Organ-Specific vs. Patient Risk-Specific Tube Current Modulation in Thorax CT Scans Covering the Female Breast

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Introduction

Tube current modulation (TCM) techniques, amongst other developments, are used in clinical CT to reduce dose administered to the patient while maintaining image quality or vice versa. Commonly used methods are, for example, mAs-minimizing TCMs (mAsTCM). Also, a variety of organ specific approaches (osTCM) exist. For this study, we use an implementation for the osTCM curve that is similar to the X-Care algorithm (Siemens Healthineers) which reduces the mAs product to a certain reference value for 120° in front of the patient [1]. With that, dose delivery to the breast tissue is reduced. However, neither of these approaches minimizes the actual patient risk but rather simple physical quantities. The recently proposed riskTCM, in contrast, minimizes the risk in terms of effective dose D_{eff} by considering all dose-sensitive organs in its cost function.

This work aims at evaluating the dose reduction achievable with riskTCM in comparison to mAsTCM and osTCM. A special focus is laid on the evaluation of the dose delivered to the female breast as this is the organ accounted for by osTCM in thoracic CT scans.

Material and Methods

For the osTCM curves, we consider two cases. In the first case, the mAs in front of the patient is reduced to 25% ($\mathrm{osTCM}_{25\%}$), in the other case it is reduced to 0% ($\mathrm{osTCM}_{0\%}$) while keeping the total mAs-product constant.

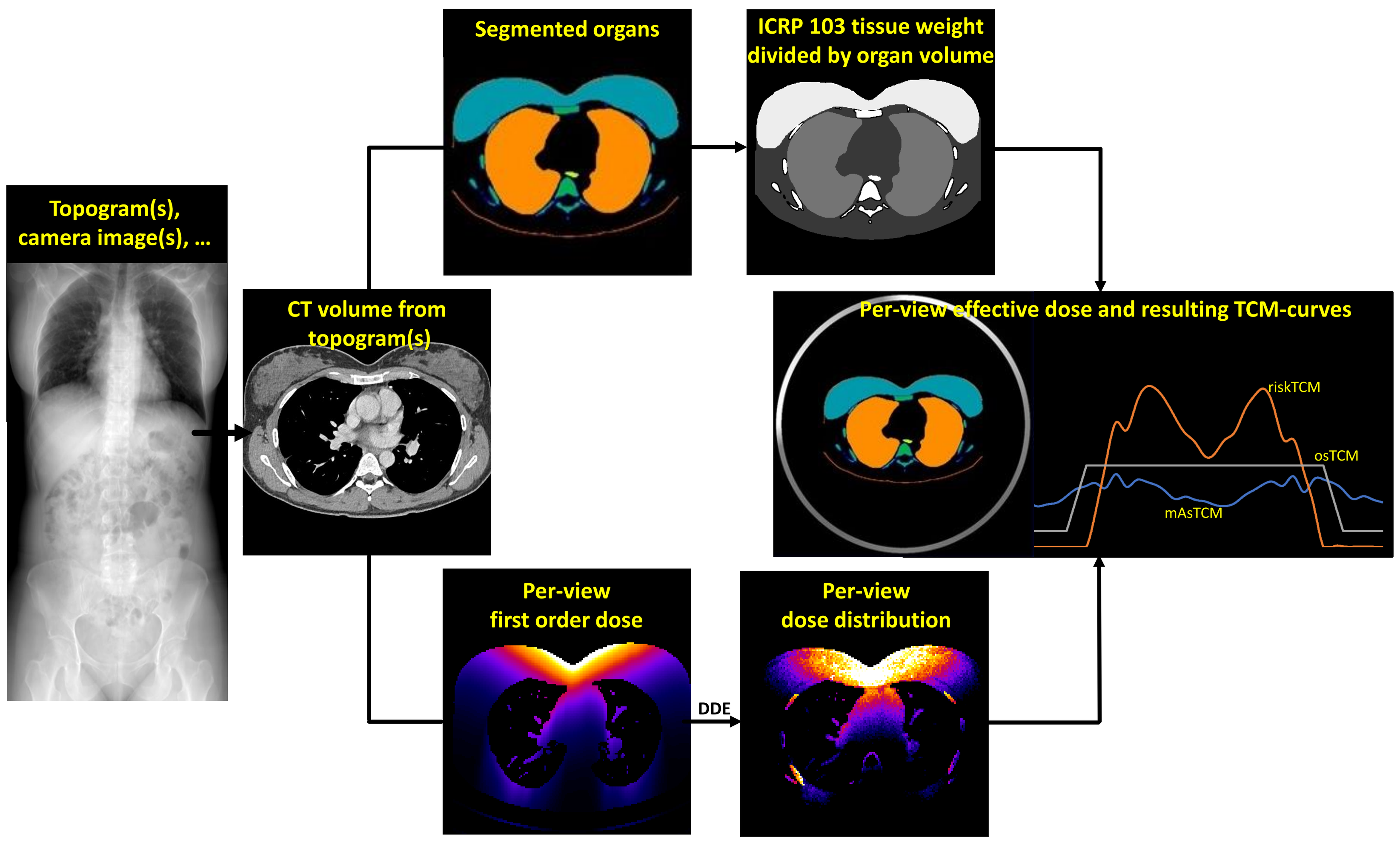


Figure 1: Sketch of the riskTCM workflow.

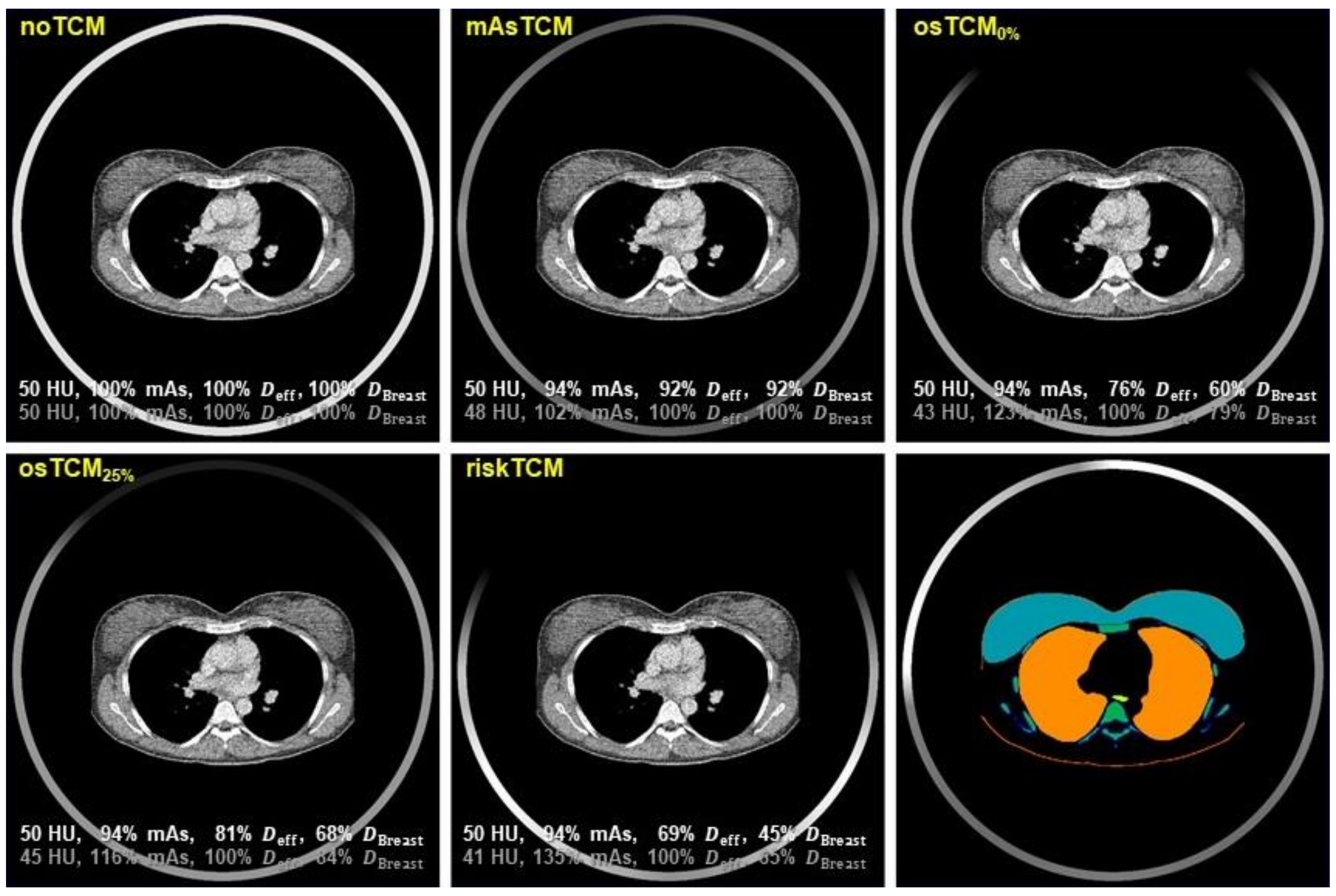
To calculate the riskTCM curve, the workflow shown in Figure 1 is followed [2]. An organ segmentation as well as the dose distribution per view α is required to compute $D_{\mathrm{eff}}(\alpha)$ [3]. The riskTCM algorithm also accounts for complementary rays resulting in different effective dose values. Then, the effective dose can be minimized. For the evaluation, the reconstructed volumes of seven CT scans are used. The tube current curves were scaled to either obtain the same image noise for all TCM algorithms or to obtain the same D_{eff} for all TCM approaches. This allows for an easy comparison of either the resulting effective dose values or the resulting image noise values.

Results and Discussion

The reduction of total effective dose is listed in Table 1 for three different regions, that is the thorax, abdomen, and pelvis. For a thorax exam, the effective dose value compared to the case of noTCM is 86% for mAsTCM, 82% for $\mathrm{osTCM}_{25\%}$, 79% for $\mathrm{osTCM}_{0\%}$, and reduces down to 67% for riskTCM. The dose delivered to breast tissue reduces to about 93% for mAsTCM, 72% for $\mathrm{osTCM}_{25\%}$, 64% for $\mathrm{osTCM}_{0\%}$, and 45% for riskTCM compared to noTCM. In Figure 2, an example is shown for one representative slice of a patient. Similar dose reduction can be observed for other anatomical regions.

Table 1: Effective dose values for different anatomical regions and all investigated TCM techniques relative to noTCM averaged over all patients.

Region	mAsTCM	$\mathrm{osTCM}_{25\%}$	$\mathrm{osTCM}_{0\%}$	riskTCM
Thorax	86%	82%	79%	67%
Abdomen	92%	88%	87%	70%
Pelvis	74%	82%	78%	65%



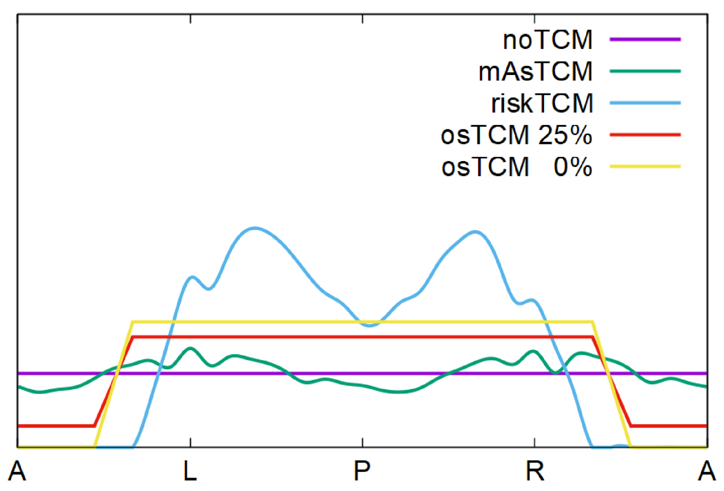


Figure 2: Top: noTCM, mAsTCM, $\mathrm{osTCM}_{0\%}$, $\mathrm{osTCM}_{25\%}$, and riskTCM images (*C/W*= 25/400 HU) as well as the segmentation image. The circular density plots show the TCM curves for the reconstructions and the effective dose D_{eff} for the segmentation image. Right: TCM curves $I(\alpha)$ as a function of angular position.

Conclusions

The risk-minimizing TCM evaluated in this work reduces the risk to a patient by minimizing the effective dose while maintaining image quality. The resulting effective dose reduction of riskTCM is up to 35% in comparison to mAsTCM and up to 30% compared to osTCM depending on the anatomical region and the patient's anatomy. The dose reduction to the breast tissue is the highest for riskTCM followed by osTCM. That is, riskTCM could potentially reduce the dose to the breast further compared to methods used clinically today and reduce the risk inherent to imaging modalities using ionizing radiation.

[1] Ketelsen, Buchgeister, Fenchel, et al. Automated Computed Tomography Dose-Saving Algorithm to Protect Radiosensitive Tissues. Invest Radiol 2021;47:148-152

[2] Klein, Kachelrieß et al. Patient-specific radiation risk-based tube current modulation for diagnostic CT. Med Phys. 2022;1-13.

[3] Chen, Zhong, Hu, et al. Automatic multi-organ segmentationin dual-energy CT (DECT) with dedicated 3D fully convolutional DECT networks. Med Phys. 2020;47:552-562