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Proton radiography as a quality control tool for 3D and 4D thorax synthetic CTs

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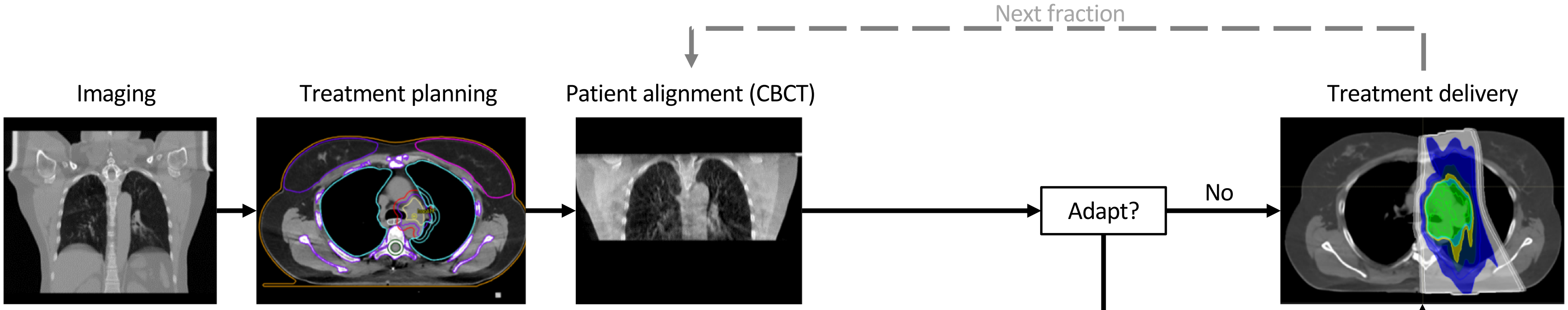
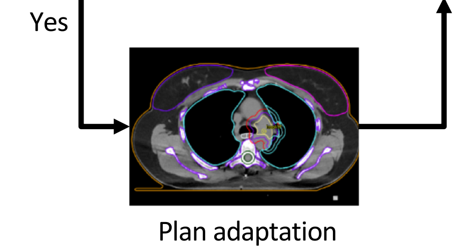
Disclosures

UMCG

	COI status	Names of companies / organizations
① Post of executive / consultant	No	
② Stocks	No	
③ Patent royalties	No	
④ Stage moneys/Man	No	
⑤ Off Label Devices	Yes	Proton Range Devices, Clinical Infrastructure Platform and Software, AI Algorithms
⑥ Grant / Research funding	Yes	Department of Radiation Oncology has research collaborations with: IBA, Siemens, Mirada, Elekta and VisionRT
⑦ Other rewards	No	

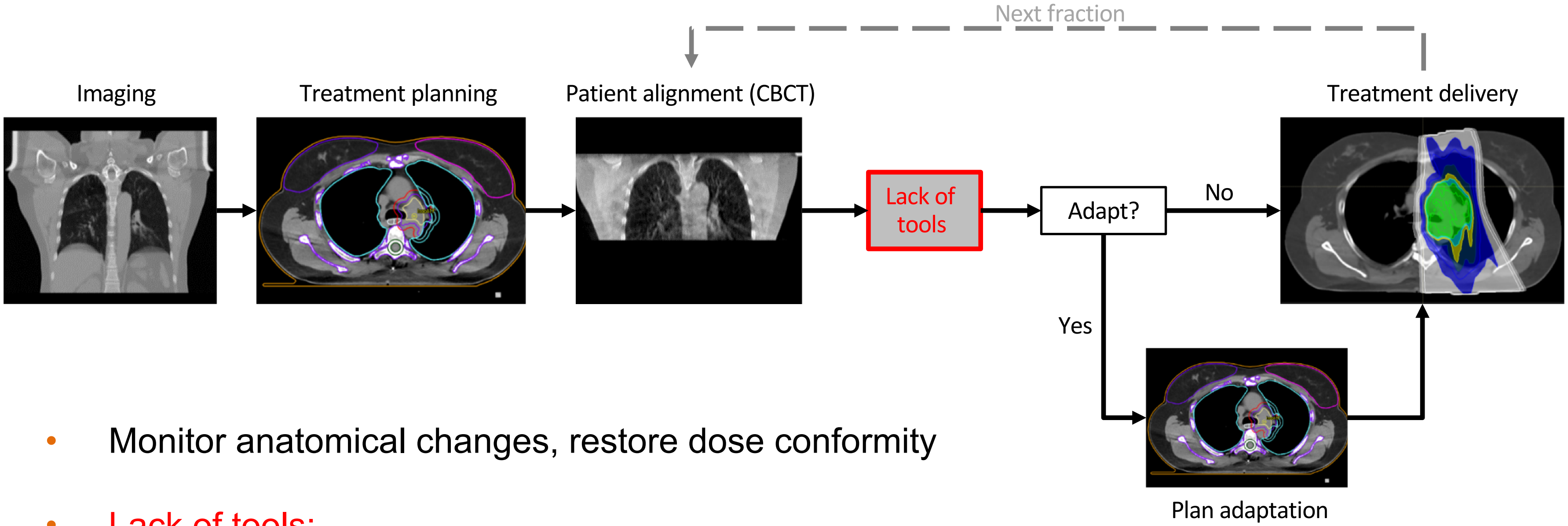
Online adaptive proton therapy





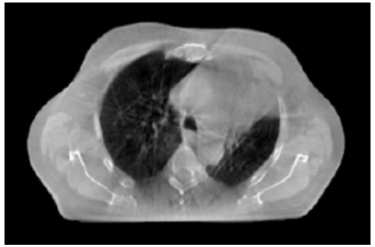
- Monitor anatomical changes, restore dose conformity
  - Current practice: weekly CTs

Online adaptive proton therapy

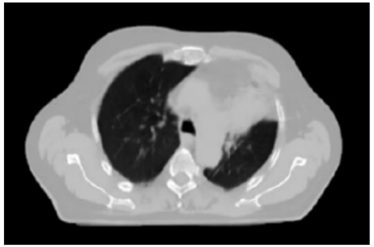


- Monitor anatomical changes, restore dose conformity
- Lack of tools:
  - High quality daily 3D images → synthetic CTs
  - Quality control tools → proton radiography

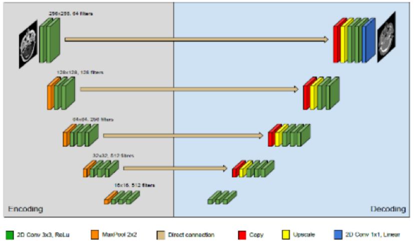
Synthetic CT generation via DL



CBCT
Right before treatment
Wrong CT numbers
Image artefacts



Synthetic CT (3D, 4D)

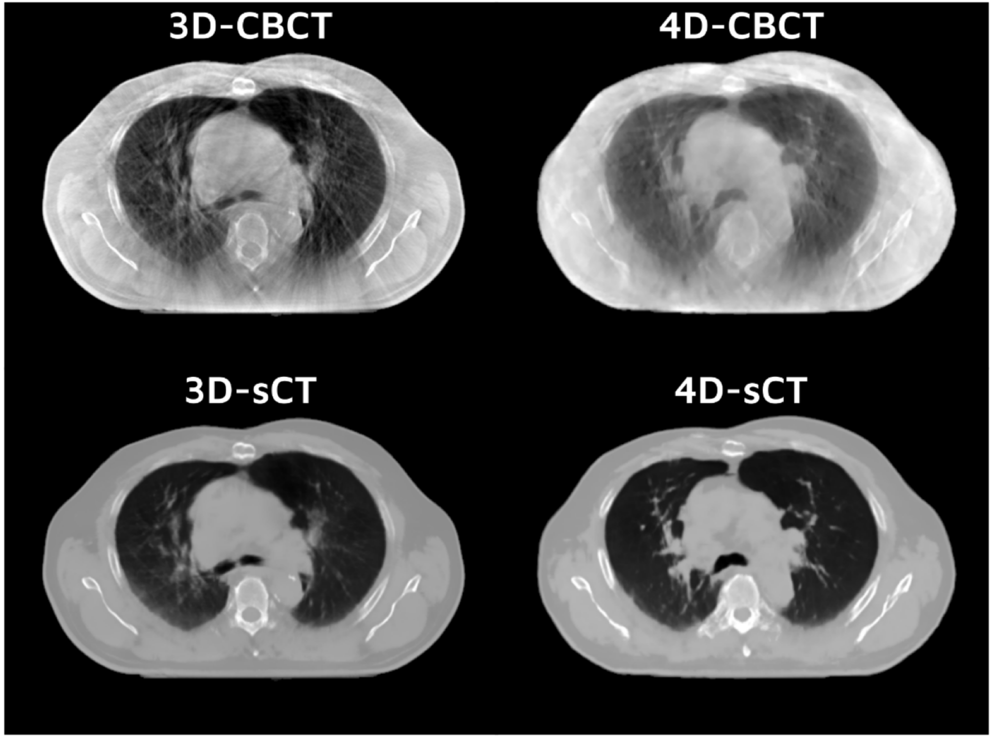


- Deep conv. neural network
  - U-net
- CT - CBCT image pairs
- 25 patients
- 4D-sCTs:
  - 3D CBCTs phase binned
  - 4D reconstruction (MC-Rooster)

Synthetic CT generation via DL

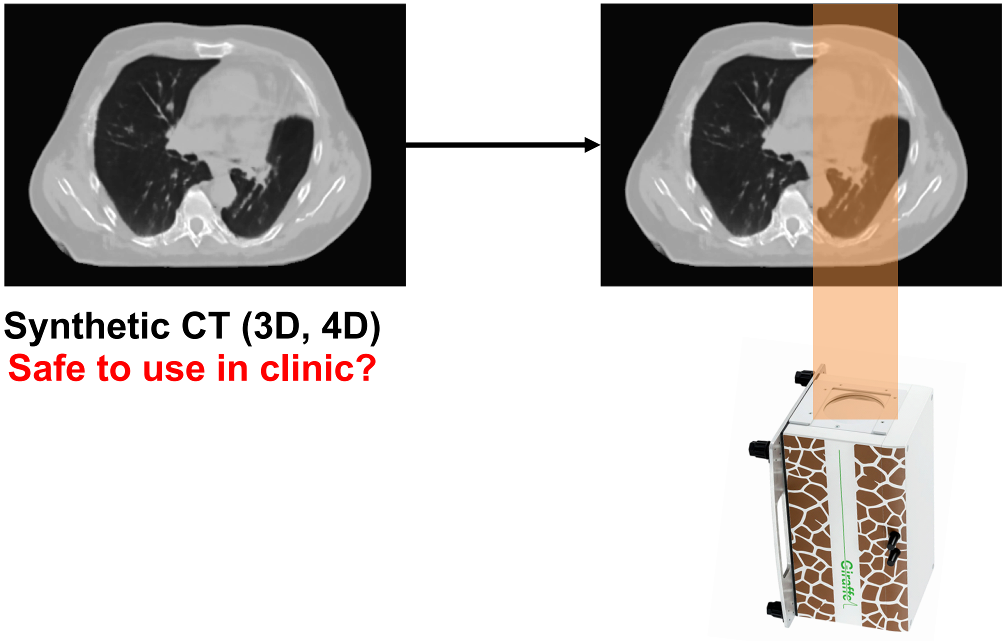
Input

Output



Different CBCT image quality for 3D and 4D training

Quality control of synthetic CTs



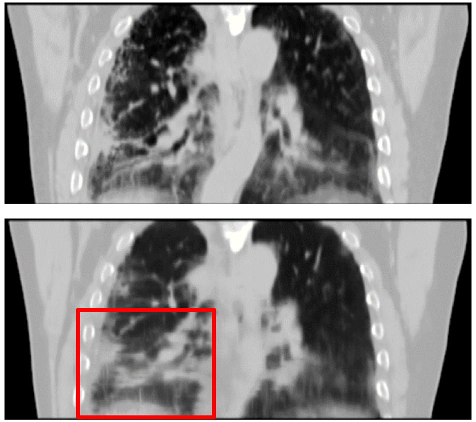
Synthetic CT (3D, 4D)
Safe to use in clinic?

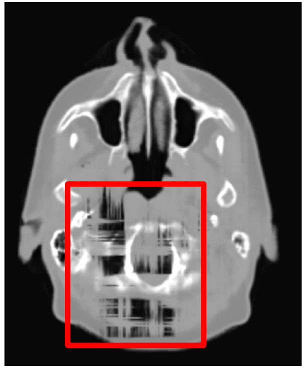
Proton radiography
Quality control

- Proton dose calculations on synthetic CTs
- Implementation in adaptive workflows
- Daily anatomy

Why do we need quality control tools?

- Detect outliers in DL output
  - Anatomical abnormalities
  - Positioning
  - Implants
  - Acquisition settings
  - System updates





Elements that fall outside the training distribution

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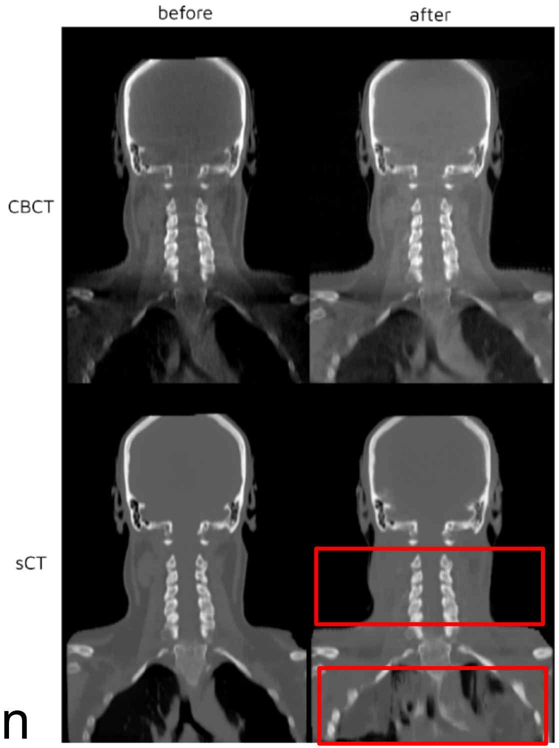
Elements that fall outside the training distribution



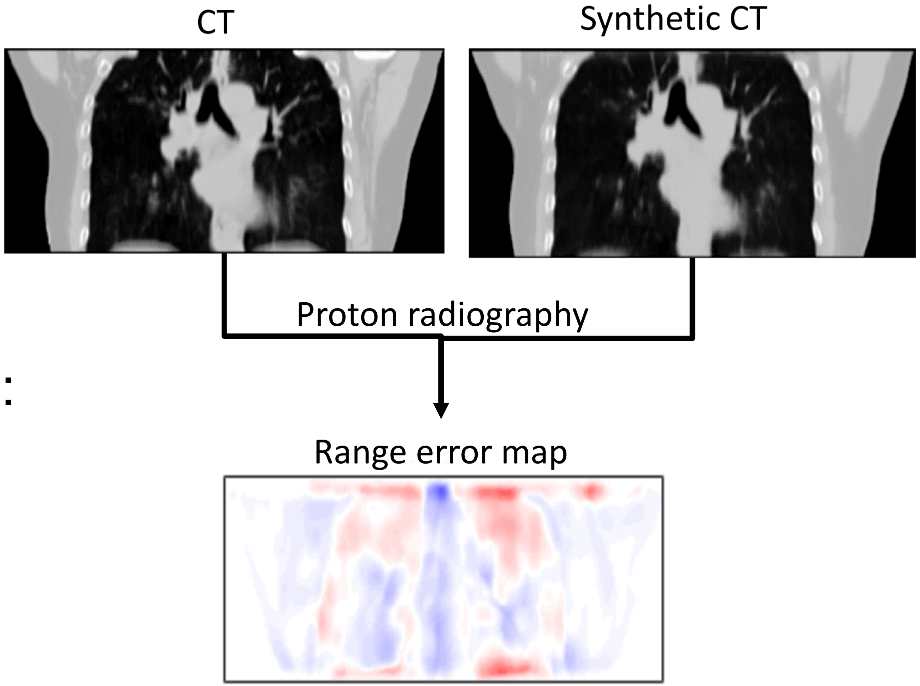
Aim of this study

Evaluate 3D and 4D thorax synthetic CTs in terms of CT number accuracy via proton radiography simulations

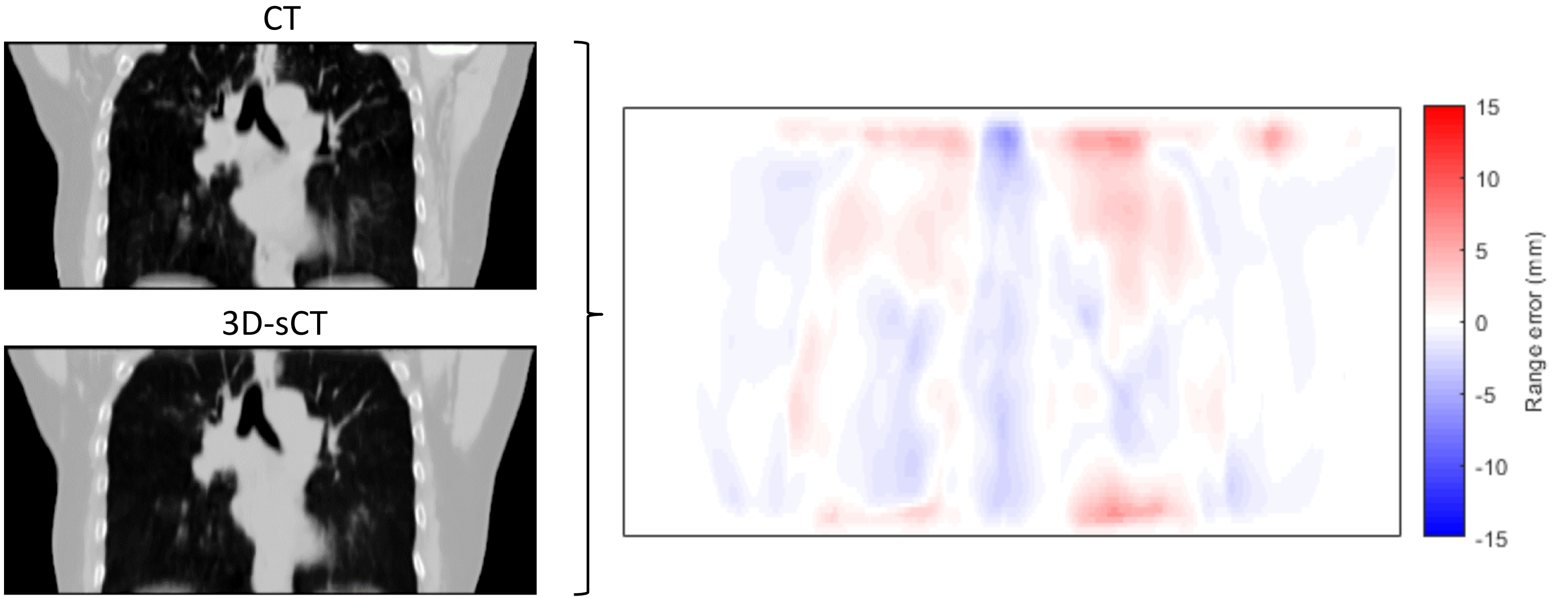
Proton radiography simulations

- Gantry angle 0 degrees
- Multi-layer ionization chamber
- 15 patients

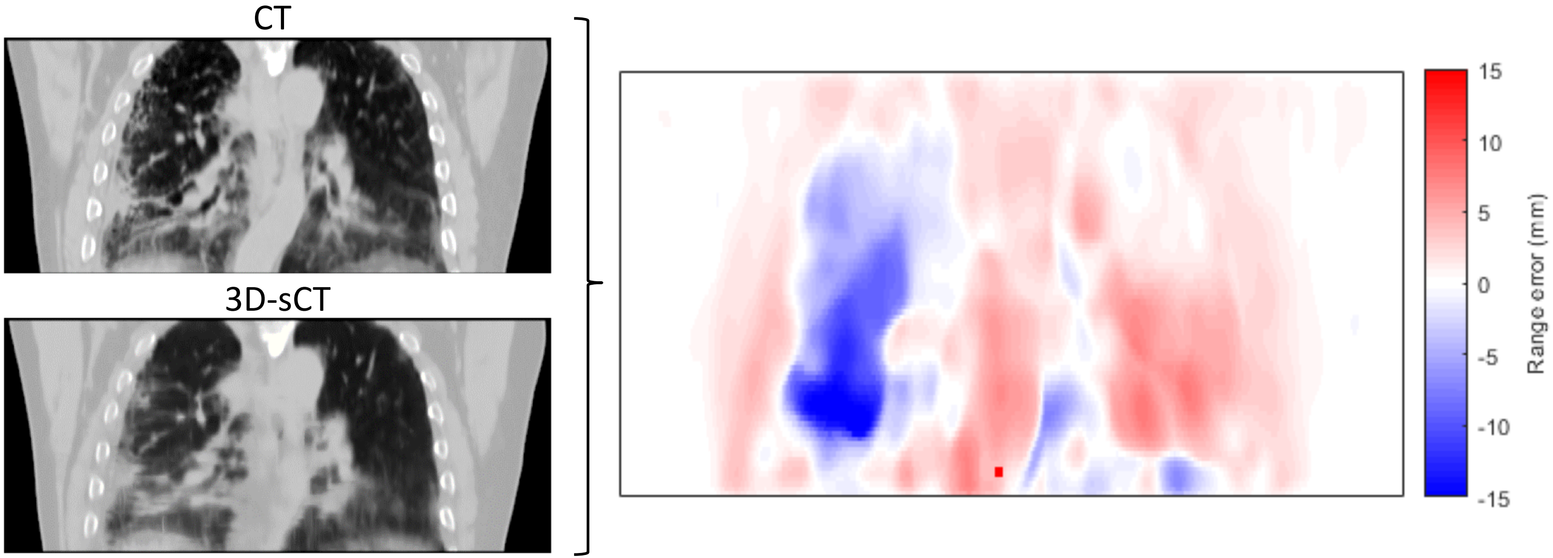
- Range errors maps in 3 scenarios:
  1. 3D sCT
  2. 4D sCT (50%)
  3. average 4D sCT



Examples of sCT quality

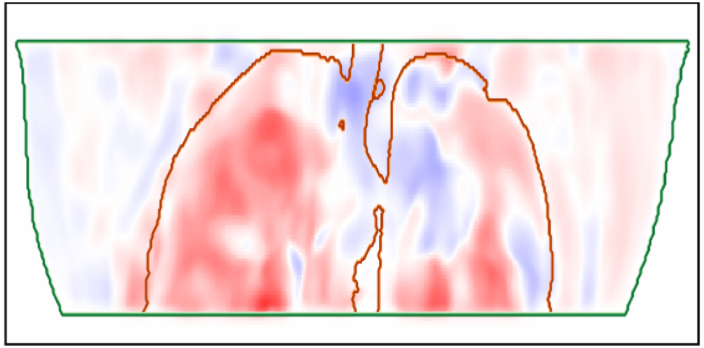


Examples of sCT quality

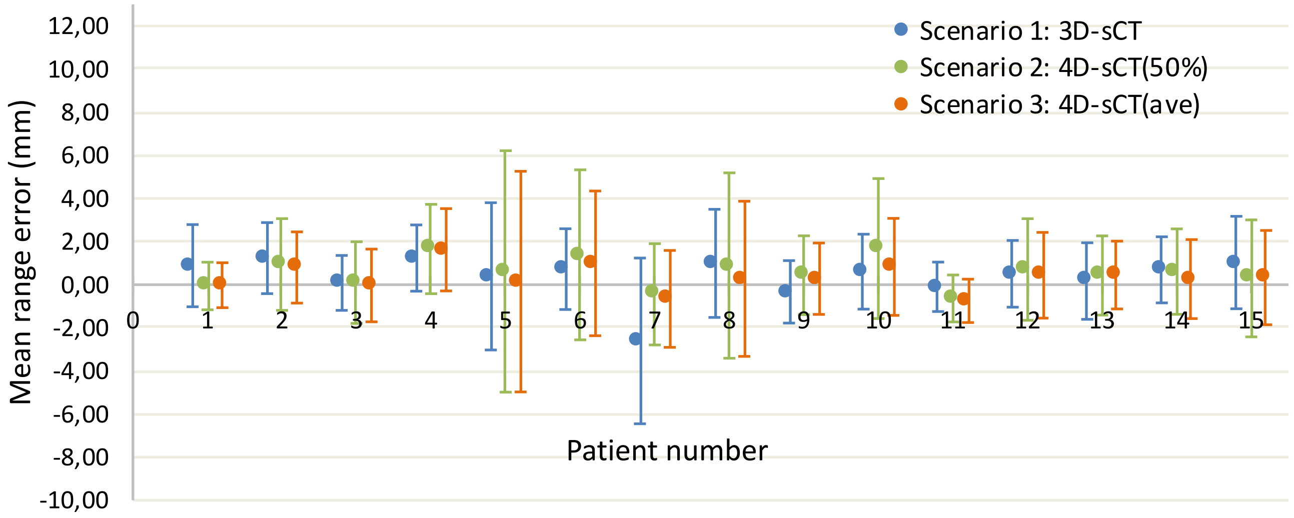


Range error map quantification

- Mean (MRE) and standard deviations (SD)
  a) whole anatomy
  b) only lung tissue
  c) whole anatomy excl. lung

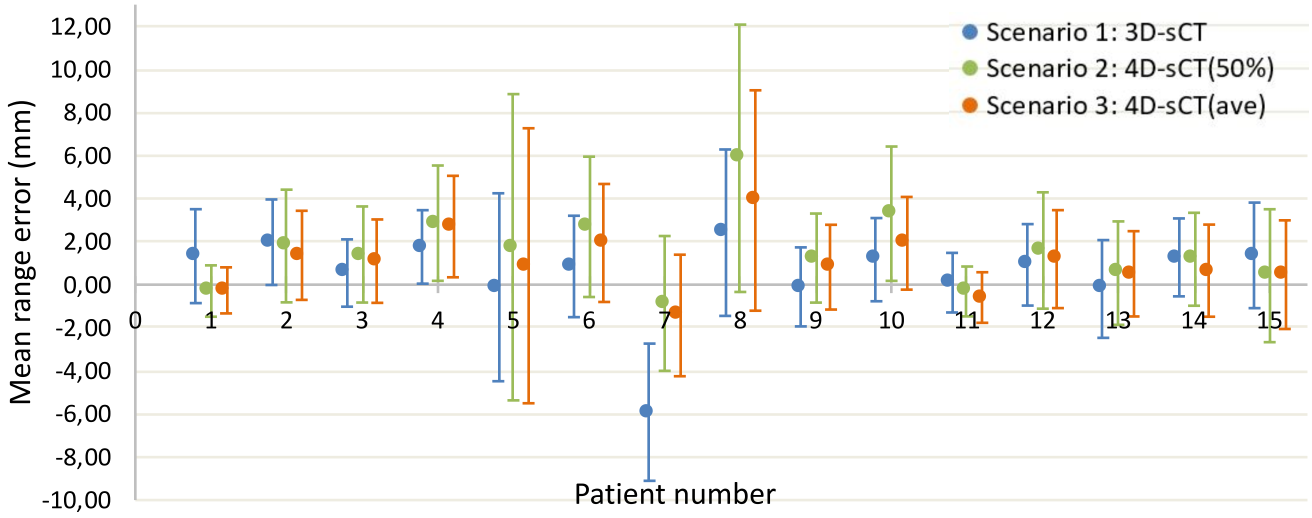


Results: whole anatomy



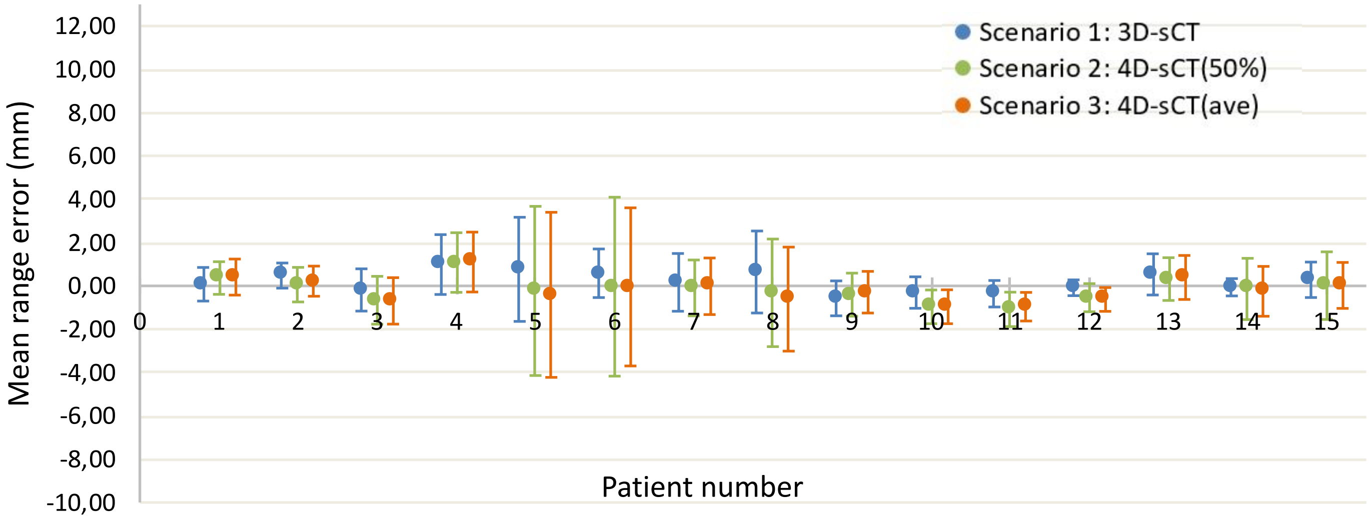
- High variability across patients: MREs between 0.0±1.0mm and 0.6±5.6mm
- Comparable results between 3D and 4D
- Systematically positive MREs → why?

Results: lungs



- Increased MRE and SDs in lungs
- Lower CT number accuracy in lung tissue

Results: anatomy excl. lungs



- Reduced MREs and SDs in the rest of the anatomy

Conclusions

- Proton radiography as a quality control tool for synthetic CTs.

- Highlight CT number inaccuracies in synthetic CTs.

- CT number accuracy of synthetic CTs is particularly challenging in lung tissue.

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Deep learning–based 4D-synthetic CTs from sparse-view CBCTs for dose calculations in adaptive proton therapy

Adrian Thummerer, Carmen Seller Oria, Paolo Zaffino, Sabine Visser, Arturs Meijers, Gabriel Guterres Marmitt, Robin Wijsman, Joao Seco ... See all authors

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Future perspectives

- In vivo range verification in thoracic patients
  - Patient specific dosimetry checks
  - 4D synthetic CT validation with ground truth measurements

- QA workflows for AI-based tools in the clinic

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Thank you for your attention!