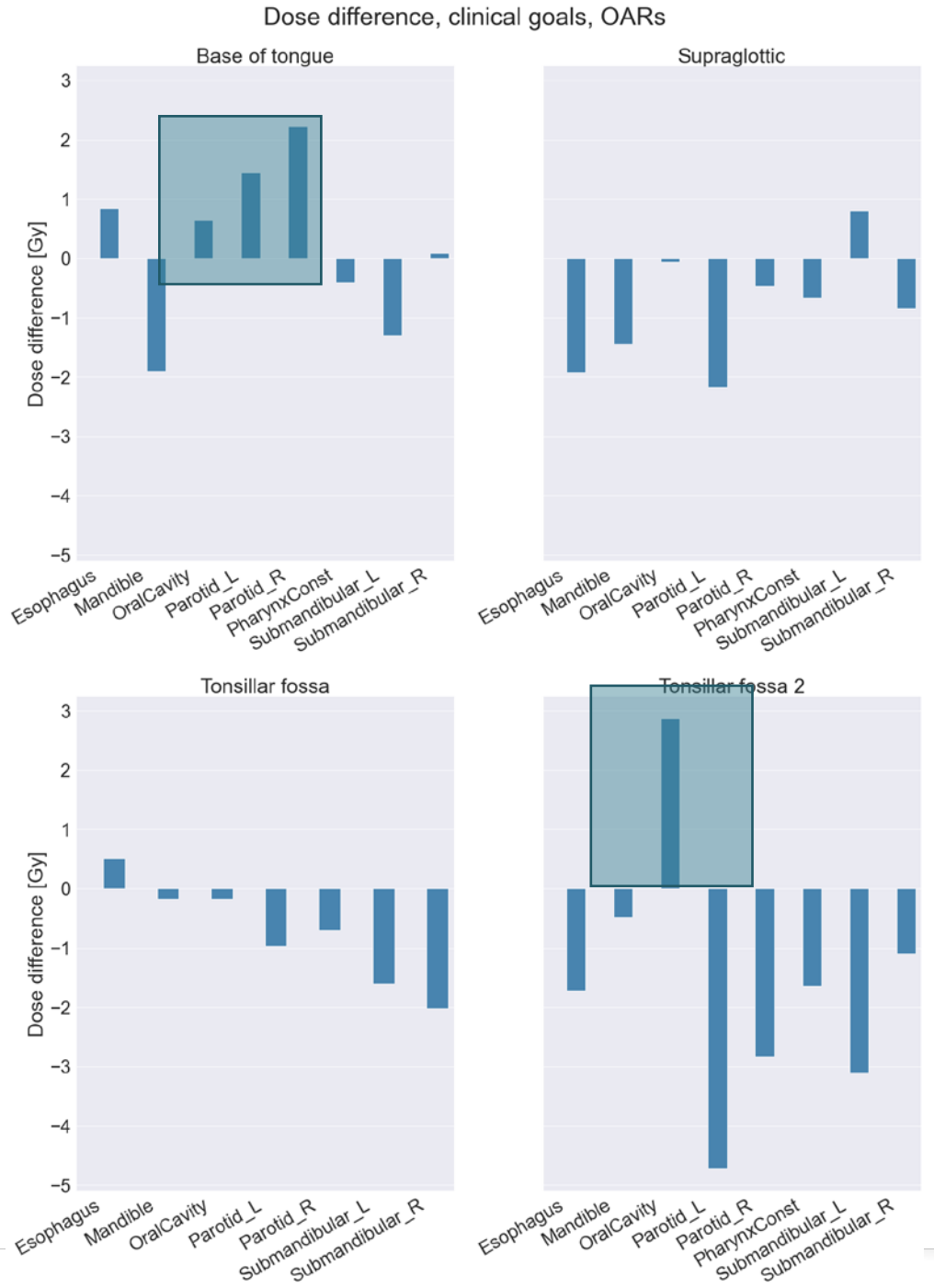


Summed doses

Adaptive plan difference to Reference plan 1mm

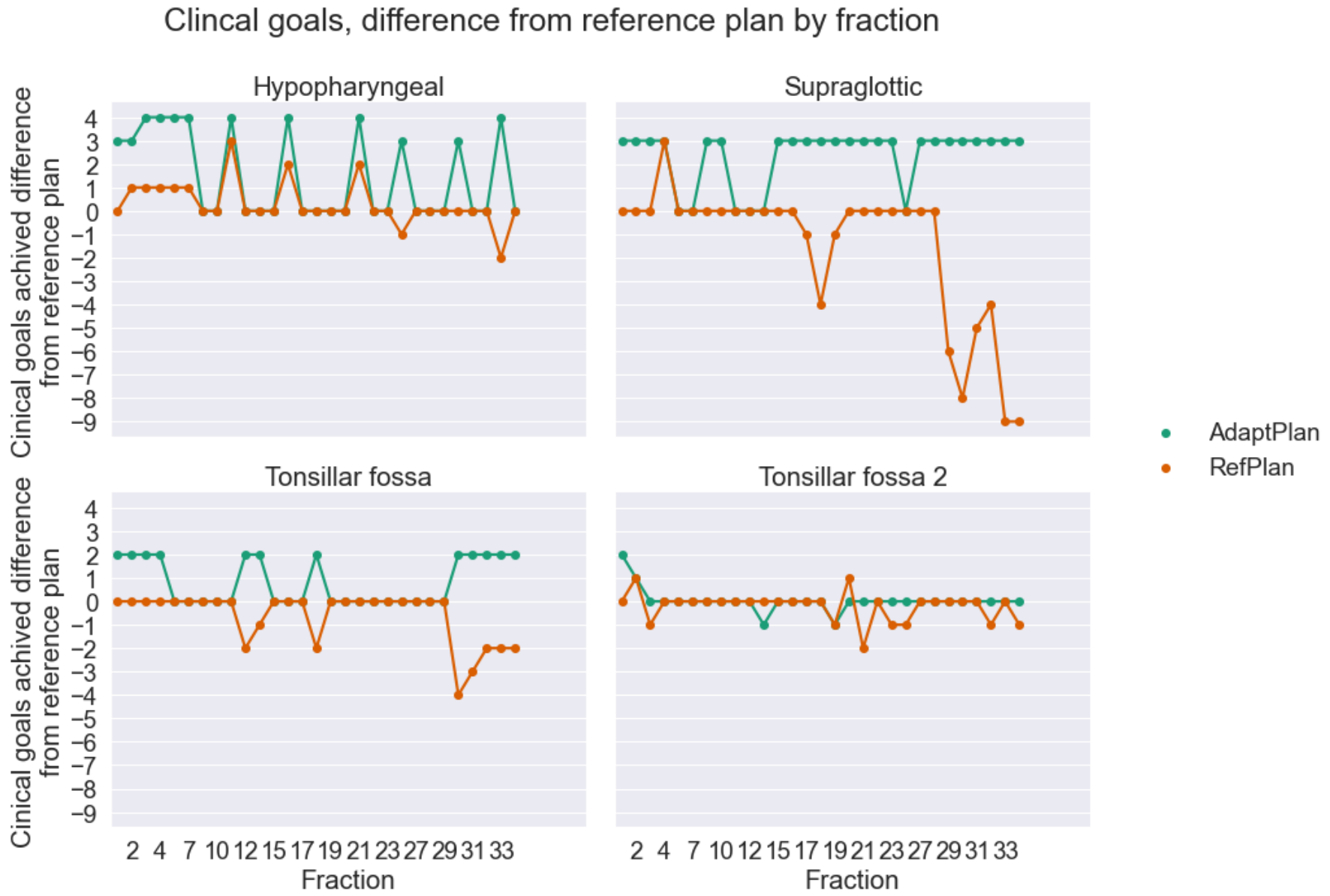
Dose to selected organs at risk for reference plan 1mm
Reference plan 3mm adapted plan 1mm

Accumulated on daily image and deformed to reference CT

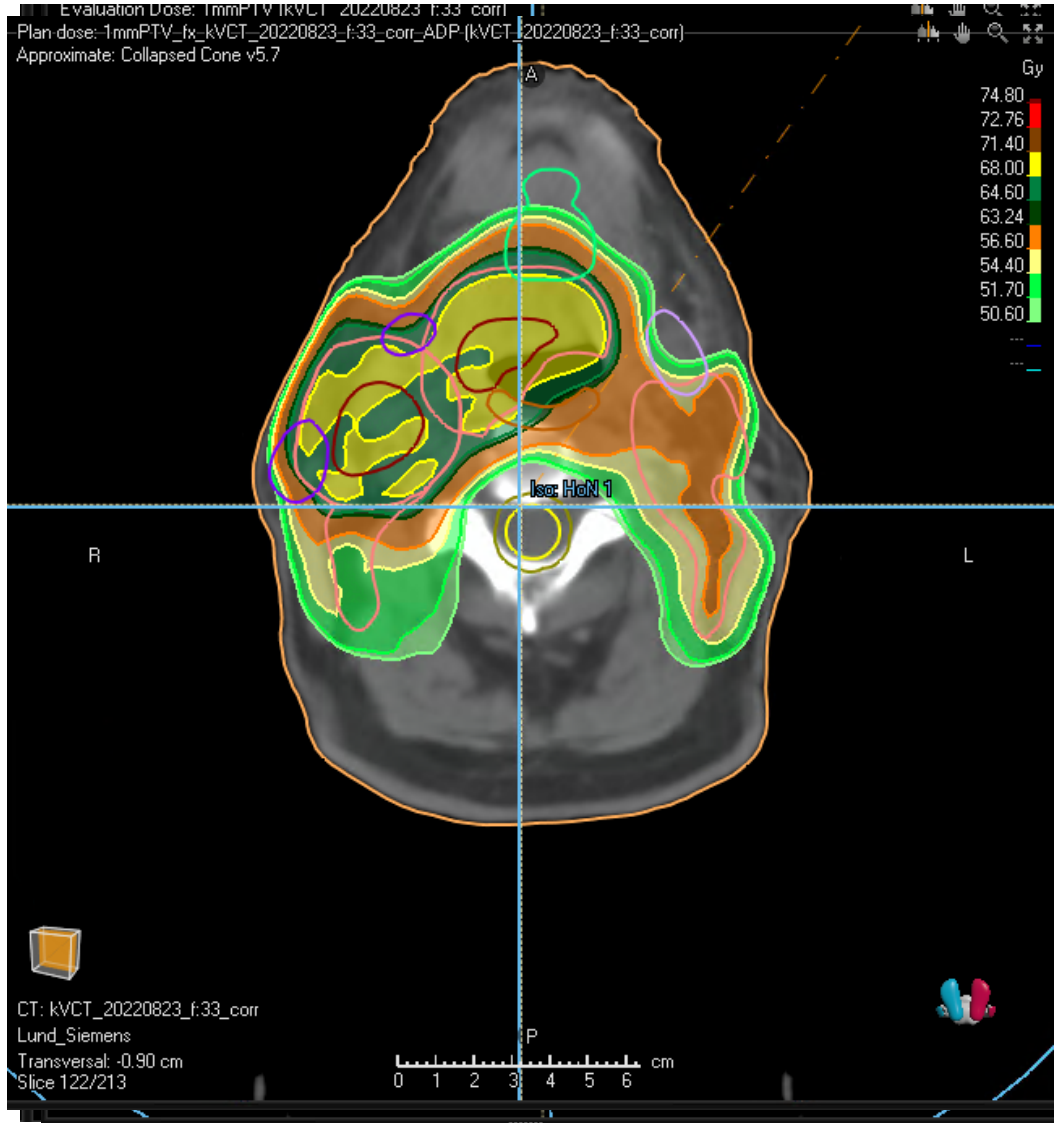


Progression of clinical goals relative baseline as reference plan on reference CT.

Blue, adaptive 1mm plan
Orange, reference 1mm on daily image



Example dose coverage

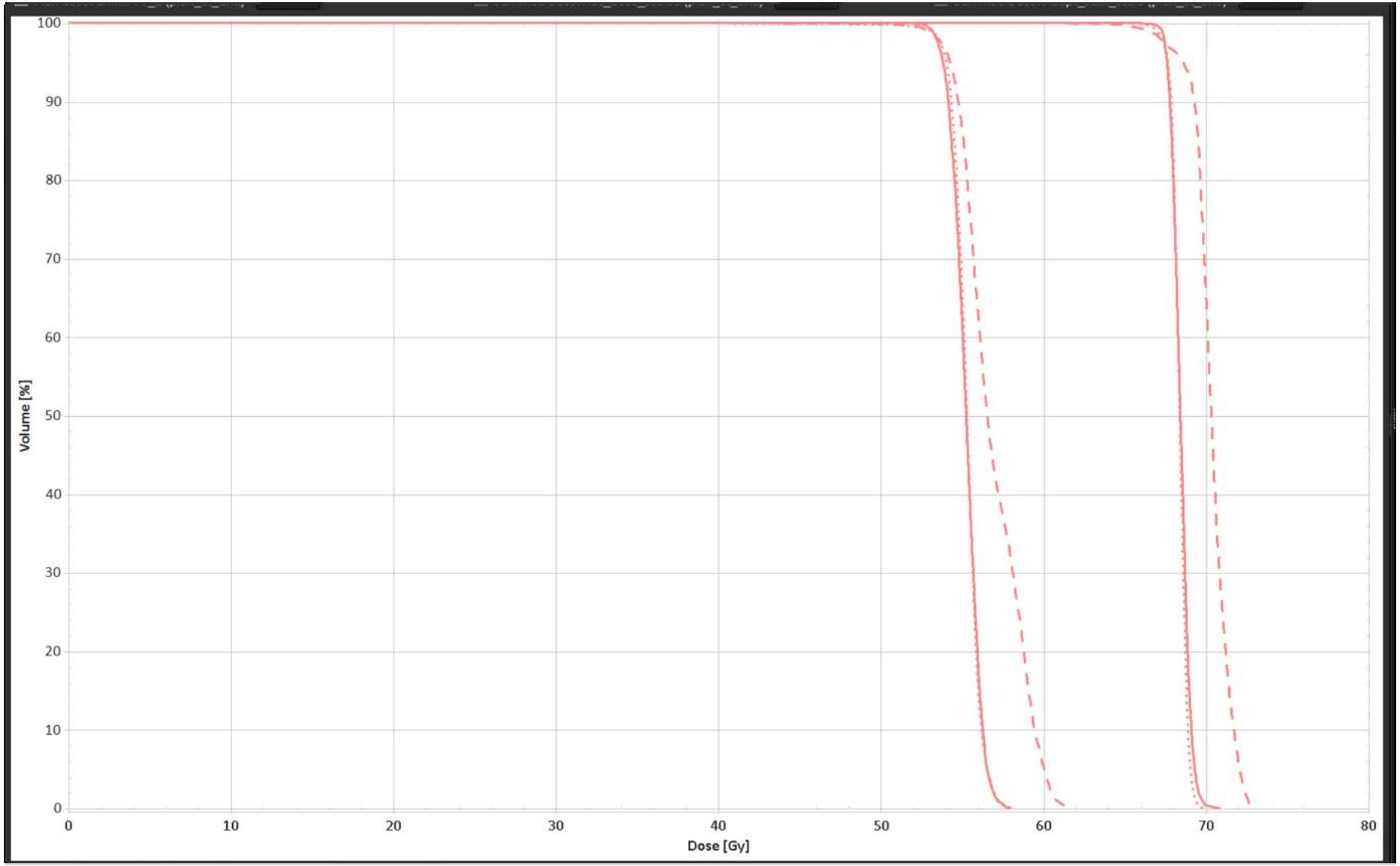


PlanAdapt_daily
Daily Adaptive

PlanRef1mm_daily
recalculated

PlanRef3mm_daily
reference recalculated

Reference plan – reference CT Reference plan – daily CT Adaptive plan – daily CT



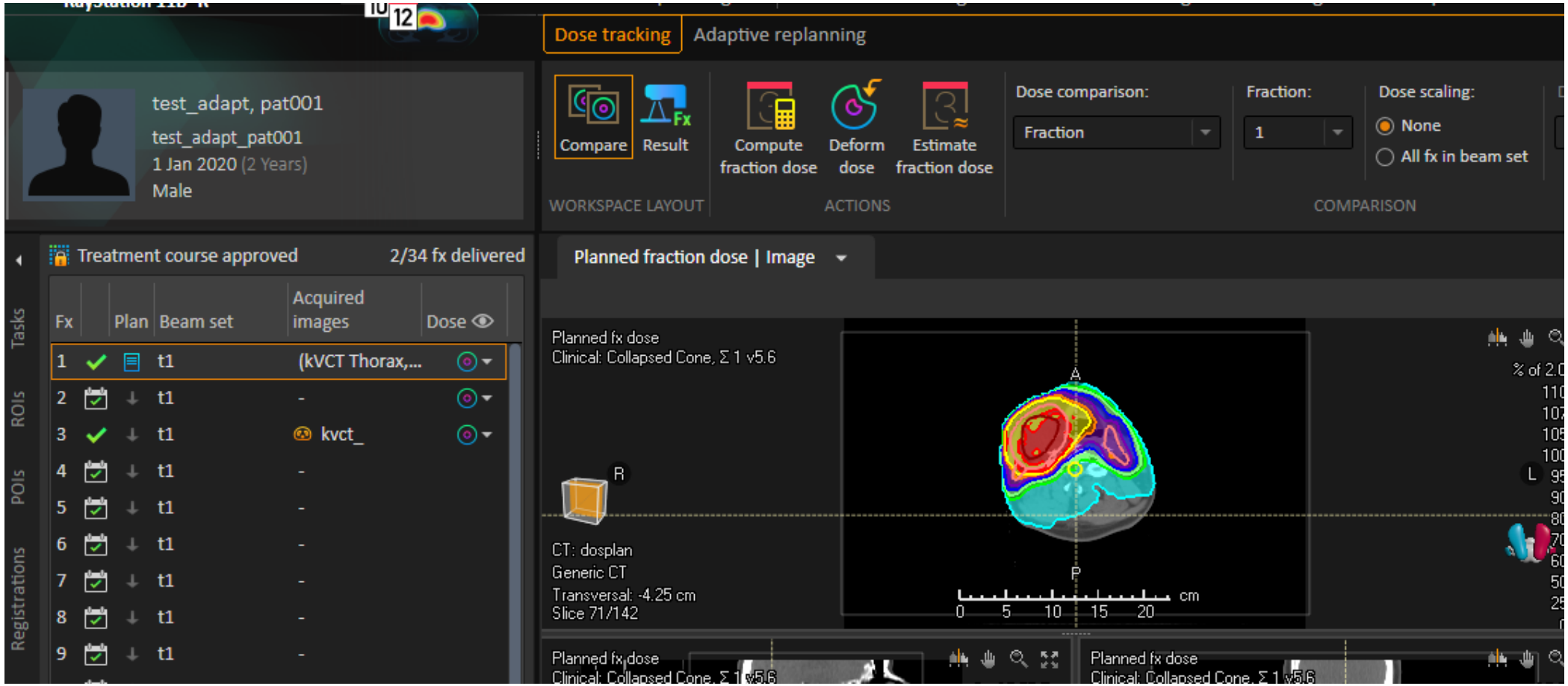
Parotid/submand. glands

Esophagus
Larynx
Spinal cord

CTVT 68.0
CTVN 54.4

Simulated daily workflow online ART

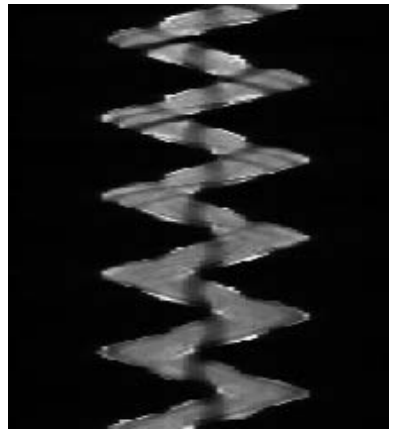
Simulated daily workflow online ART



Quality assurance in online adaptive radiotherapy

Plan complexity benchmarking

Independent dose calculation



Delivery analysis – post/live

Plan complexity

nPopen_under50=open leafs under 20ms

nPopen_under100=open leafs under 50ms

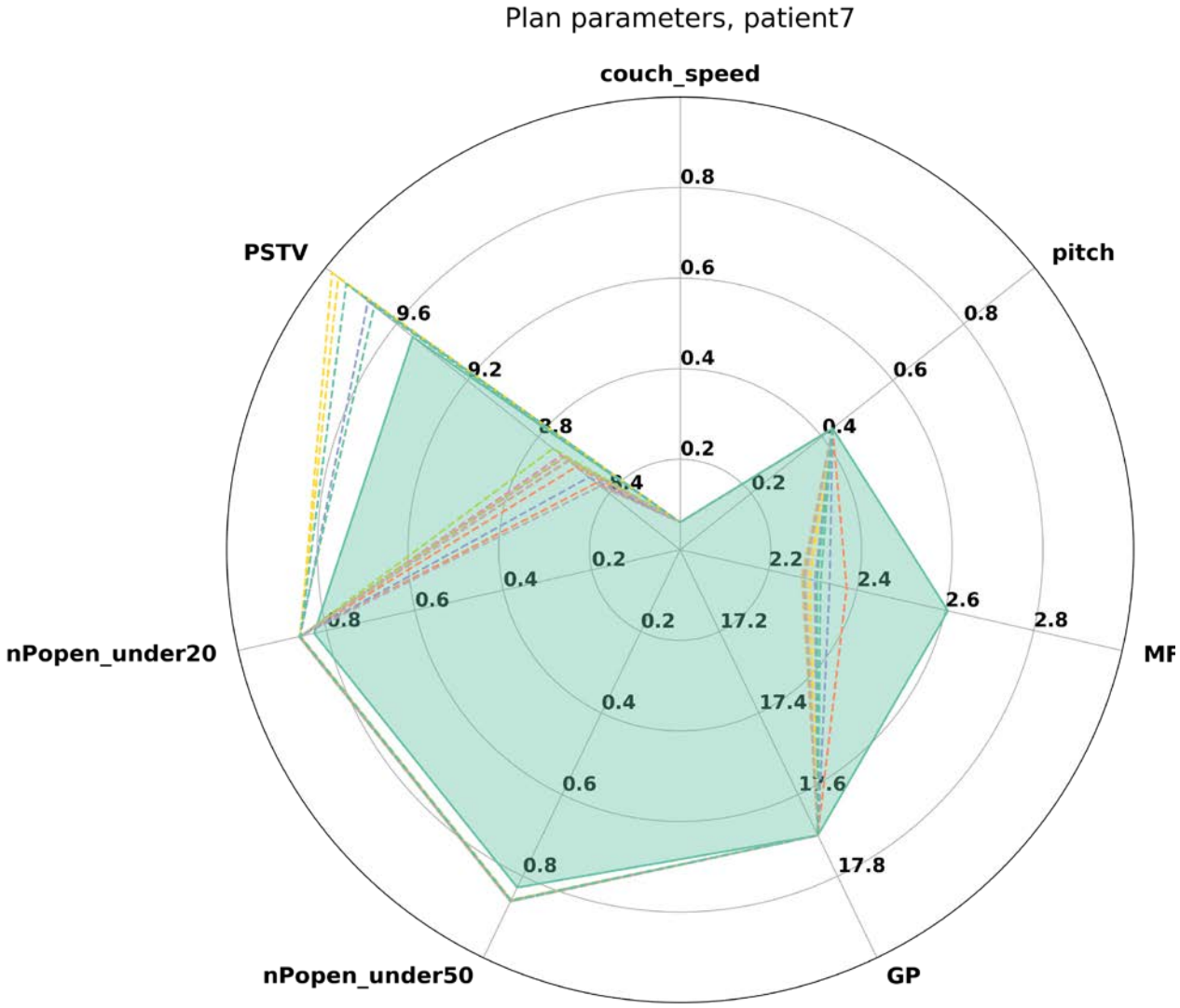
PSTV = The Plan Time Sinogram Variation

GP = gantry period

MF = modulation factor

Pitch = period overlap per field width

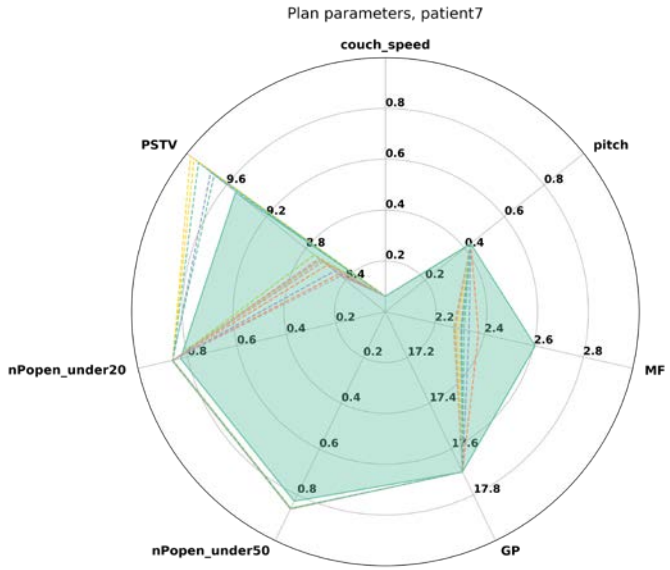
Couch speed

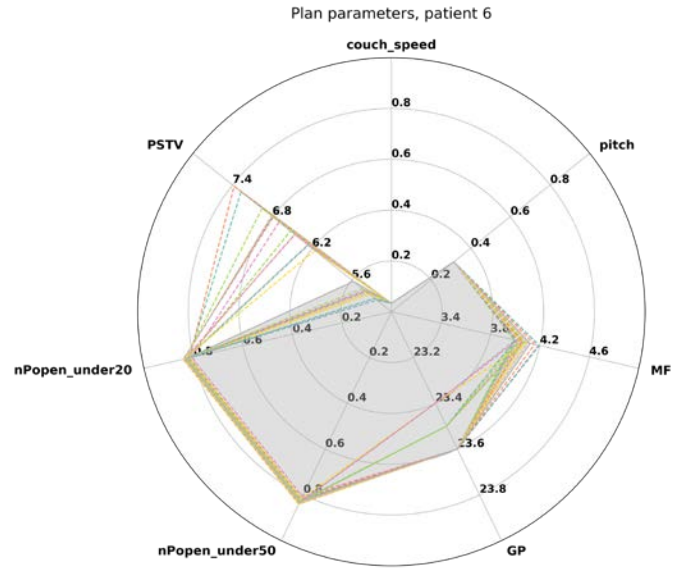


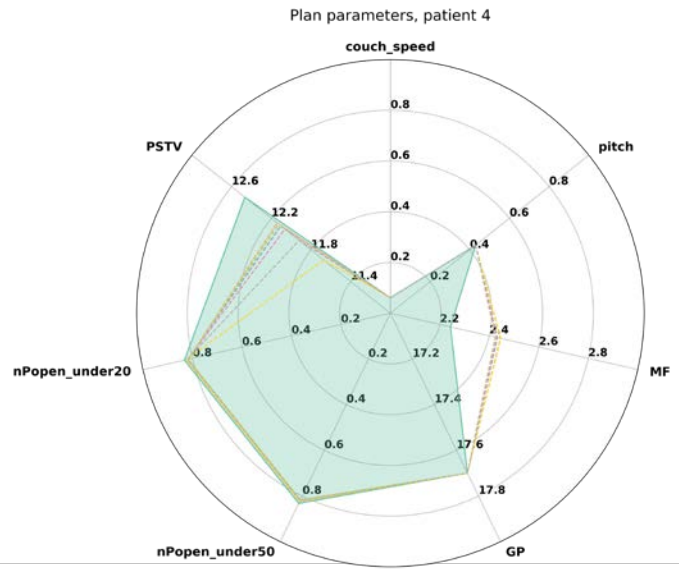
References

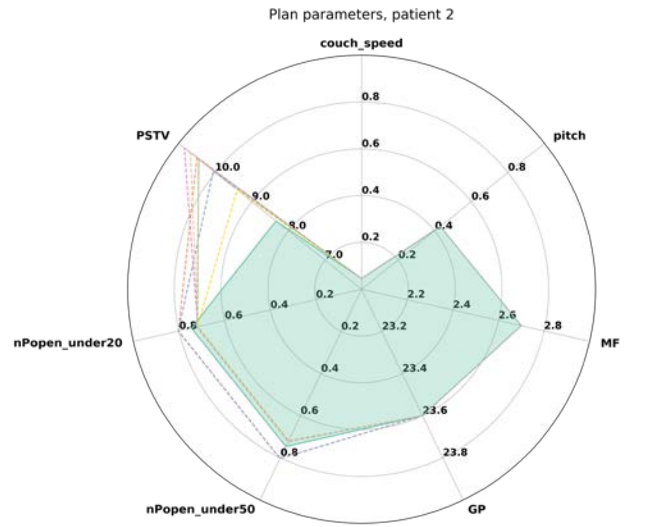
Boyd, R et al. 'Determining efficient helical IMRT modulation factor from the MLC leaf-open time distribution on precision treatment planning system'

Santos, 2020. 'On the complexity of helical tomotherapy treatment plans'

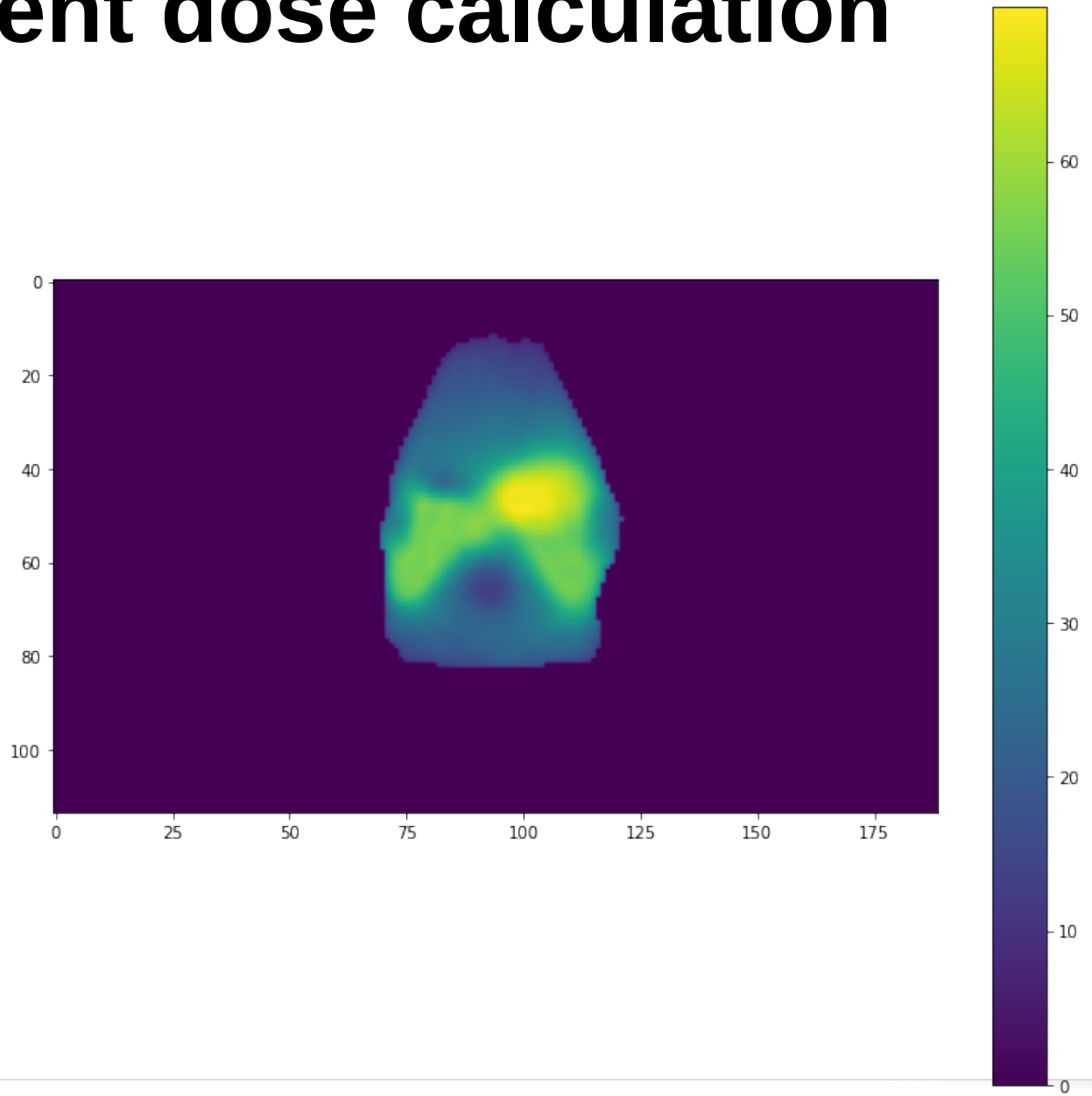

Plan parameters, patient7
couch_speed
pitch
MF
GP
nPopen_under50
nPopen_under20
PSTV


Plan parameters, patient 6
couch_speed
pitch
MF
GP
nPopen_under50
nPopen_under20
PSTV

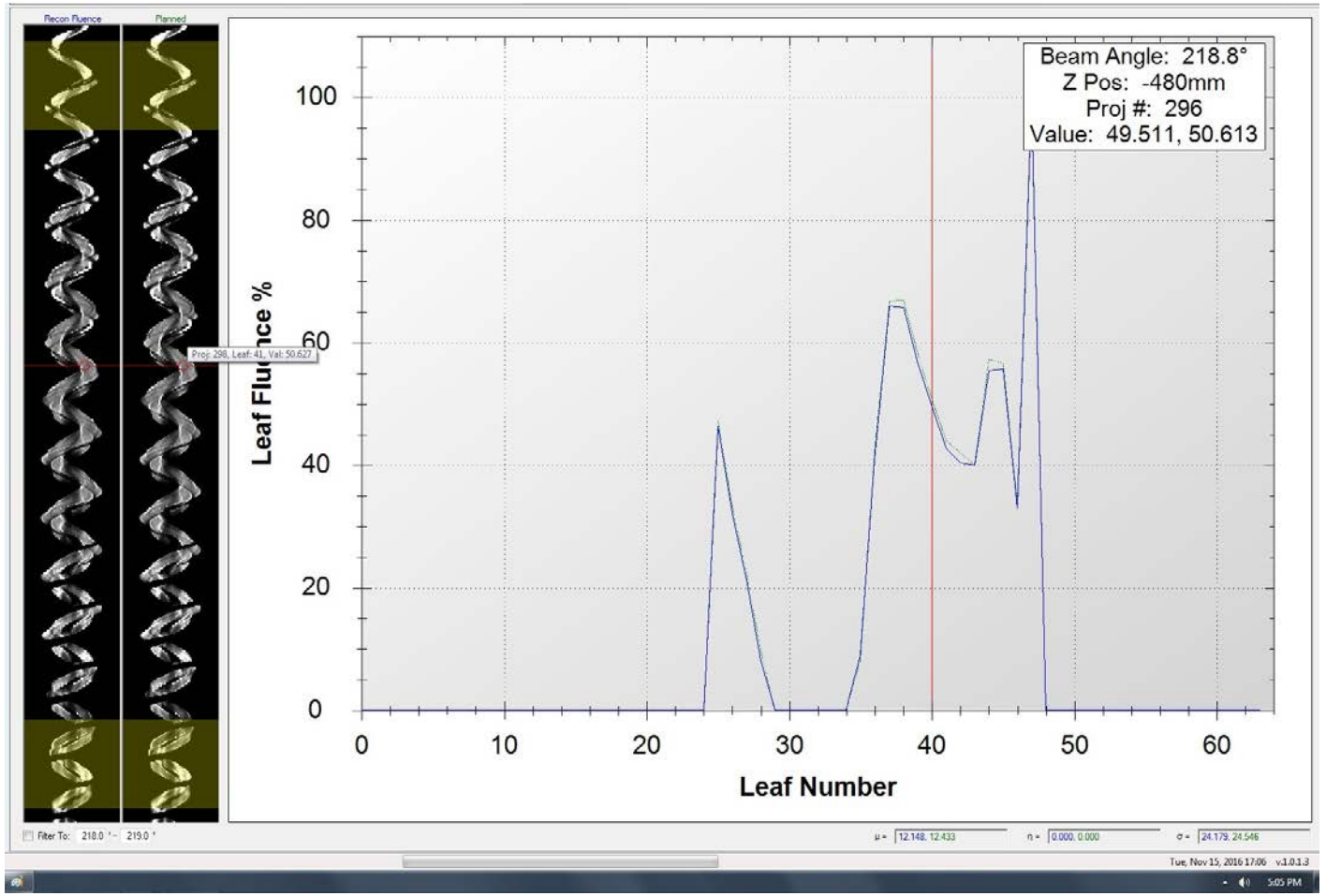

Plan parameters, patient 4
couch_speed
pitch
MF
GP
nPopen_under50
nPopen_under20
PSTV


Plan parameters, patient 2
couch_speed
pitch
MF
GP
nPopen_under50
nPopen_under20
PSTV

Independent dose calculation



Delivery analysis



Conclusions

Online adaptive radiotherapy - a daily decision

- Reduced margins?
- Less resource intense?

- Decision support
- Robust daily workflow
- Plan QA that are feasible and relevant
- Clinical decision delegation?

Thank you!