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Verification study of the dose calculation algorithm for carbon beam therapy based on dual energy CT image and LEM IV biological model

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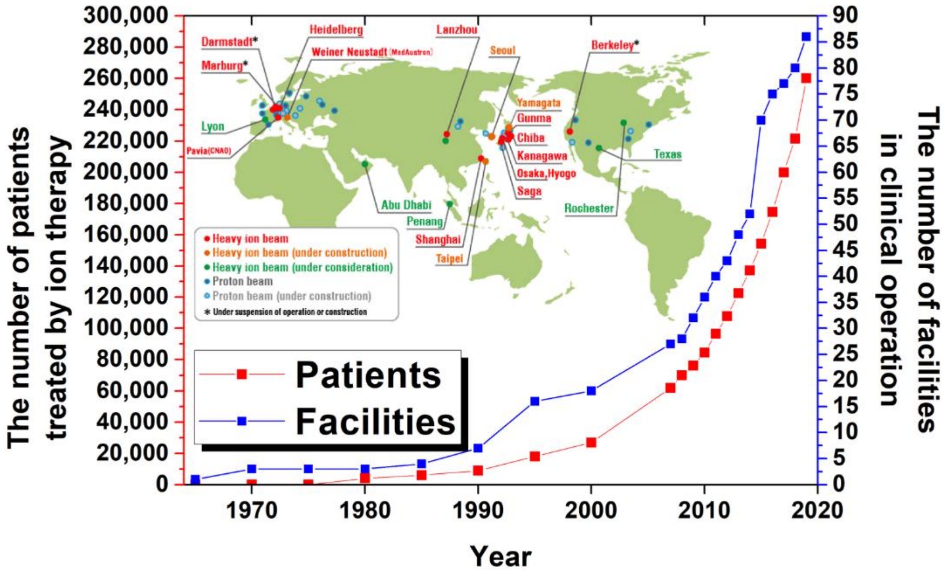
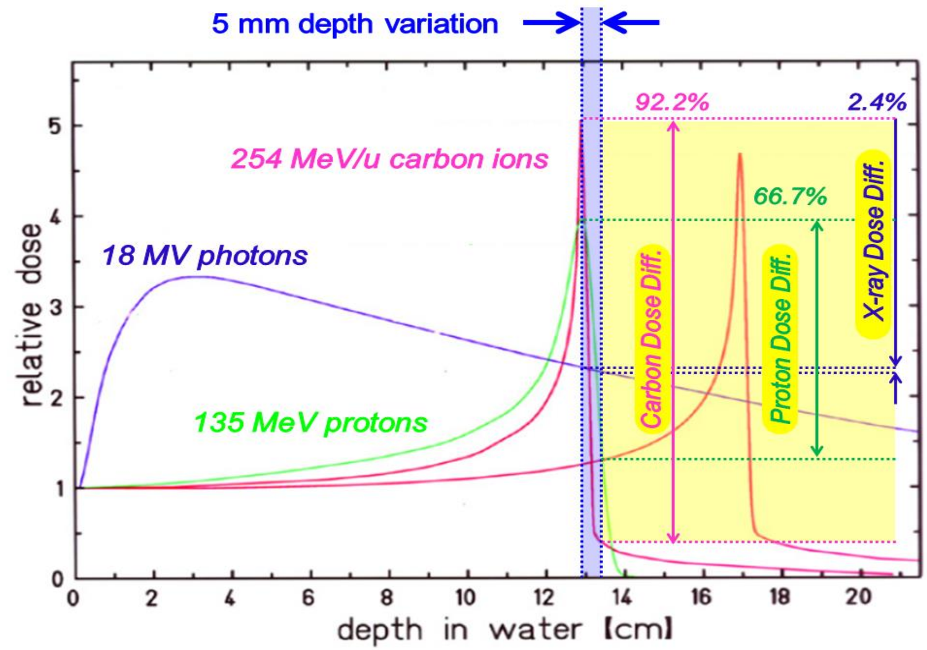
Characteristic of particle beam therapy

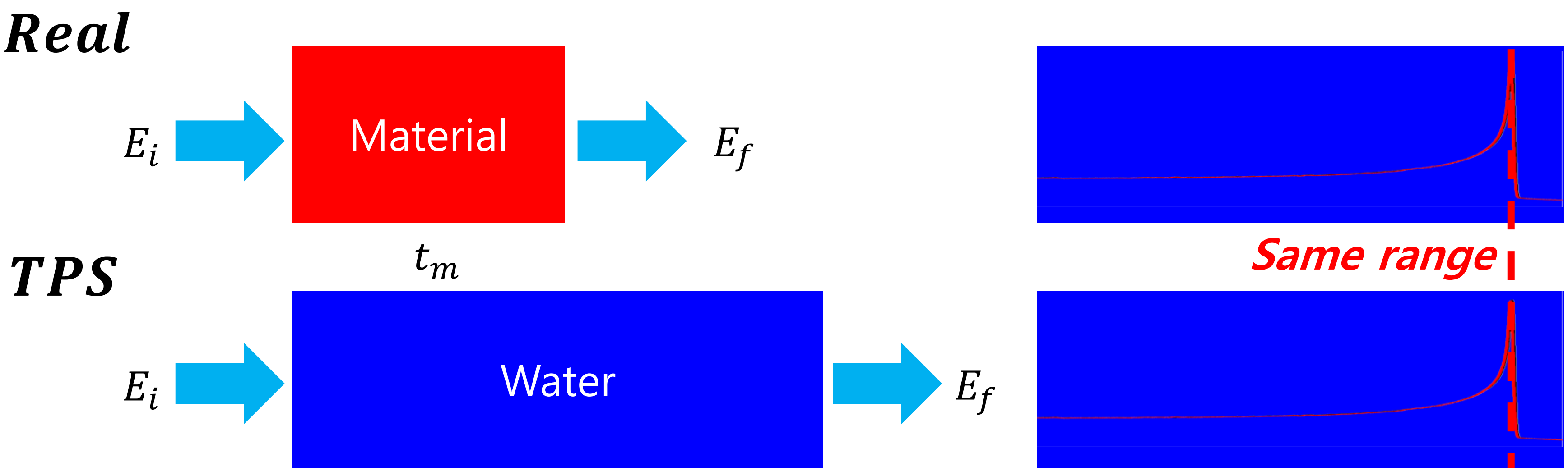


PTCOG, Particle Therapy Patient Statistics



- High conformal dose to the target volume using Bragg peak
- Range uncertainties due to the setup error, dose calculation algorithm, CT calibration …

Pencil beam based dose calculation algorithm

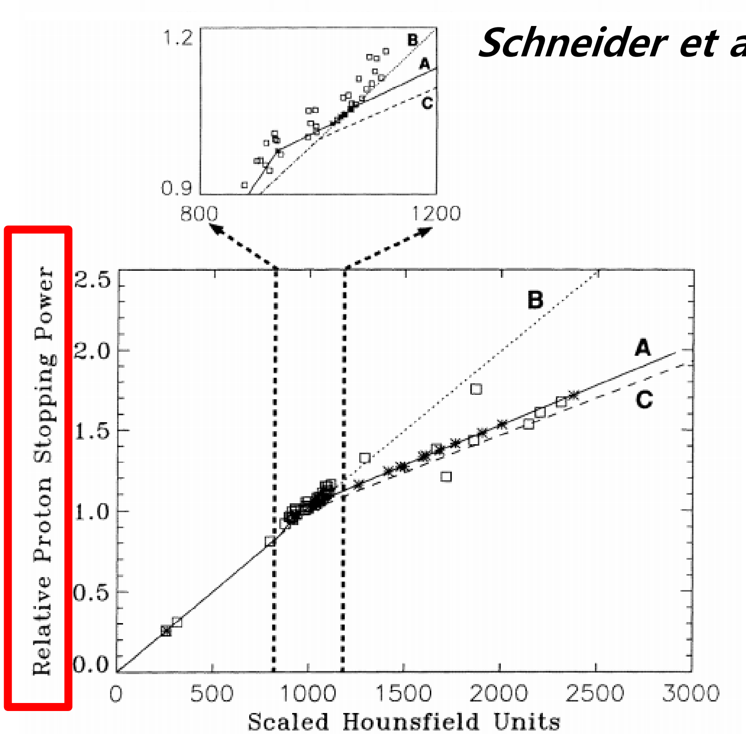


$$t_w = t_m(\rho_m/\rho_w)(\bar{S}_m/\bar{S}_w)$$

- Water equivalent thickness (WET)
- Relative stopping power (RSP)

Conventional method using Computed Tomography (CT)

Schneider et al. (1996)



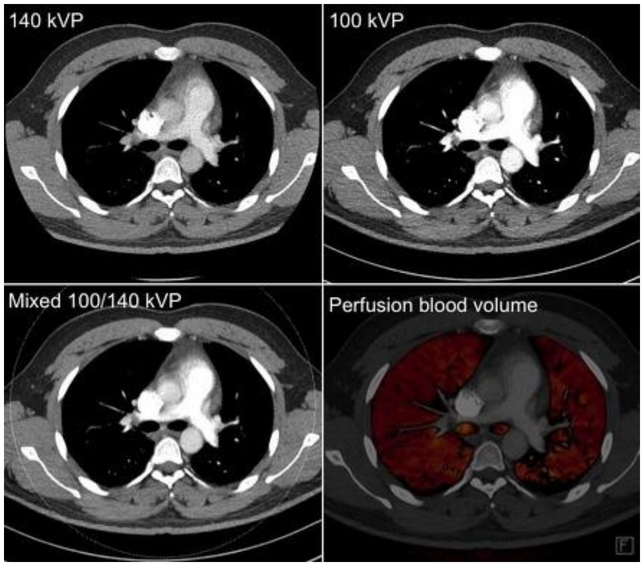
Paganetti et al. (2012)

Source of range uncertainty in the patient	Range uncertainty
Independent of dose calculation	
Measurement uncertainty in water for commissioning	±0.3 mm
Compensator design	±0.2 mm
Beam reproducibility	±0.2 mm
Patient setup	±0.7 mm
Dose calculation	
Biology (always positive) ^	+~0.8%
CT imaging and calibration	±0.5% [a]
CT conversion to tissue (excluding I-values)	±0.5% [b]
CT grid size	±0.3% [c]
Mean excitation energy (I-values) in tissues	±1.5% [d]
Range degradation; complex inhomogeneities	−0.7% [e]
Range degradation; local lateral inhomogeneities *	±2.5% [f]
Total (excluding *, ^)	2.7% + 1.2 mm
Total (excluding ^)	4.6% + 1.2 mm

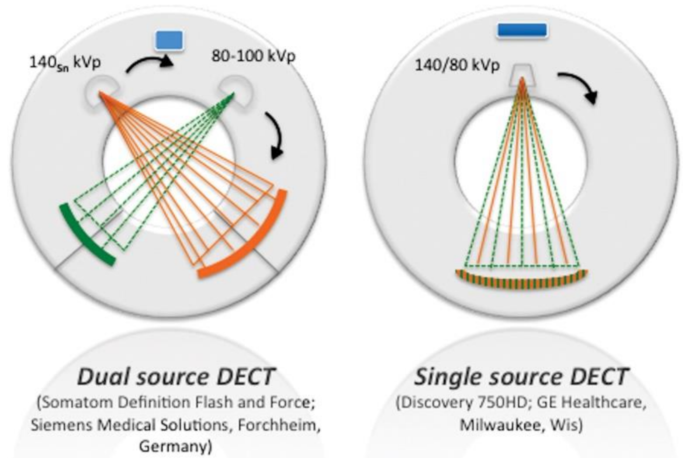
- CT Hounsfield unit (HU)
  - Weak correlation with RSP

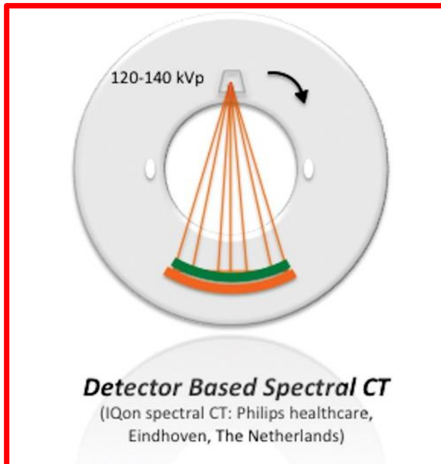
RSP calibration using dual energy CT (DECT)

Patino et al. (2016)



Charlie, rID: 31363



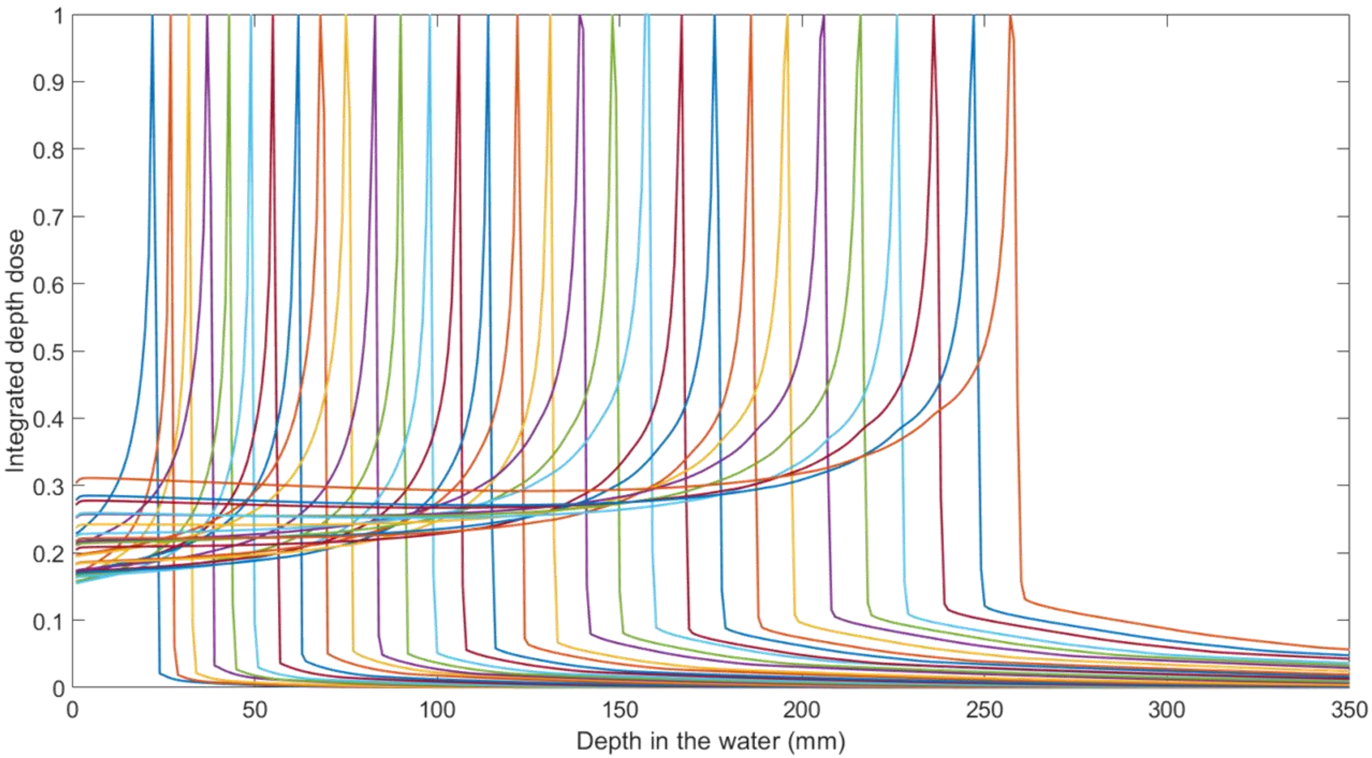


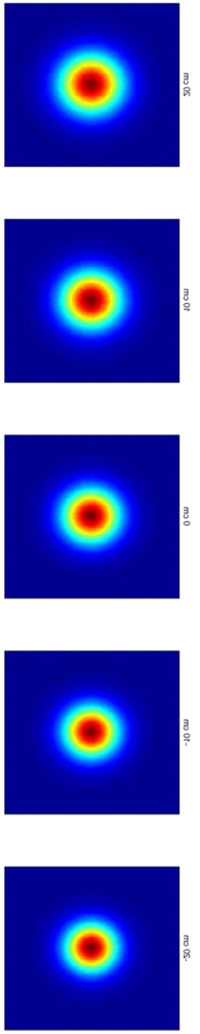
- Pros
  - Material decomposition (Z_{eff} and ρ_e)
  - Close correlation with RSP
- Cons
  - Extra imaging dose

Purpose

- The purpose of this study is to develop a carbon dose calculation algorithm based on the DECT images using Philips iQon dual-layer CT
- To quantitatively evaluate the influence of the DECT by comparing with conventional CT on pencil beam dose calculation

Carbon beam data calculated by Geant4

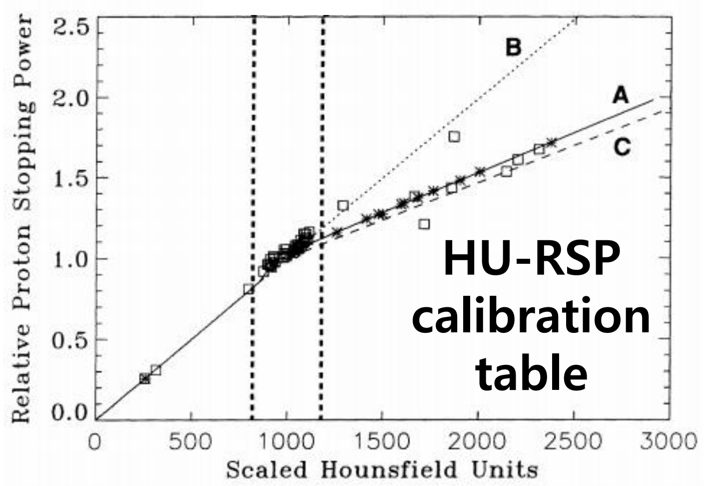




- QGSP_BIC_HP_EMY modular physics
- 100-430 MeV/u (5 MeV/u energy bin)

Philips iQon dual-layer CT and material decomposition

SECT image
(HU value)



RSP image

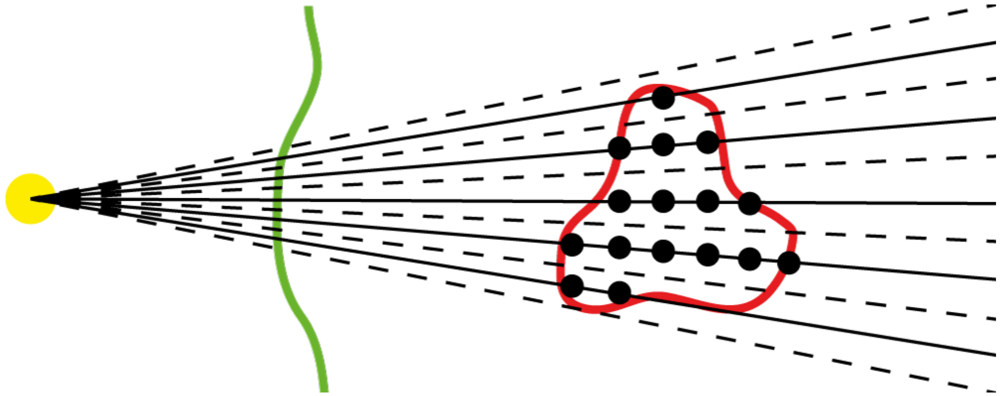
DECT image
(HU_{high} and HU_{low})

Z_{eff} and ρ_e map

Joshi method
Vender specific algorithm

Bethe-Bloch
formula

matRad software



matRad

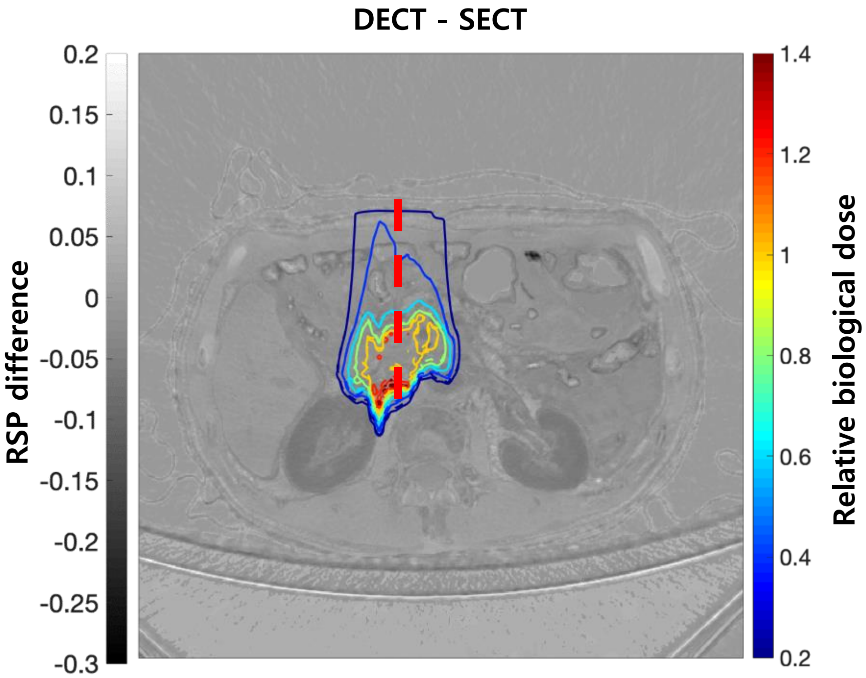
Wieser et al. (2017)

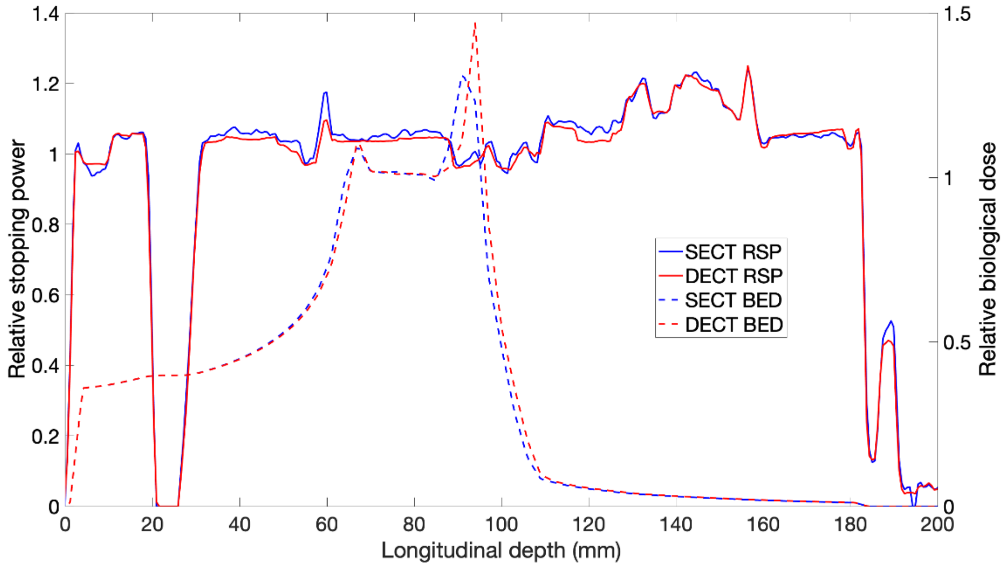
- MATLAB-based treatment planning system
- Dose calculation algorithm for photon and particle beam
- Biological dose calculation based on LEM IV model

Influence of DECT on patient cases

- Total 3 patient cases
  - Abdomen, Lung, Head&neck cases
- Treatment plan
  - Single port
  - Same plan for both SECT and DECT image
- Biological dose and range uncertainty

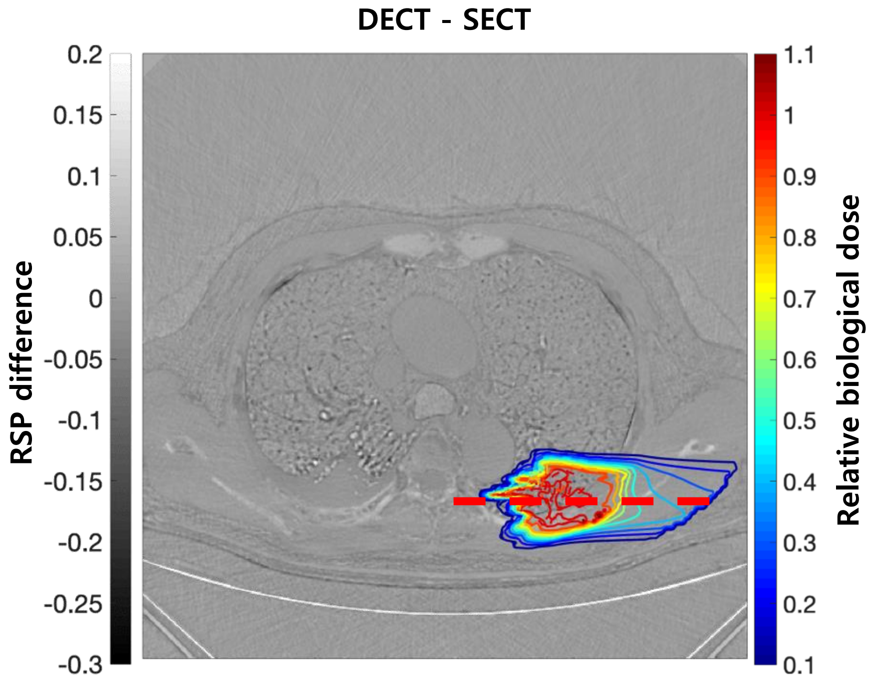
Abdomen case

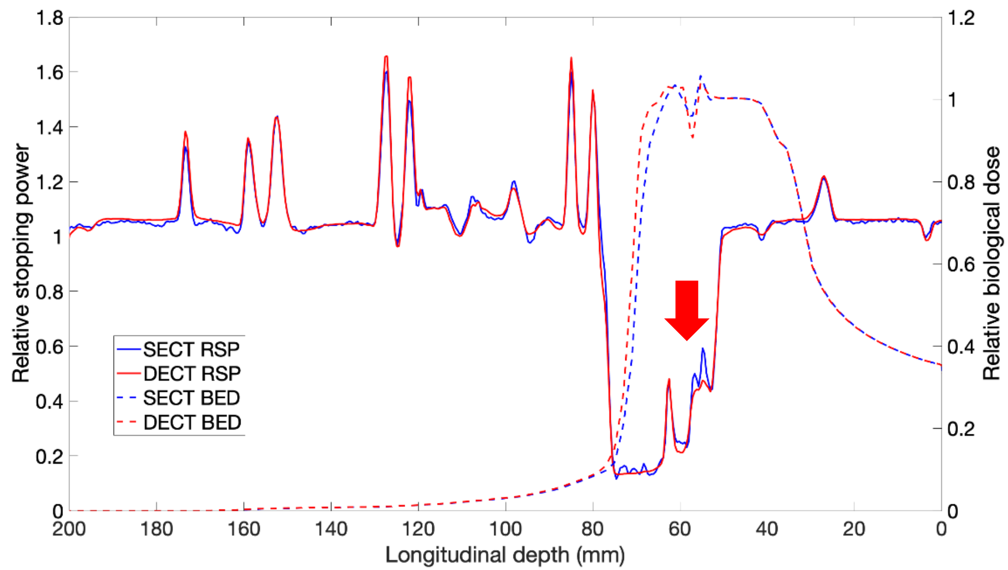




- Maximum RSP difference of 10% in kidneys and stomach
- Range uncertainty up to 2.02 mm

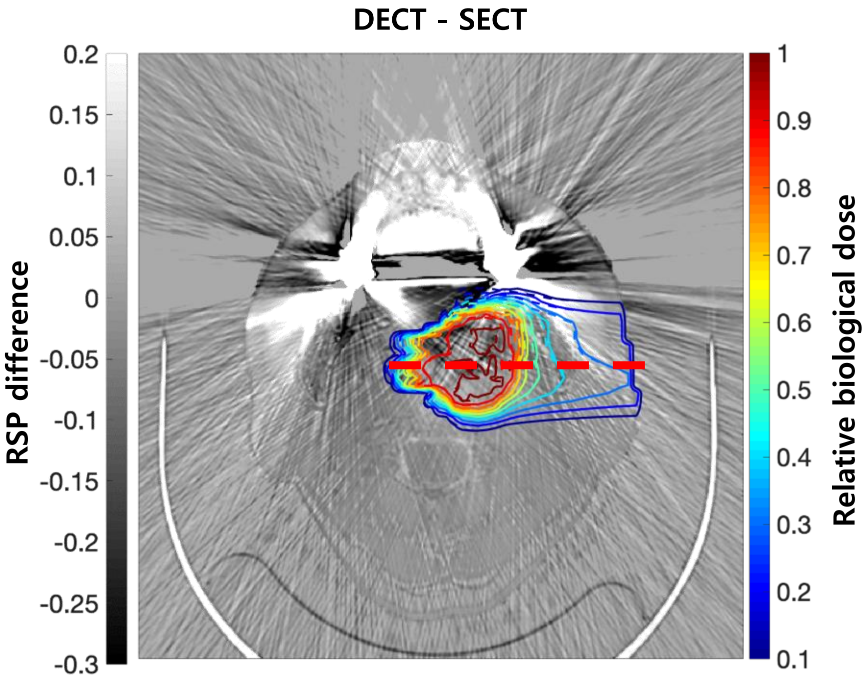
Lung case

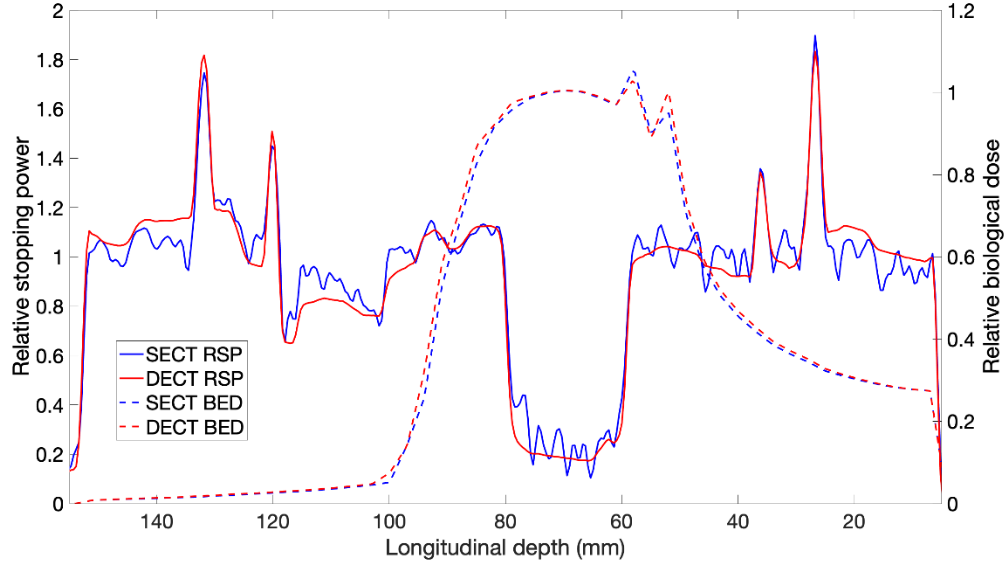




- Relatively large RSP disagreement at lung vessel (about 20%)
- Range uncertainty up to 2.25 mm

Head & neck case





- Beam hardening and photon starvation artifact
- Range uncertainty up to 1.15 mm

Conclusions

- The plausibility of the dose calculation algorithm based on DECT image has been verified in this study.
- DECT could be used to correct up to 2.25 mm range uncertainty due to the CT conversion method of conventional CT.
- In further, quantitative evaluation of the DECT influence according to beam path media will be performed, and post-processing algorithms for beam hardening artifact would be investigated.

Thank you for listening