Impact of the Tube Start Angle on Patient Dose in Single and Dual Source Spiral CT Scans

Edith Baader[1,2], Laura Klein[1,2], Joscha Maier[1], Stefan Sawall[1,2] , and Marc Kachelrieß[1,2]

[1]German Cancer Research Center (DKFZ), Heidelberg, Germany
[2]Heidelberg University, Heidelberg, Germany

Disclosure

The authors have nothing to disclose.

Background

- Non-uniform quasiperiodic dose patterns are created during spiral scans. This leads to dose variations particularly in the periphery regions of the scanned object[1,2,3].
- The tube start angle affects organ dose values, especially for small peripheral organs[4].
- Previous studies considered the dose reduction potential for single organs by choosing the optimal start angle[2,4].

[1]Zhang D, Savandi AS, Demarco JJ, et al. Variability of surface and center position radiation dose in MDCT: Monte Carlo simulations using CTDI and anthropomorphic phantoms, Medical Physics 36, 1025–1038 (2009).
[2]Winslow JF, Tien CJ, Hintenlang DE. Organ dose and inherent uncertainty in helical CT dosimetry due to quasiperiodic dose distributions, Medical Physics 38, 3177–3185 (2011).
[3]Yang K, Li X, Yu L, et al. Visualization and comparison of CT dose distribution between axial and helical acquisitions, Medical Physics 50, 4797–4808 (2023).
[4]Zhang D, Zankl M, DeMarco JJ, et al. Reducing radiation dose to selected organs by selecting the tube start angle in MDCT helical scans: A Monte Carlo based study, Medical Physics 36, 5654–5664 (2009).

Purpose

To determine organ doses and the effective dose in

- **single source CT (SSCT) and**
- **dual source CT (DSCT) scans**

with

- **constant tube current (noTCM) or**
- **tube current modulation minimizing the mAs-product (mAsTCM)**

as a function of

- **tube start angle and**
- **spiral pitch value**

to identify the dose reduction potential by selecting the optimal start angle.

METHODS

Monte Carlo Dose Simulations

- Dose simulations for various tube positions in increments of $d\alpha = 10°$ and $dz = 4.5$ mm
- Source spectrum: Tucker spectrum at $U = 120$ kV, filtered by 6 mm aluminium and a bowtie filter
- Collimation: $C = 38.4$ mm
- Calculation of organ doses D_T via

$$D_T = \frac{\int_T D(x,y,z)\rho(x,y,z)dV}{\int_T \rho(x,y,z)dV}$$

D(x, y, z): simulated dose distribution
ρ(x, y, z): density distribution

- Calculation of effective dose E via

$$E = \sum_T w_T D_T$$

w_T: tissue weighting factor according to ICRP 103[1]

[1]ICRP, 2007. The 2007 Recommendations of the International Commission on Radiological Protection. ICRP Publication 103. Ann. ICRP 37 (2-4).

Calculation of Dose of Spiral Scans

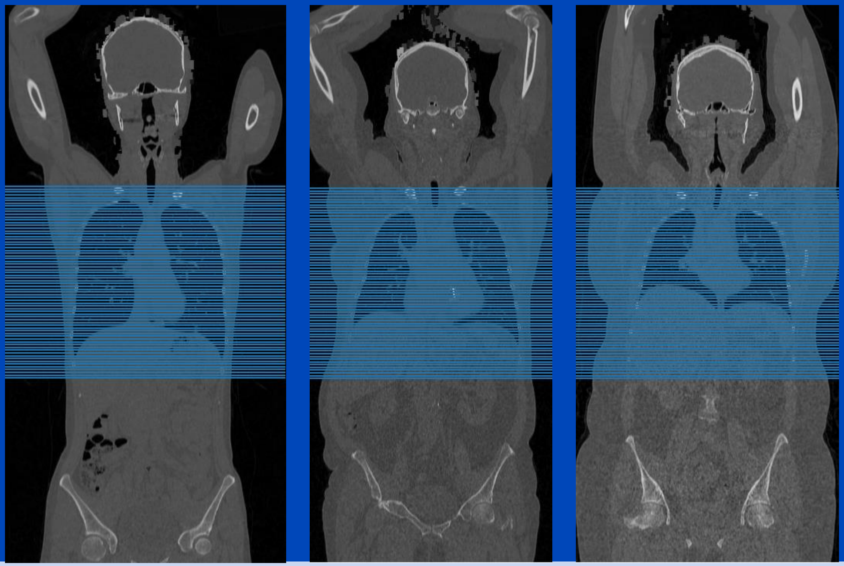
- **Sum of dose values along spiral trajectory for different tube start angles α_0 with angular increments of 10° and linear interpolation of dose values in longitudinal direction**
- **For mAsTCM, every dose value is weighted by the corresponding tube current value**
- **In DSCT, the stated angle corresponds to one tube, the other tube is assumed to be at +90°**
- **Pitch values *p*: *p* = 0.5 … 1.5 SSCT, *p* = 0.5 … 3 DSCT**
- **Best tube start angle minimizes dose:** $\min_{\alpha_0} D(p, \alpha_0)$
- **Maximum possible dose reduction for given pitch value:**

$$\text{Dose reduction}(p) = 1 - \frac{\min_{\alpha_0} D(p, \alpha_0)}{\max_{\alpha_0} D(p, \alpha_0)}$$

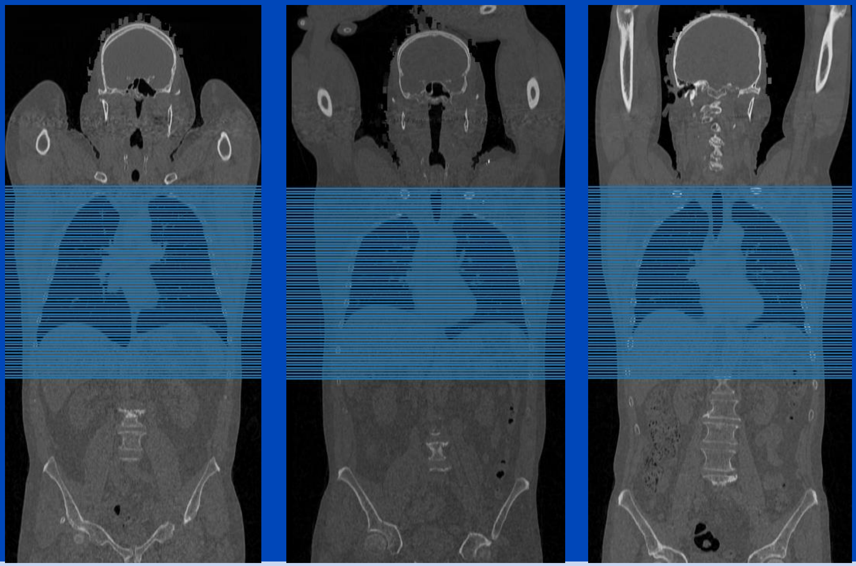
Patient Study

- 3 female and 3 male patients from the Visual Concept Extraction Challenge in Radiology (Visceral)[1]
- Dose simulations over a scan range of 35 cm (indicated by the blue lines) in the thorax region as short scan times and high pitch values are particularly relevant there

Female Patients



Male Patients



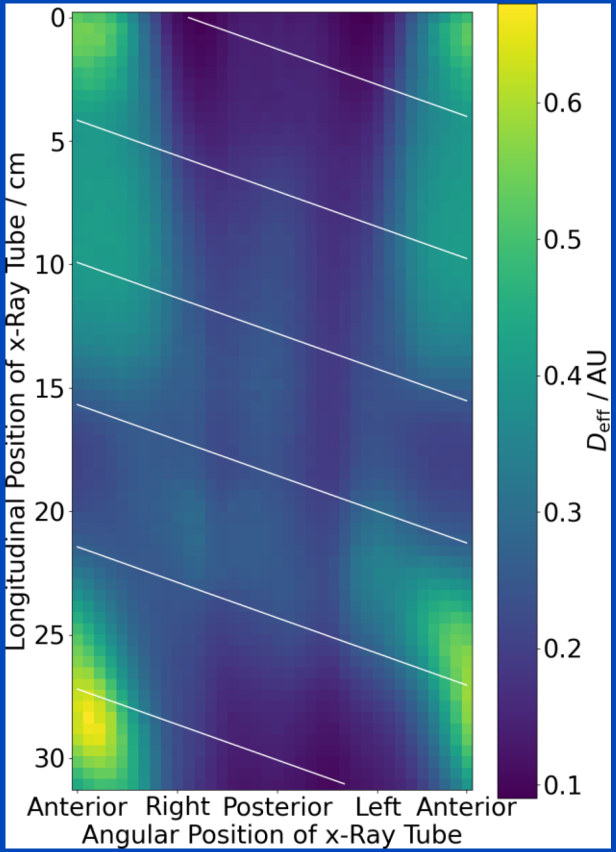
[1]del Toro OJ, Muller H, Krenn M, et al. Cloud-based evaluation of anatomical structure segmentation and landmark detection algorithms: VISCERAL anatomy benchmarks. IEEE Trans Med Imaging. 2016;35:2459-2475

RESULTS

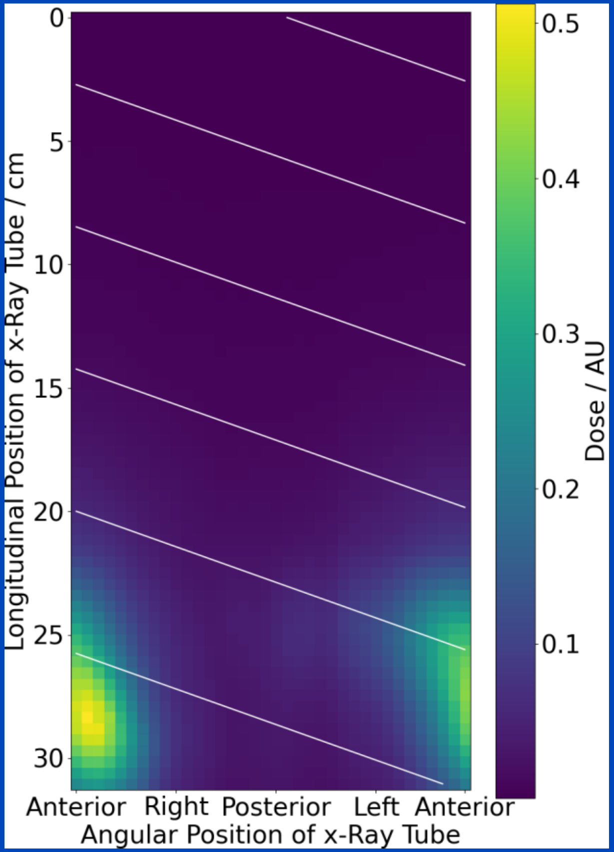
Organ Doses and Effective Dose as a Function of Tube Position

Example Patient

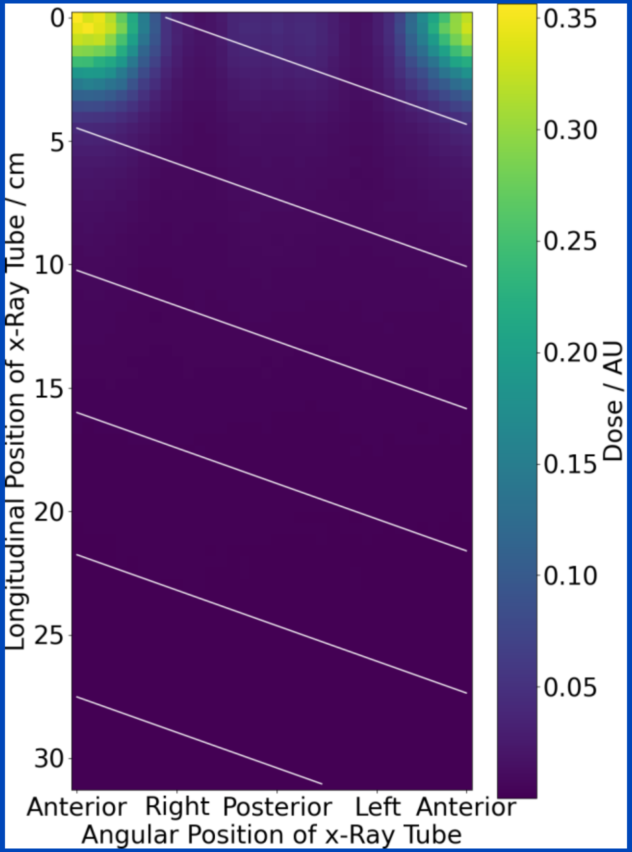
Effective Dose



Stomach Dose



Thyroid Gland Dose

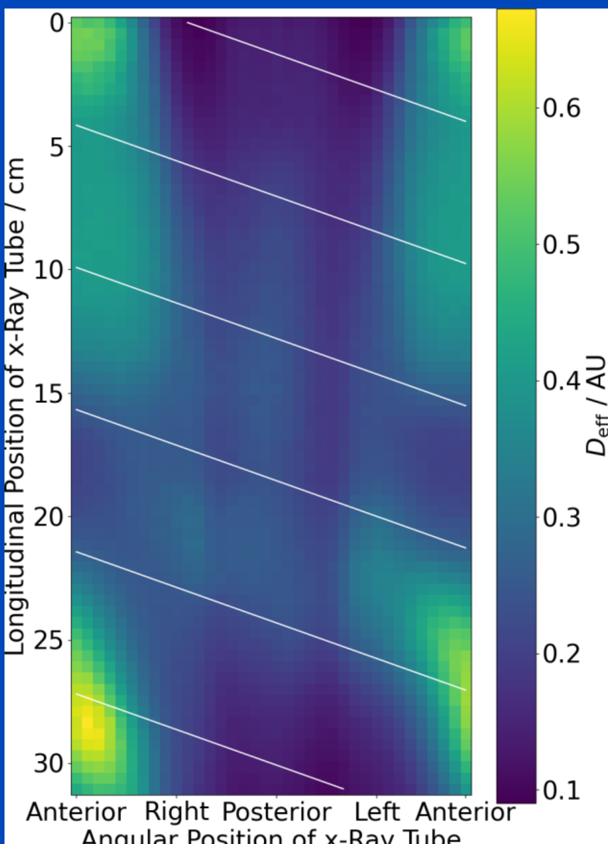


White lines indicate the best trajectory for a SSCT scan with pitch 1.5 and constant tube current.

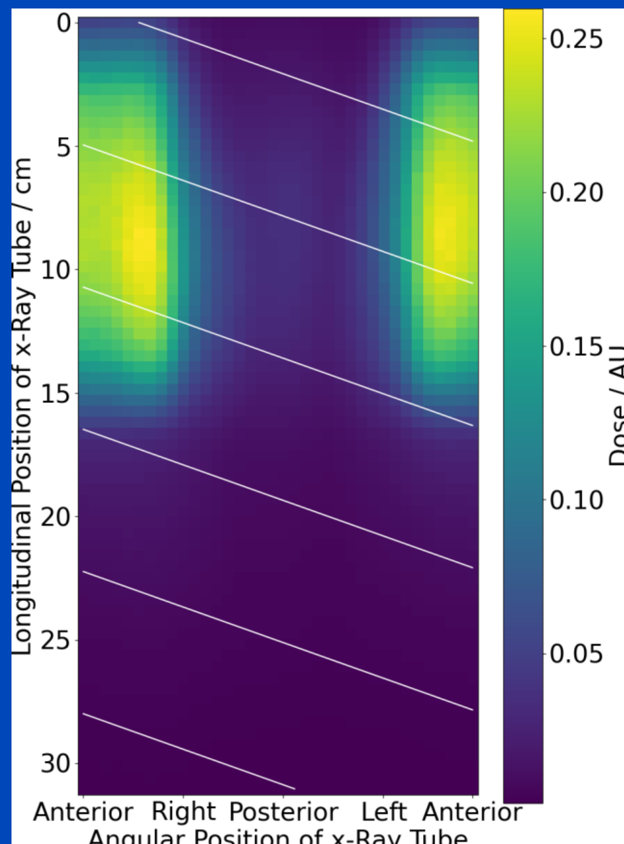
Organ Doses and Effective Dose as a Function of Tube Position

Example Patient

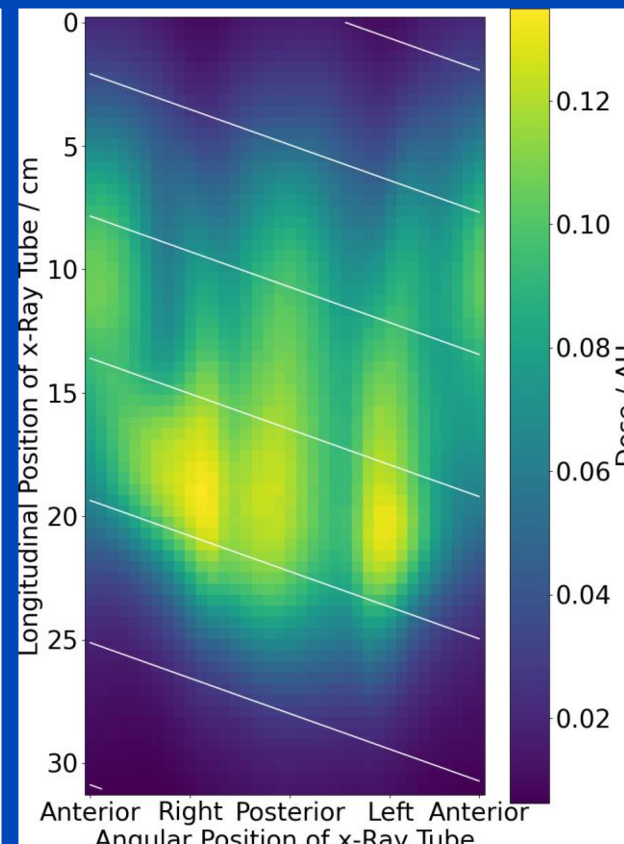
Effective Dose



Breast Dose



Lung Dose

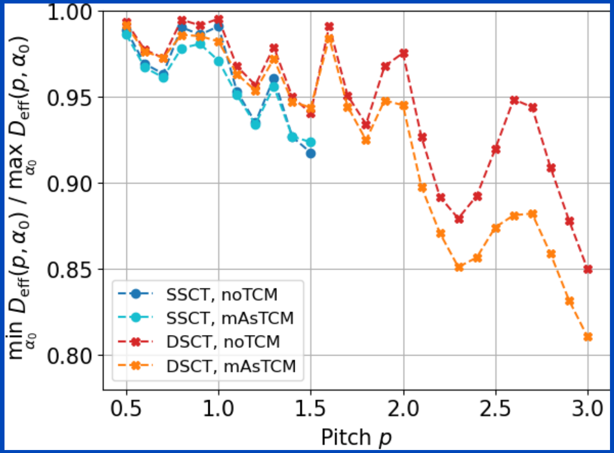


White lines indicate the best trajectory for a SSCT scan with pitch 1.5 and constant tube current.

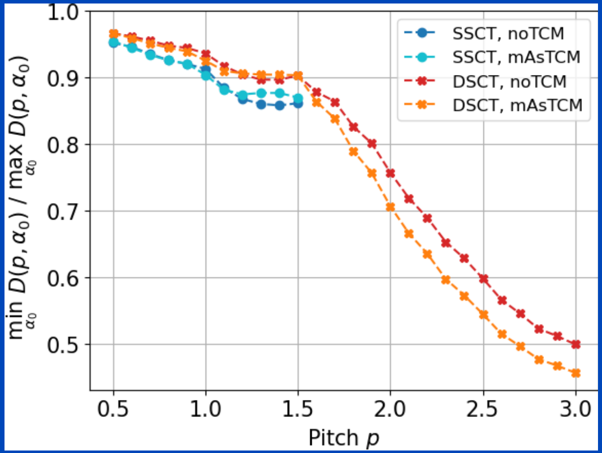
Relative Dose of Best Start Angle Compared to Worst Start Angle

Example Patient

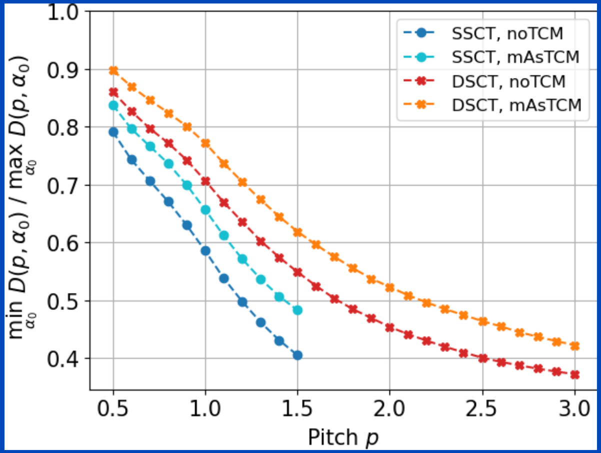
Effective Dose



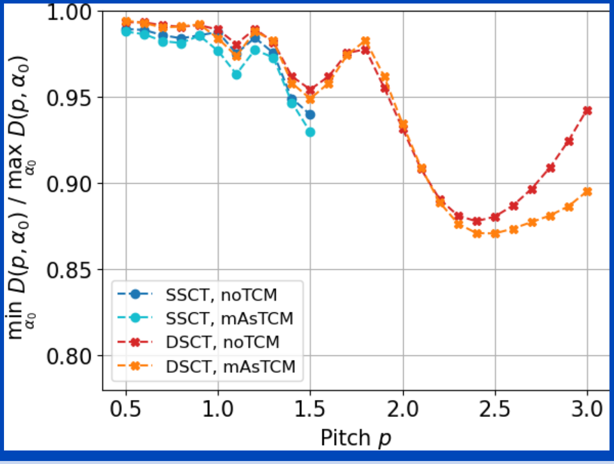
Stomach Dose



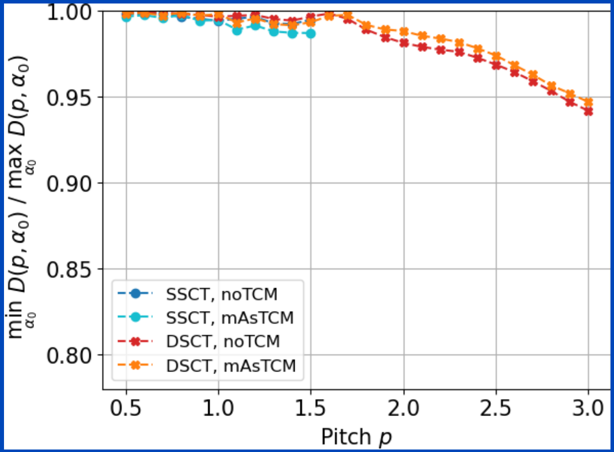
Thyroid Gland Dose



Breast Dose



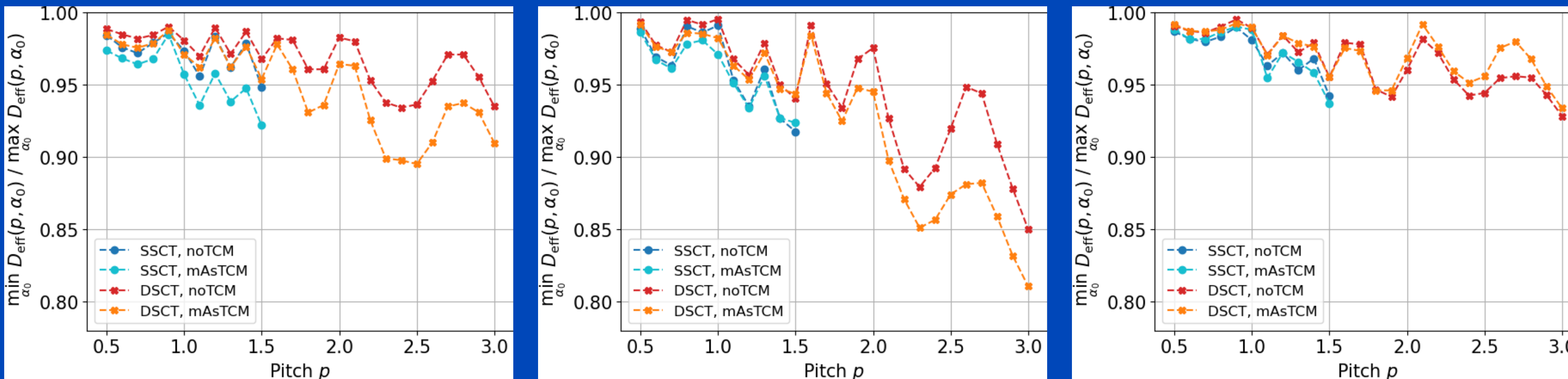
Lung Dose



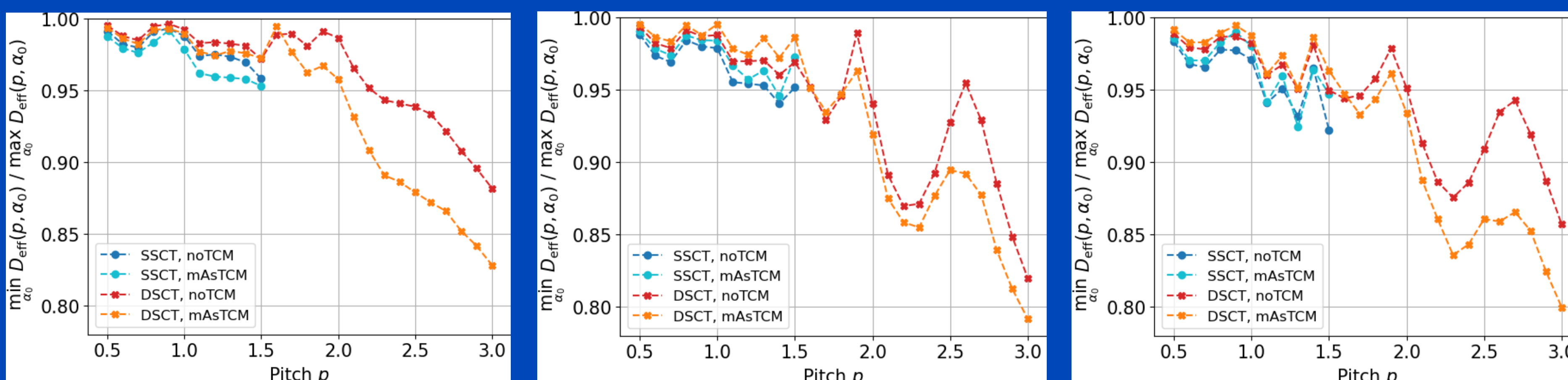
Relative Effective Dose of Best Start Angle Compared to Worst Start Angle

All Patients

Female Patients



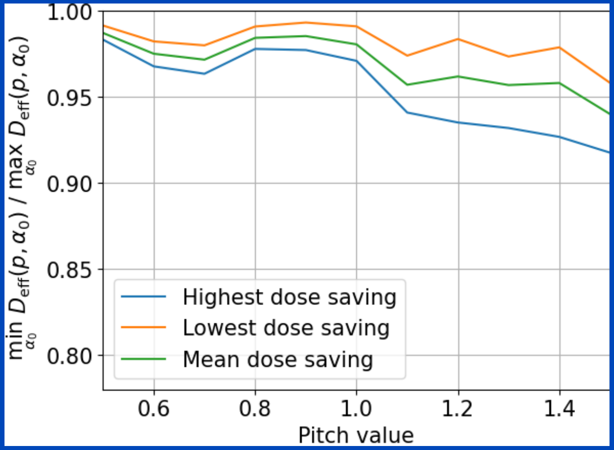
Male Patients



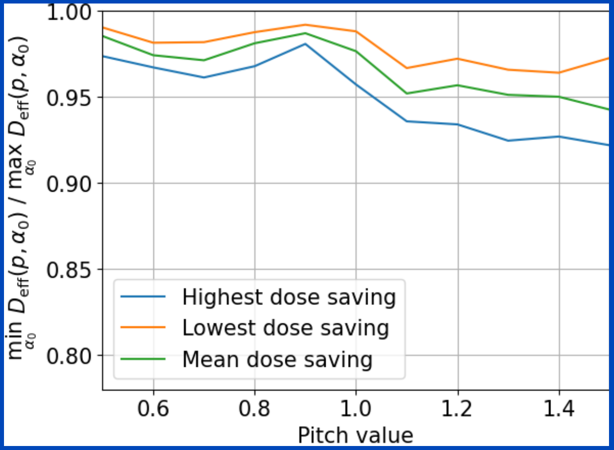
Relative Effective Dose of Best Start Angle Compared to Worst Start Angle

Summary over all Patients

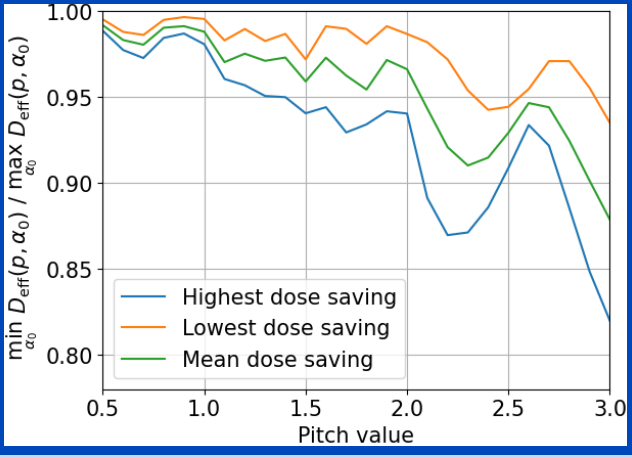
SSCT, noTCM



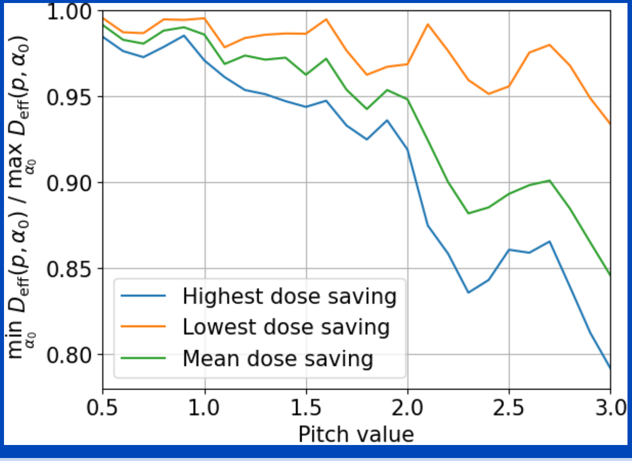
SSCT, mAsTCM



DSCT, noTCM



DSCT, mAsTCM



SUMMARY AND CONCLUSIONS

Summary

- Dose reductions for single organs are highly organ-specific.
- While the tube start angle affects the lung dose less than 5%, higher variations occur e.g. for the dose to the thyroid gland and the stomach.
- For the effective dose, dose reductions of up to 7% for SCCT and up to 20% for DSCT can be achieved in particular for high pitch values when selecting the optimal start angle for the simulated patients.

Discussion

- Selecting the optimal tube start angle should not affect image quality.
- Waiting for the optimal start angle might cause a delay of up to one rotation time of typically 0.25 s to 0.75 s.
- For contrast-enhanced scans and prospectively triggered cardiac CT, this time delay imposes a challenge.

Conclusions

- Variation of the start angle in spiral scans exhibit substantial differences in radiation dose for high pitch values.
- By selecting the optimal start angle, substantial dose reductions could be achieved.
- The translation to clinical scanners would require only software changes.
- Vendors should provide a method to automatically select the optimal scan start angle.

Thank You!

Job opportunities through marc.kachelriess@dkfz.de.

This study was supported by the Helmholtz International Graduate School for Cancer Research.
The Monte Carlo dose estimation method RayConstruct-MC was provided by RayConStruct® GmbH, Nürnberg, Germany.