4D ADAPTIVE PROTON THERAPY

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POP ART PT

The Patterns Of Practice for Adaptive and Real-Time Particle Therapy (POP-ART PT) questionnaire aims to determine the status of Adaptive Particle Therapy (APT) and (Real-time Respiratory Motion Management RRMM) implementation worldwide.

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Original Article

Patterns of practice for adaptive and real-time radiation therapy (POP-ART RT) part I: Intra-fraction breathing motion management

Gail Anastasi [a,*,1], Jenny Bertholet [b,c,1], Per Poulsen [d], Toon Roggen [e], Cristina Garibaldi [f], Nina Tilly [g,h], Jeremy T Booth [i], Uwe Oelfke [b], Ben Heijmen [j], Marianne C Aznar [k,l]

Radiotherapy and Oncology 153 (2020) 88–96

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Original Article

Patterns of practice for adaptive and real-time radiation therapy (POP-ART RT) part II: Offline and online plan adaption for interfractional changes

Jenny Bertholet [a,b,*], Gail Anastasi [c], David Noble [d], Arjan Bel [e], Ruud van Leeuwen [f], Toon Roggen [g], Michael Duchateau [h], Sara Pilskog [i,j], Cristina Garibaldi [k], Nina Tilly [l,m], Rafael García-Mollá [n], Jorge Bonaque [o], Uwe Oelfke [a], Marianne C. Aznar [p,q], Ben Heijmen [r]

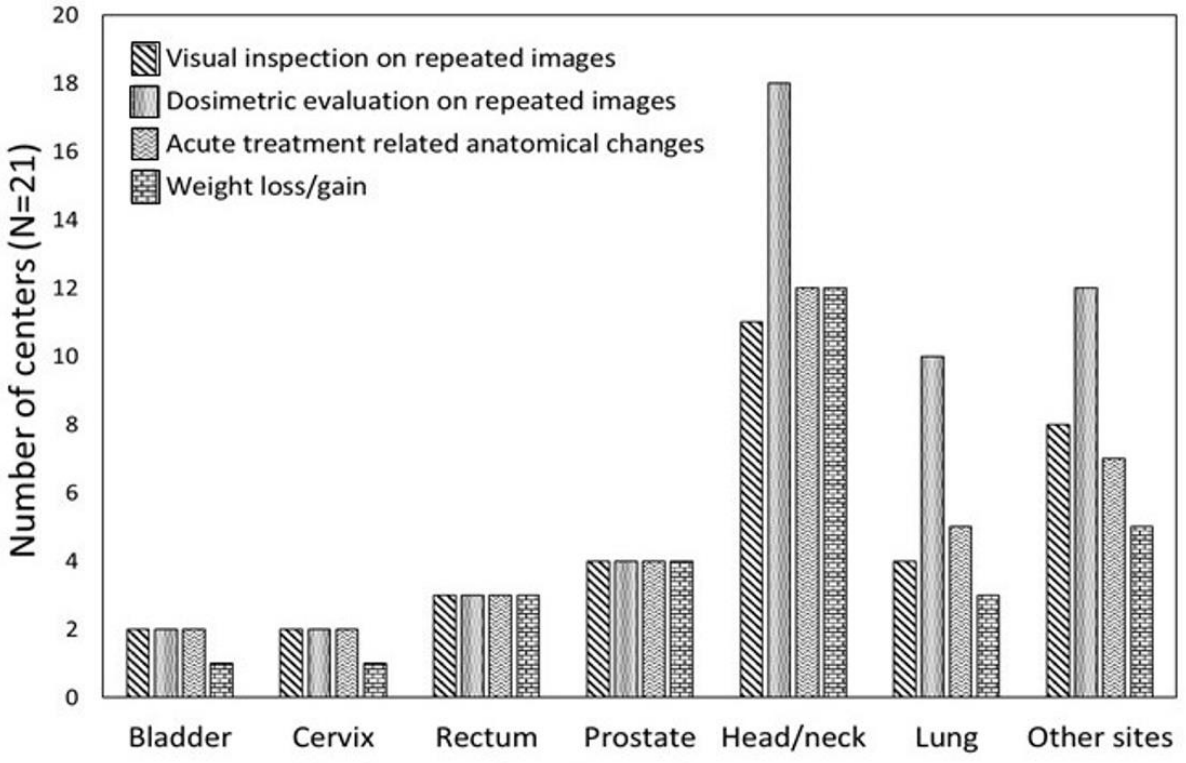
POP ART PT

>90% response rate for Europe and Japan

>50% response rate for the US

Europe:

- all centres are equipped with PBS
- 70% treat moving targets
- 95% use APT
  - → 50% for 4D indications (mainly lung)
- Ad-hoc offline adaptation



Reasons for adaptation per treatment site

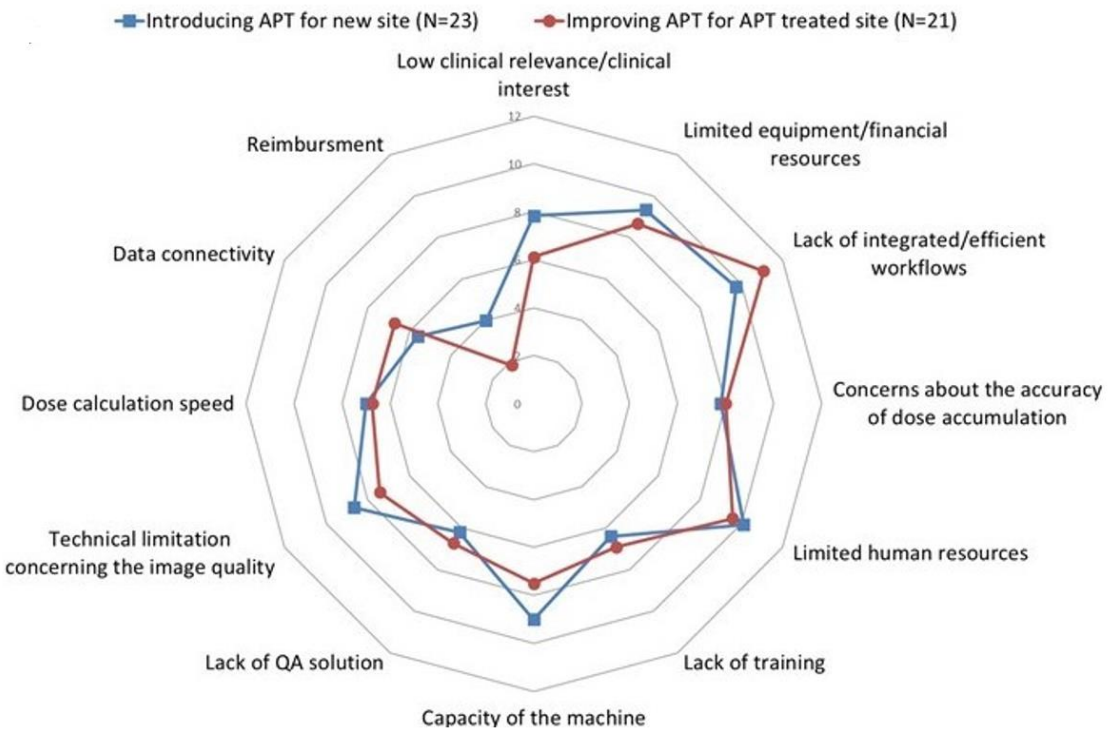
Trnkova et al. oral presentation ESTRO 2021

POP ART PT

In Europe no center performs online APT (plan libraries or daily adaptation).

A majority of European centres would like to improve APT workflows and would like to implement it for more indications

The main barrier for the extension of APT is the lack of integrated and efficient workflows



Barriers for extending APT

Trnkova et al. oral presentation ESTRO 2021

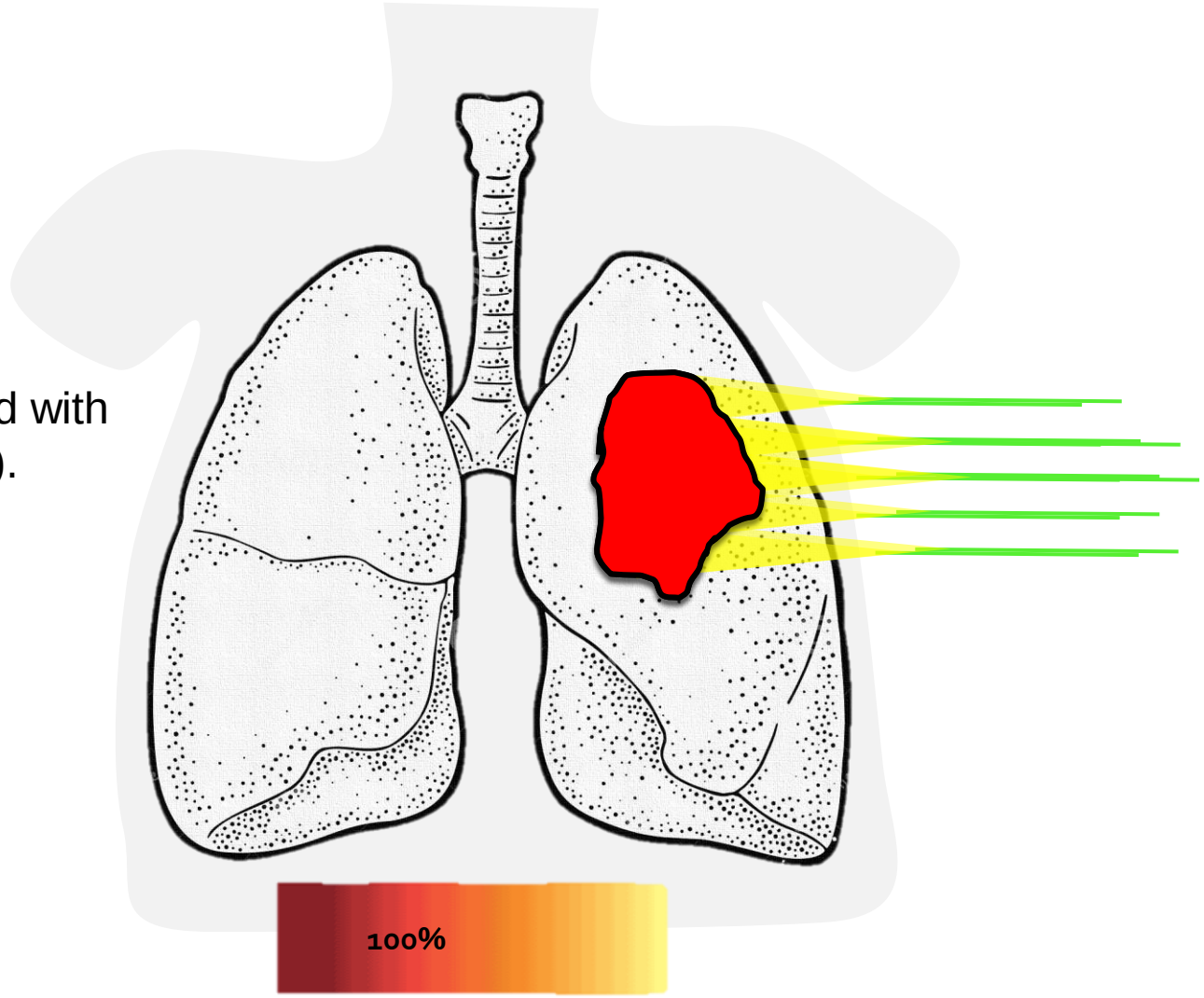
4D adaptive proton therapy is just translated into the clinical practice with a lot of potential for further development , increasing impact.

4D dose reconstruction & accumulation

Challenges

- interplay effect

Modern PT facilities are equipped with pencil beam scanning (PBS).



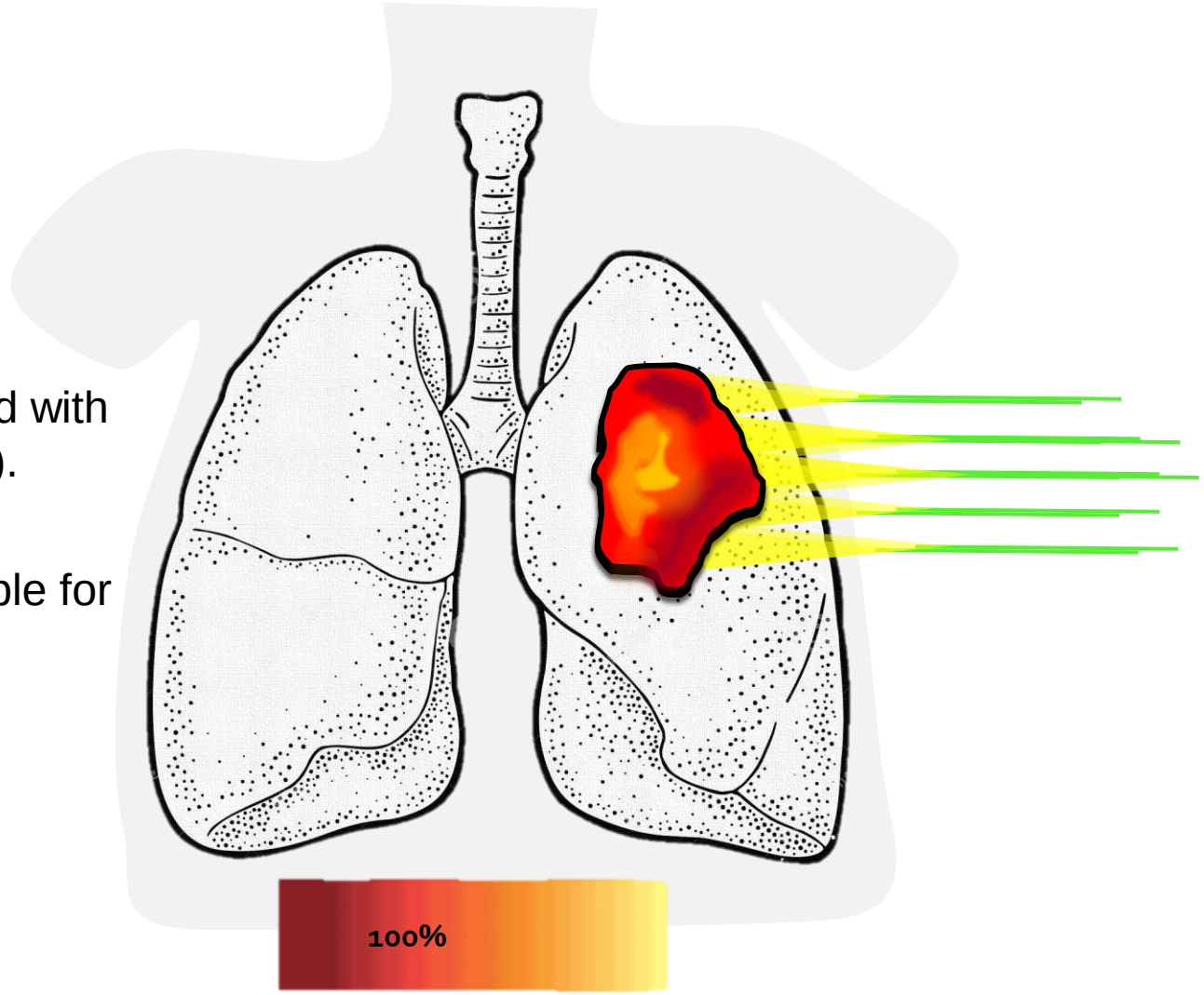
4D dose reconstruction & accumulation

Challenges

- interplay effect

Modern PT facilities are equipped with pencil beam scanning (PBS).

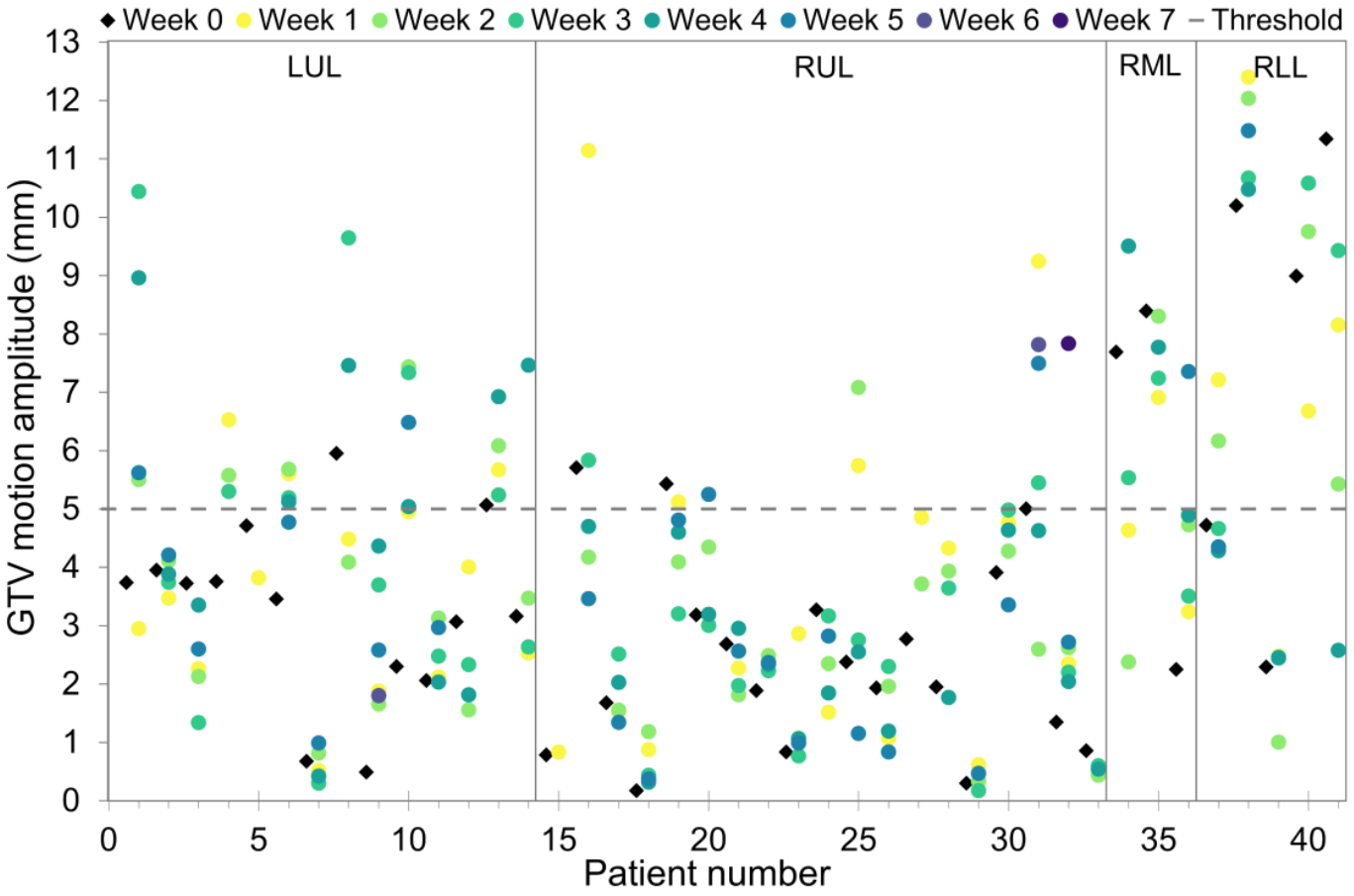
PBS-PT treatments are susceptible for interplay effects.

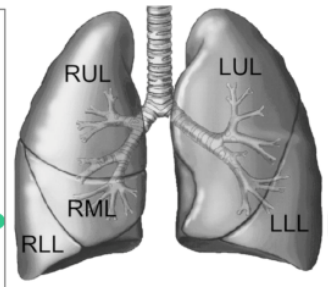


4D dose reconstruction & accumulation

Challenges

- varying motion



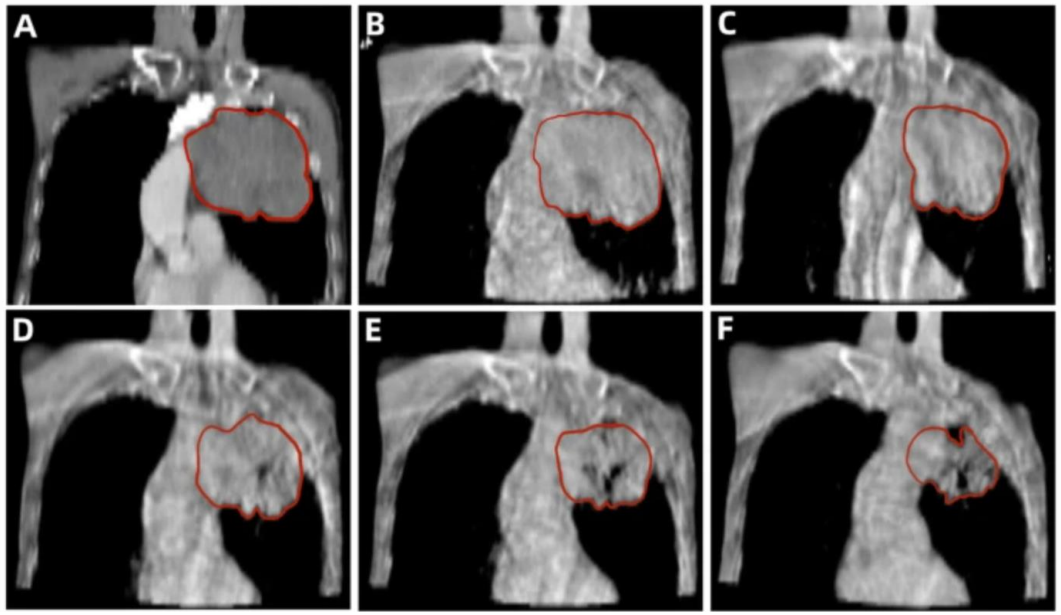


den Otter et al. doi: 10.1002/mp.14345

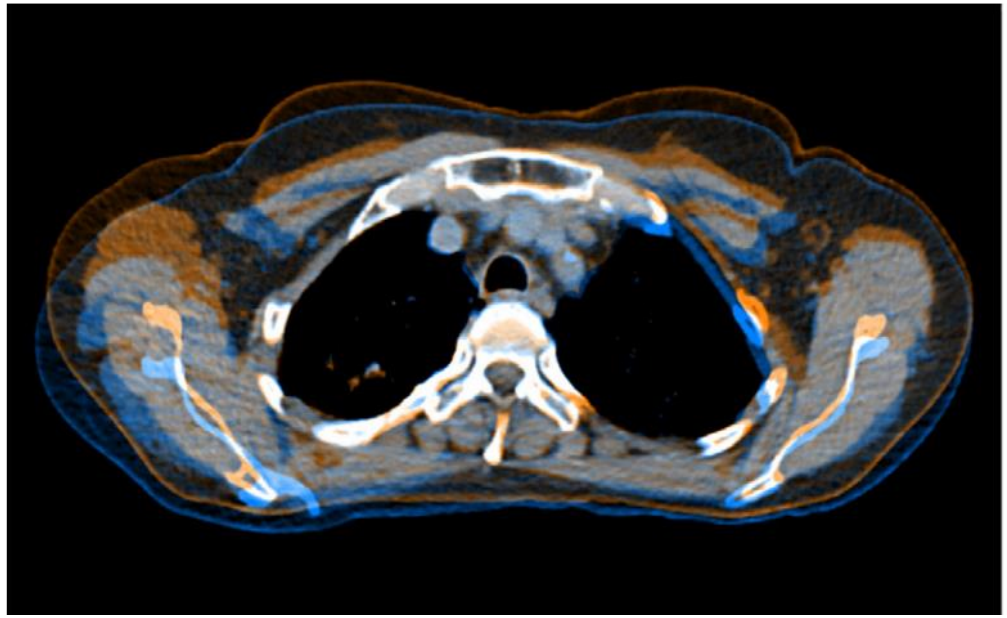
4D dose reconstruction & accumulation

Challenges

- anatomical changes



Fast tumour regression during radiotherapy^



Inconsistant patient setup*

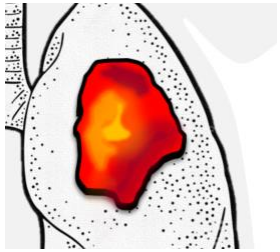
^Wang et al. doi: 10.1186/s12885-020-07617-3

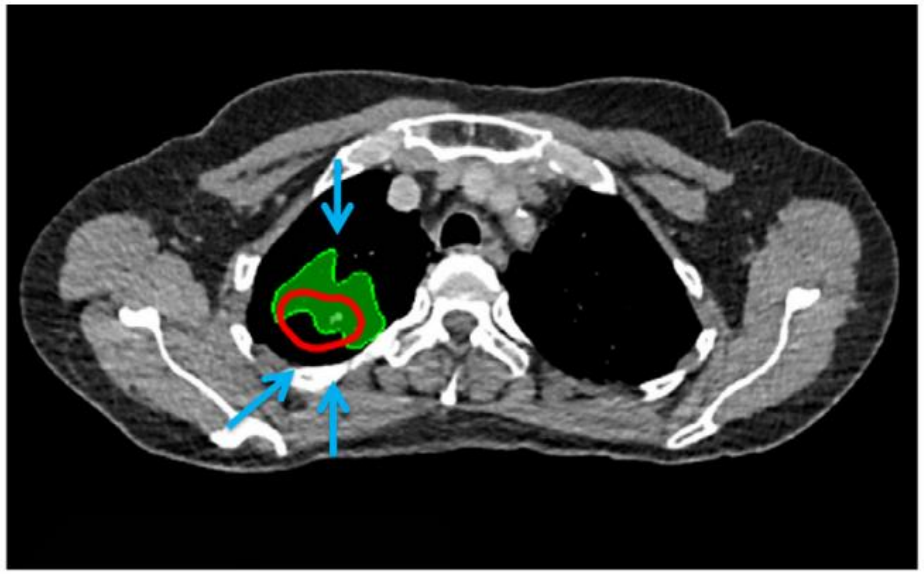
*Ribeiro et al. doi: 10.1016/j.radonc.2021.01.014

4D dose reconstruction & accumulation

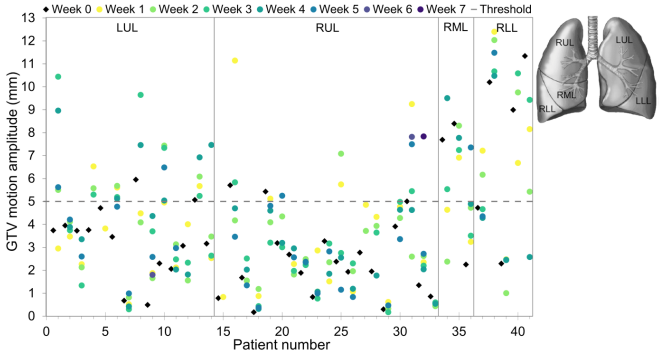
Challenges

- interplay effect



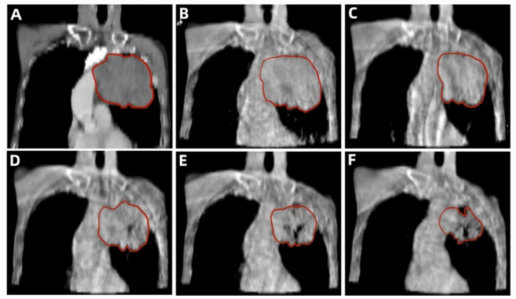


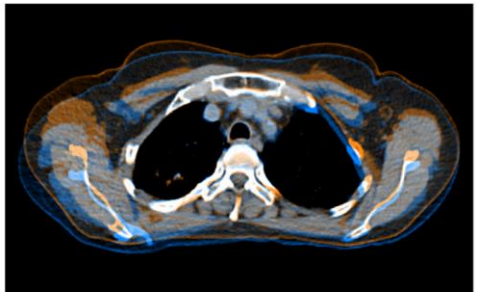
- varying motion



→dosimetric impact*

- anatomical changes



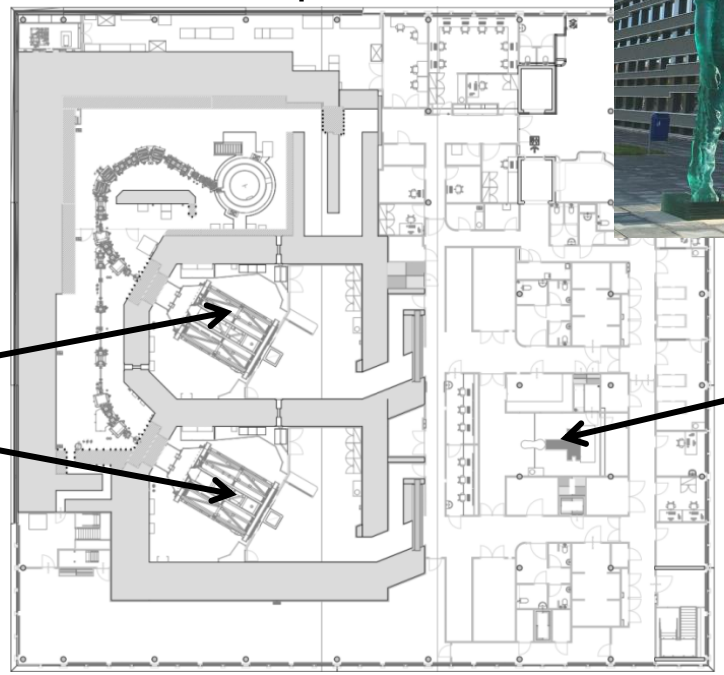


*Ribeiro et al. doi: 10.1016/j.radonc.2021.01.014

4D dose reconstruction & accumulation

Treatment monitoring

floor plan GPTC



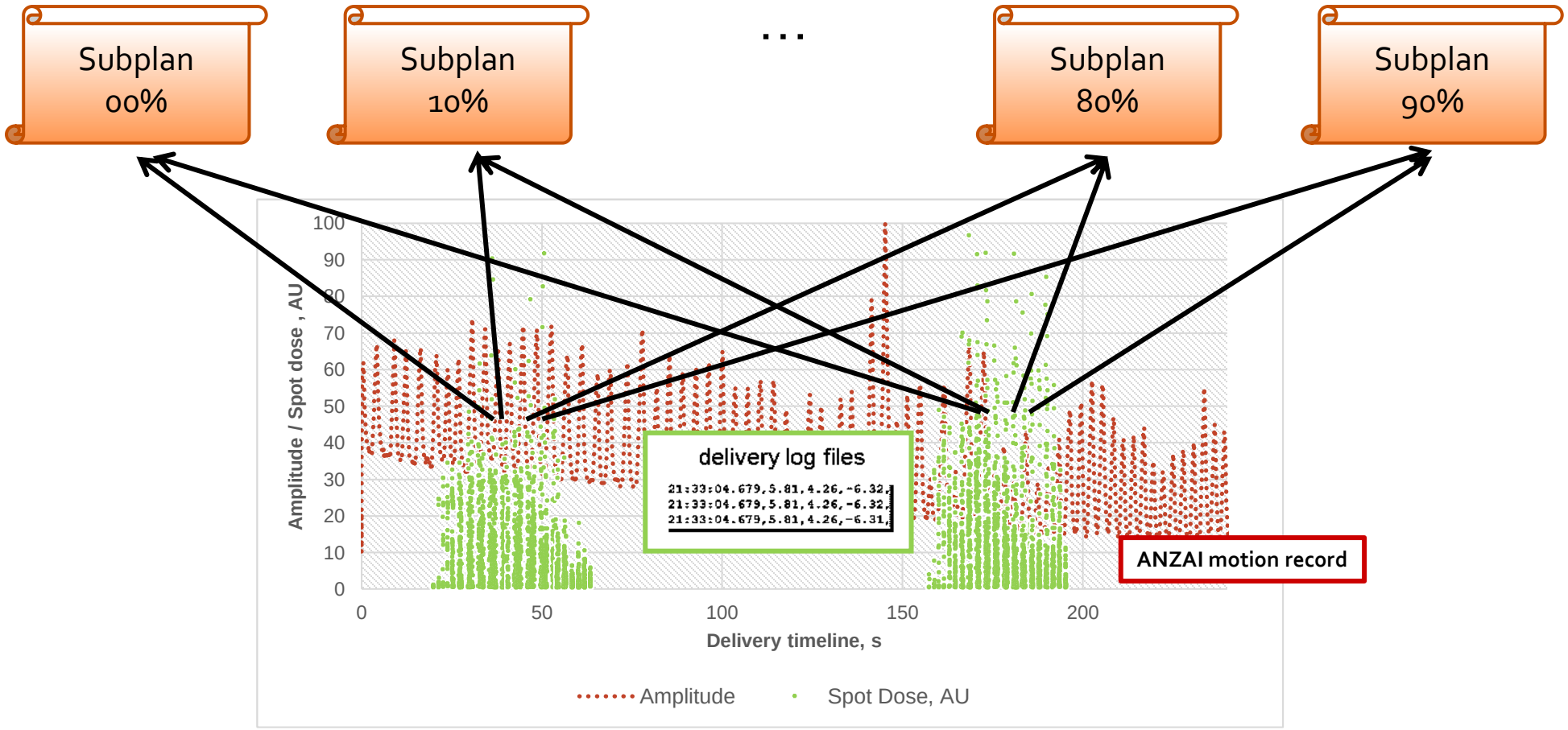
online motion record via
ANZAI belt

delivery log files

weekly repeated 4DCT

4D dose reconstruction & accumulation

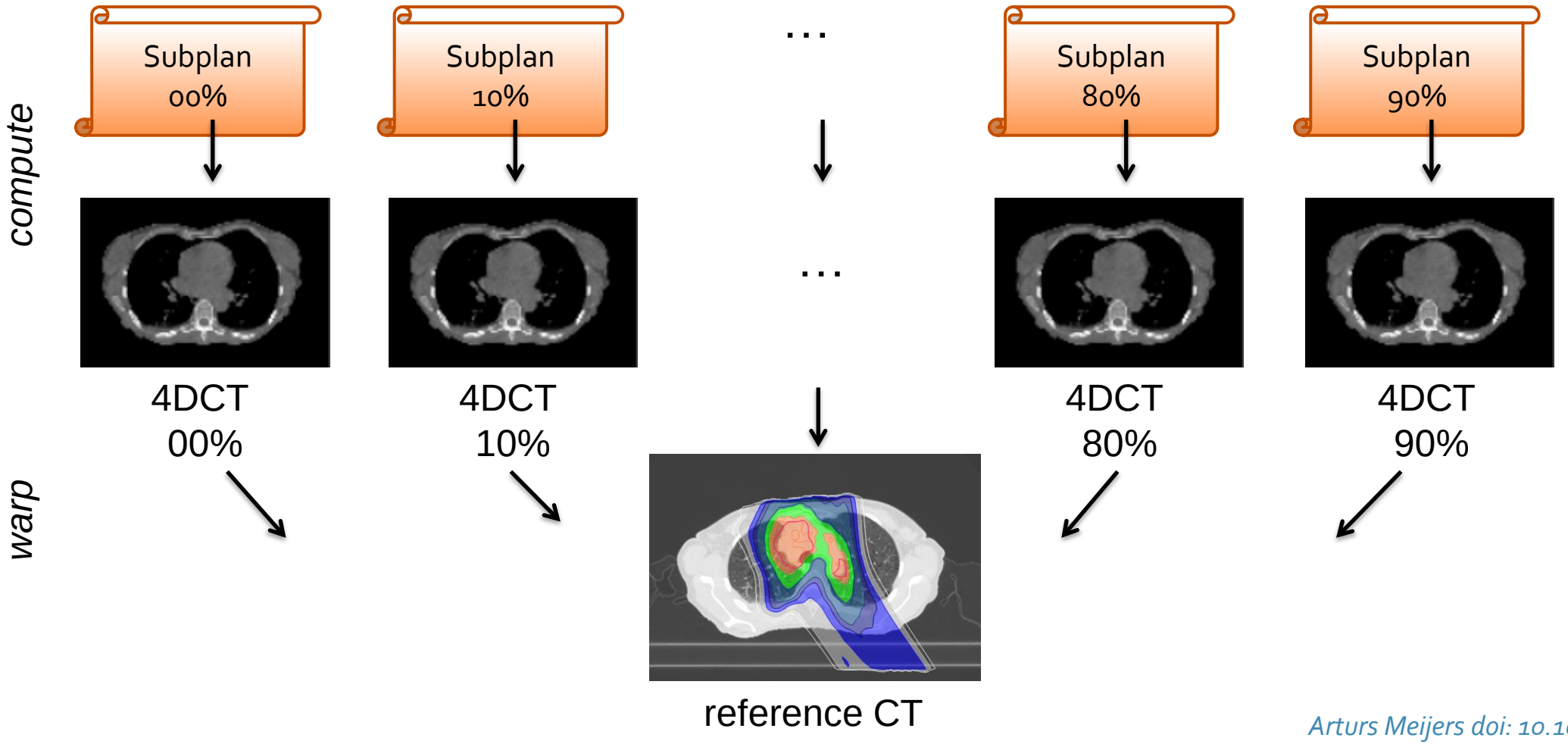
Treatment monitoring



Arturs Meijers doi: 10.1002/mp.13371

4D dose reconstruction & accumulation

Treatment monitoring



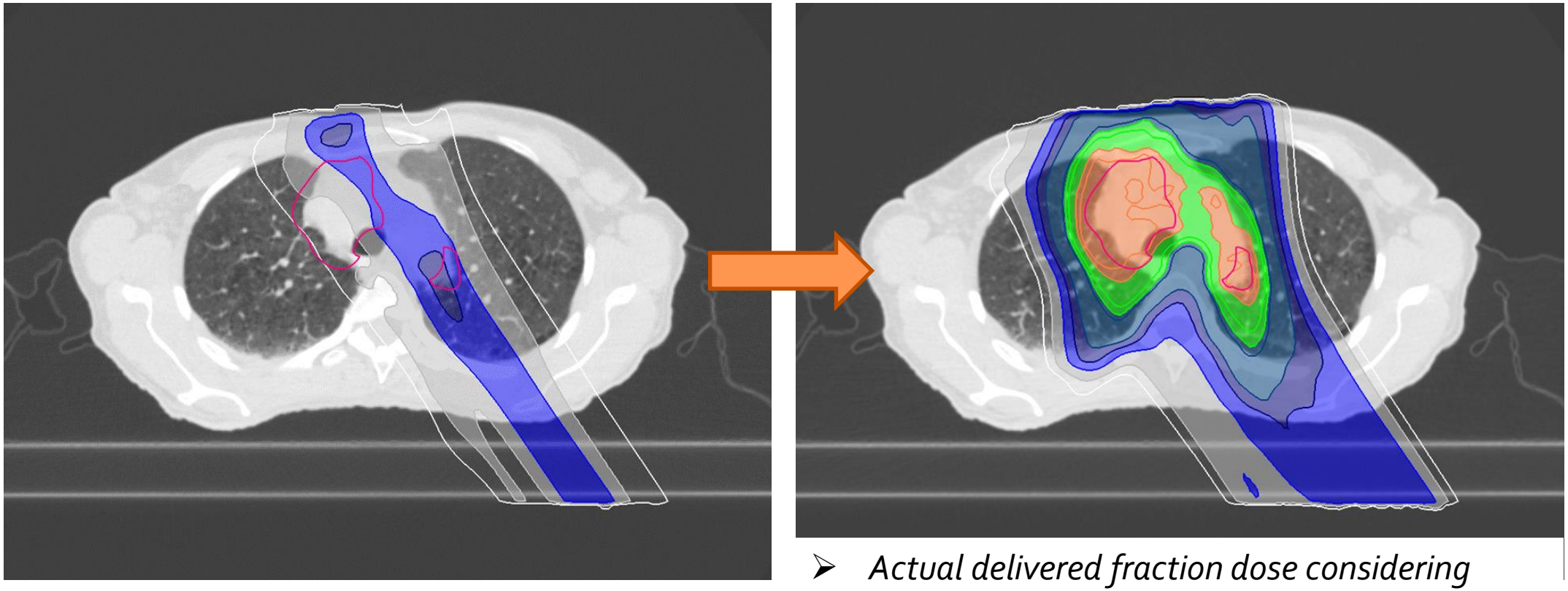
Arturs Meijers doi: 10.1002/mp.13371

4D dose reconstruction & accumulation

Treatment monitoring

phase-by-phase

warped to reference CT

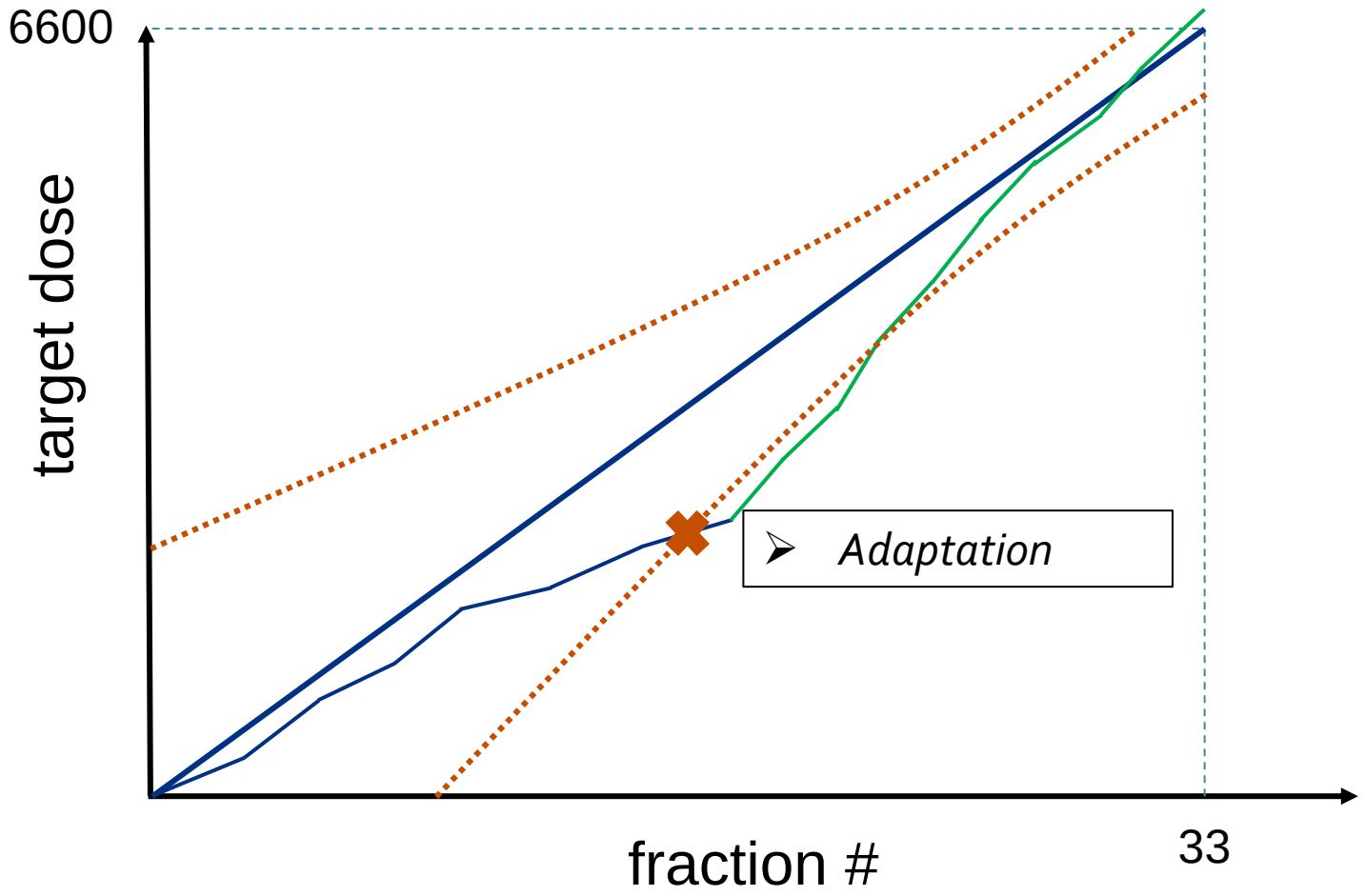


- *Actual delivered fraction dose considering inter-play effects*

Arturs Meijers doi: 10.1002/mp.13371

4D dose reconstruction & accumulation

Treatment monitoring



Arturs Meijers doi: 10.1002/mp.13371

4D dose reconstruction & accumulation

Preliminary clinical results

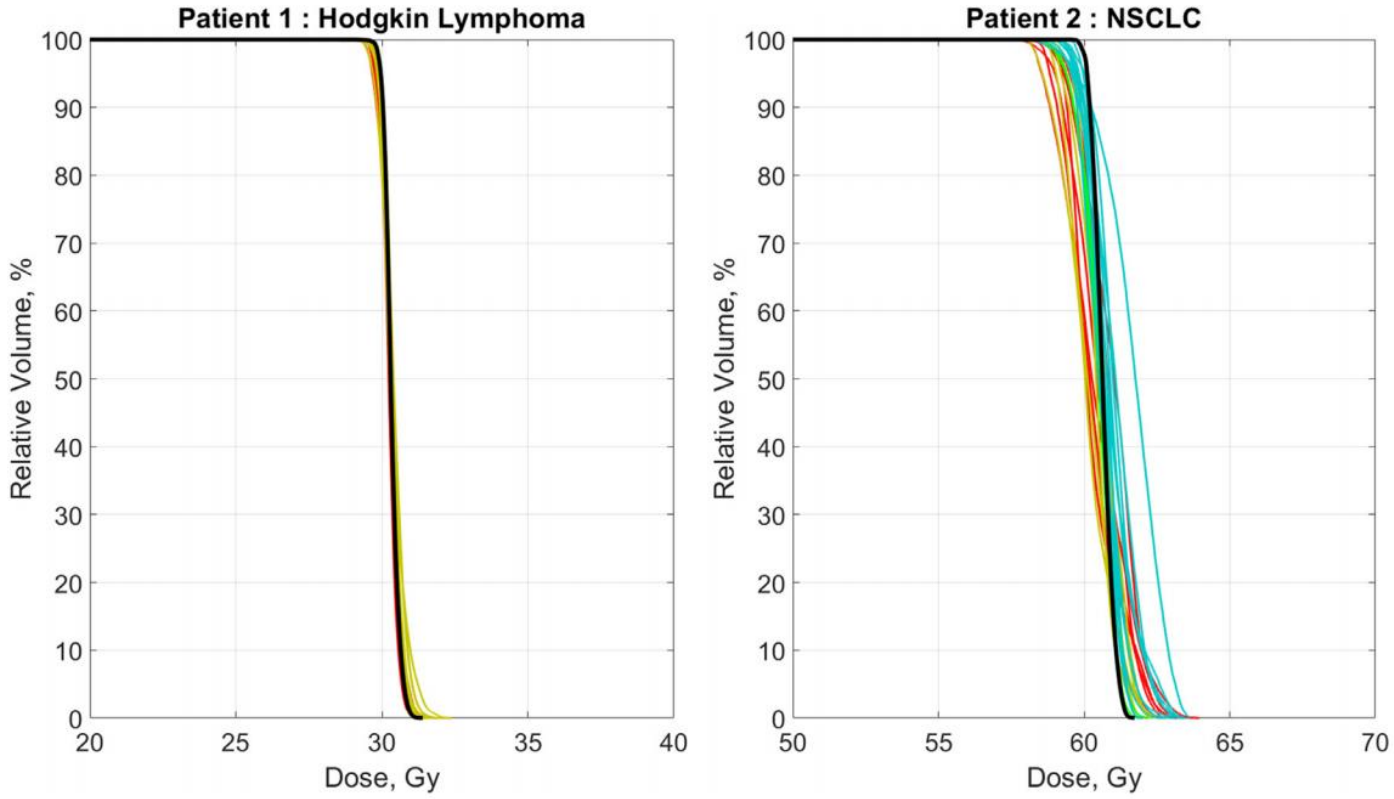


Fig. 2. DVHs of CTV for reconstructed fraction-wise 4D dose distributions and accumulated course dose. DVHs are corresponding to cases 1 and 2. Fraction doses are shown in color, while accumulated course dose is shown in black. Fraction doses that have been calculated on the same 4DCT also share the same color. Assigned colors are red, yellow, green, light blue and blue, corresponding from an earlier 4DCT to a more recent in this order.

Arturs Meijers doi: 10.1016/j.radonc.2020.07.055

4D dose reconstruction & accumulation

Preliminary clinical results

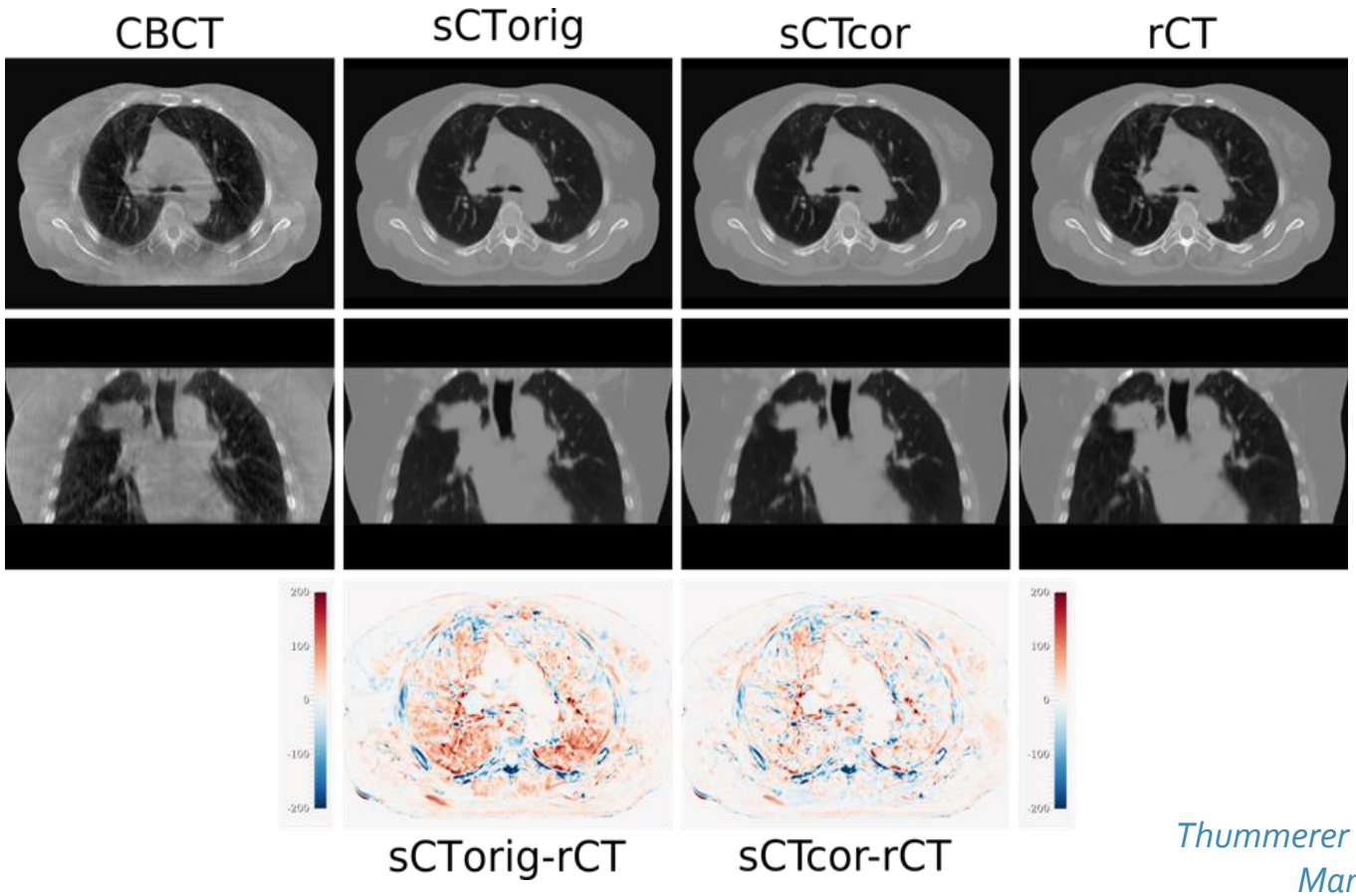
- Fraction-wise loss of target dose homogeneity due to interplay and organ motion showed no systematic pattern and smeared out with fractionation.
- Contrary to findings in prospective simulation studies, clinical 4D dose monitoring did not observe any relevant loss of target dose homogeneity due to interplay and motion effects.
- Dose degradation caused by anatomical changes showed to be more severe and caused treatment adaptations in five out of ten patients.

Arturs Meijers doi: 10.1016/j.radonc.2020.07.055

4D dose reconstruction & accumulation

Further improvements

- Daily anatomical information via CBCT based synthetic CT

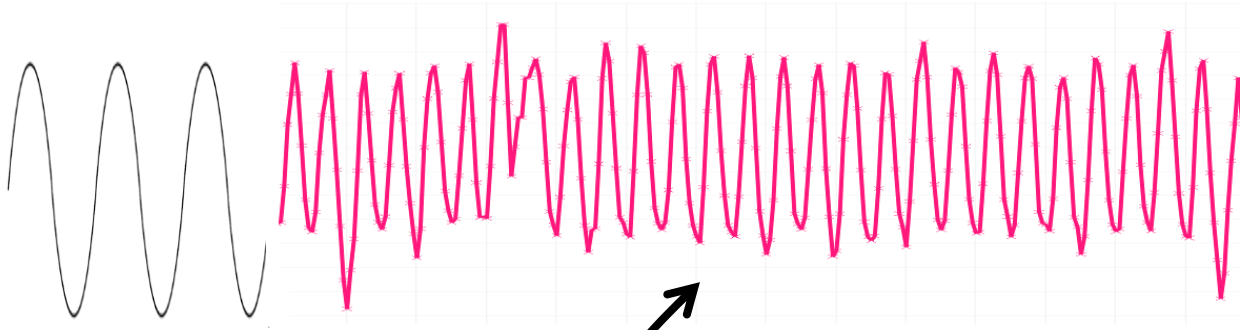


Thummerer et al. oral presentation ESTRO 2021
Manuscript under consideration at PMB

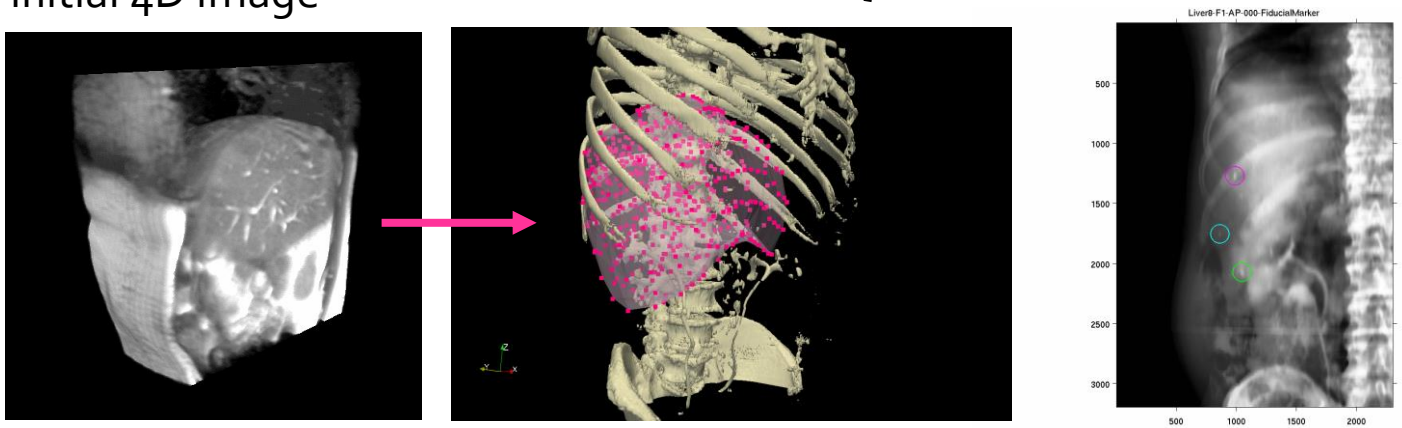
4D dose reconstruction & accumulation

Further improvements

- Consideration of motion variations



initial 4D image



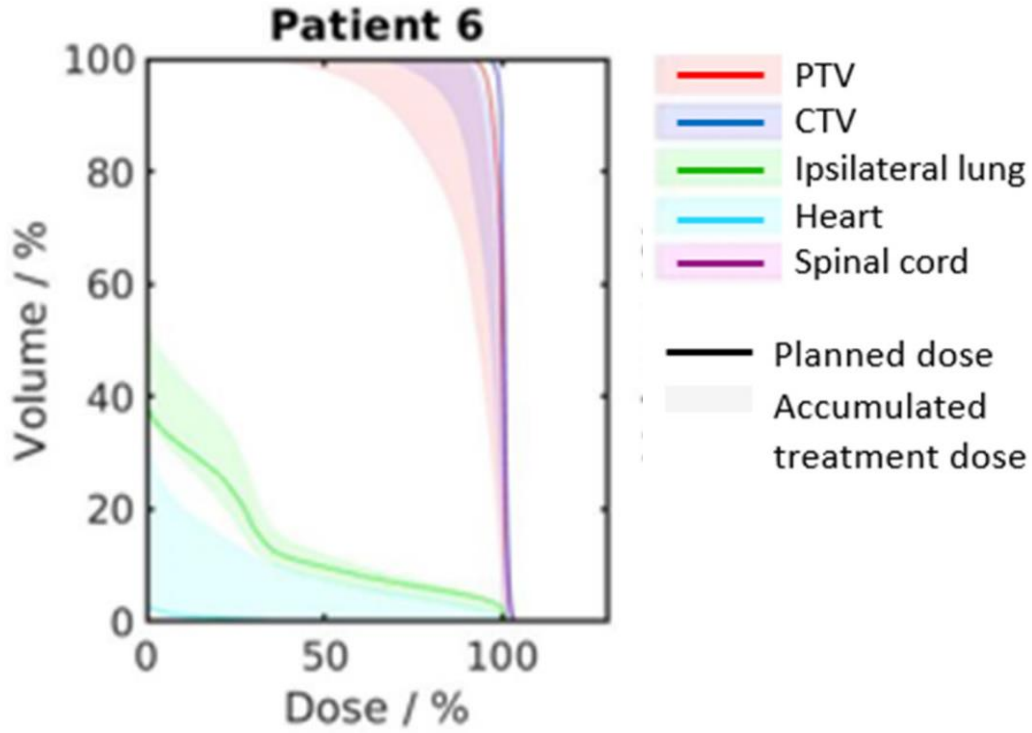
daily motion surrogate

Zhang et al. doi: 10.1088/0031-9155/58/24/8621
Boye et al. doi: 10.1118/1.4801914. PMID: 23718581
von Siebenthal et al. doi: 10.1088/0031-9155/52/6/001

4D dose reconstruction & accumulation

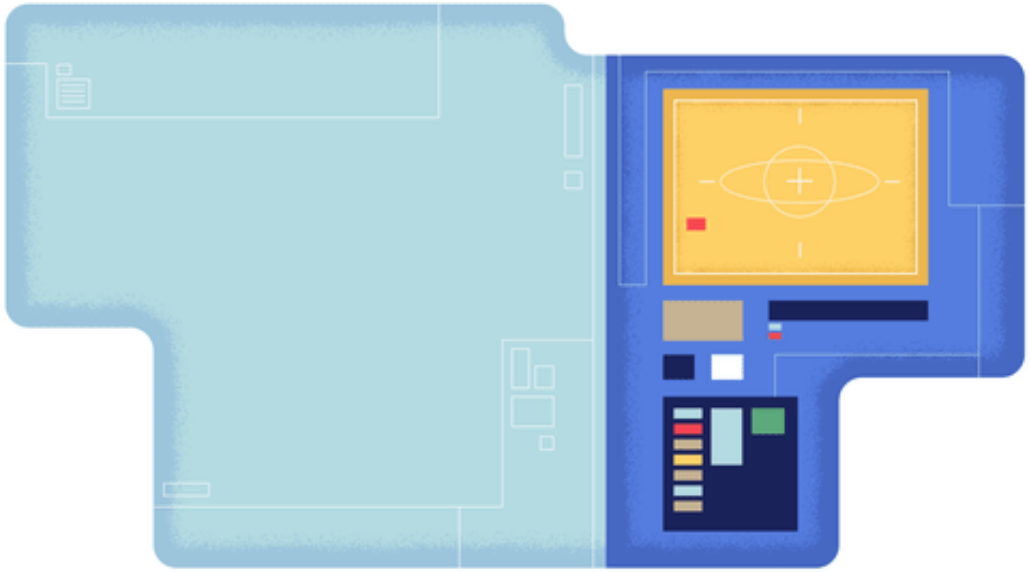
Further improvements

- Improve / validate dose warping



DVHs of CTV, PTV, ipsilateral lung, heart and spinal cord of the initial treatment plan (solid line) and the accumulated treatment dose (light coloured band), warped with different DIRs.

Nenoff et al. doi: 10.1016/j.radonc.2020.04.046



4D treatment planning and 4D dose reconstruction & accumulation enable safe and efficient proton therapy treatments for thoracic indications. Monitoring the daily delivered 4D dose could pave the way for real-time adaptive proton therapy.

Towards real-time adaptive proton therapy

Real-time Adaptive Particle Therapy of Cancer (RAPTOR)

→https://raptor-consortium.com/

- International consortium comprising clinical, academic and industry partners
- Marie Skłodowska-Curie Innovative Training Network (ITN) for 15 ESRs

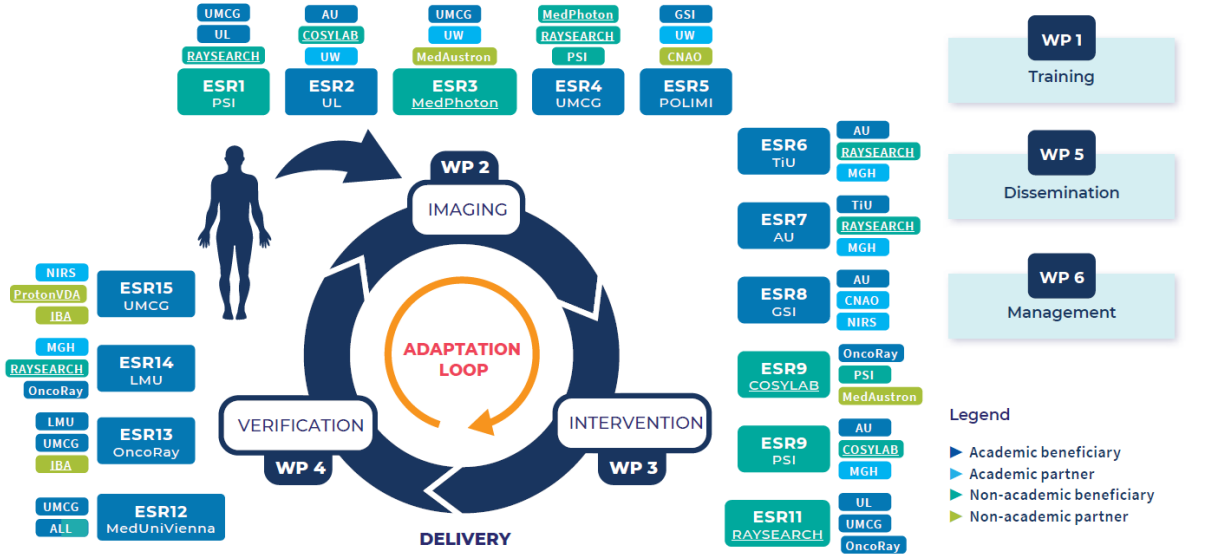


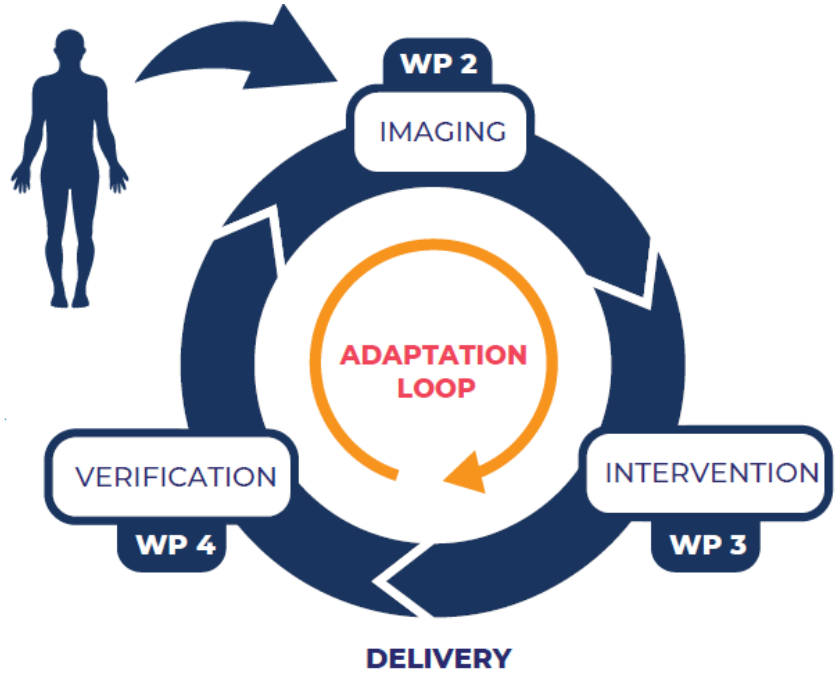
Fig. 2 Overview of partners and ESRs

Towards real-time adaptive proton therapy

Real-time Adaptive Particle Therapy of Cancer (RAPTOR)

→https://raptor-consortium.com/

RAPTOR strives to enable a paradigm shift from a currently manual step-wise treatment approach towards a future **automated seamless workflow**, integrating imaging, treatment planning, quality assurance and treatment verification into a **real-time adaptive particle therapy (PT) treatment loop.**



Thank you very much for your attention!

And thank you to the following people contribution to this talk by there outstanding work:

- Arturs Meijers
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- Lydia den Otter
- Carmen O Seller
- Adrian Thummerer
- Sabine Visser