European Radiology (2019) 29:6790–6793
https://doi.org/10.1007/s00330-019-06330-5

PAEDIATRIC

How patient off-centering impacts organ dose and image noise in pediatric head and thoracoabdominal CT

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Received: 29 April 2019 / Revised: 3 June 2019 / Accepted: 13 June 2019 / Published online: 5 July 2019
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Abstract

Objectives To assess the impact of patient off-centering on organ dose and image noise for head and thoracoabdominal CT in a pediatric phantom.

Methods An anthropomorphic phantom simulating a 5-year-old child was used. Semiconductor dosimeters were placed in various cranial and thoracoabdominal organs. Head and thoracoabdominal CT were performed using automatic tube current modulation (ATCM) and default bowtie filters. The phantom was imaged repeatedly at vertical table positions ranging from − 6 to + 6 cm from the 0-position. Tube current time products (TCTP), organ doses, and image noise were recorded. Scatter radiation was measured in the thyroid for head CT. The effect of ATCM and bowtie filters was assessed.

Results Depending on patient position, organ doses differed up to 22% for the supratentorial brain, 34% for the infratentorial brain, 19% for the eyes, 28% for the lungs, 25% for the stomach, and 22% for the liver compared with those in the 0-position. The relation between position and dose was linear and mainly affected by the bowtie filter in head CT, while it was quadratic and affected by ATCM and bowtie filter in thoracoabdominal CT. It further depended on the relative position of each organ to the isocenter. An inverse relation was found between position and image noise. Scatter radiation was not significantly related to patient positioning ($p = 0.21$).

Conclusions In pediatric CT, vertical patient positioning had a substantial impact on radiation dose with differences of up to 34%, depending on the body region and location of each individual organ.

Key Points

- *Patient off-centering has a substantial impact on organ radiation dose and image noise in pediatric CT.*
- *Impact of patient off-centering on radiation dose and noise differs between head and thoracoabdominal CT.*
- *Differences are caused by both ATCM and bowtie filter in thoracoabdominal CT, but mainly by bowtie filter in head CT.*

Keywords Child · Multidetector computed tomography · Radiation exposure · Radiation dosimeters · Phantoms, imaging

Abbreviations

ATCM	Automatic tube current modulation
TCTP	Tube current time product

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s00330-019-06330-5) contains supplementary material, which is available to authorized users.

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Introduction

Patient off-centering in CT has been identified as a common problem in routine clinical practice, which has the potential to negatively impact radiation dose and image quality [1–3]. Proper vertical patient positioning is particularly important if automatic tube current modulation (ATCM) and bowtie filters are applied [4, 5]. However, there is a lack of knowledge in regard to the effect of patient off-centering in head and thoracoabdominal CT of pediatric patients.

The purpose of our study was to quantify the impact of patient positioning on organ radiation doses for head and thoracoabdominal CT in a phantom simulating a 5-year-old child.

Materials and methods

Phantom and scan setup

An anthropomorphic pediatric dosimetry phantom simulating a 5-year-old child was imaged separately using vendor-specific protocols for head CT and thoracoabdominal CT. Multiple dosimeters were placed in different organs for both body regions. A scout image was acquired in lateral orientation in head CT and in anteroposterior orientation in thoracoabdominal CT. Details on the CT scan protocols and dosimeter positions can be found in the Supplementary Material.

The phantom was manually centered and imaged repeatedly at multiple vertical off-center positions (from − 6 to + 6 cm compared with the 0-position). In head CT, the dosimeter at the thyroid was excluded from the scan range and served as a surrogate for scatter radiation.

Assessment of tube current modulation, image noise, and organ dose

The mean tube current time product (TCTP), image noise, and organ radiation doses were measured as a function of patient position. To estimate the effect of the bowtie filter alone, the measured organ doses were normalized to the mean TCTP and the measured image noises were normalized to the mean organ doses.

Statistical analysis

Regression analysis was applied to assess the relation between patient off-centering and organ dose. A linear regression model was fitted for head CT and a quadratic polynomial non-linear model for thoracoabdominal CT. Normality test of residuals for the non-linear regression was performed using the Shapiro-Wilk test.

Results

Details of the results of TCTP, image noise, and organ radiation dose as a function of patient off-centering are illustrated in the Supplementary Material.

Impact of patient position on ATCM

In head CT, we observed two ranges of approximately constant TCTP between − 6 and 0 cm and between + 2 and + 6 cm, with a stepwise increase in between (Fig. 1a). By reviewing the lateral scout images, we observed that parts of the table with higher attenuation were absent or only partly present in the scout image at lower table positions (− 6 cm to 0 cm) but fully present at higher table positions (+ 2 cm to + 6 cm) (Fig. 1d). The additional attenuating structures of the scanner table therefore increased the overall measured attenuation in the scout image which resulted in higher TCTPs.

Impact of patient position on organ dose and image noise

Organ doses differed up to 22% for the supratentorial brain, 34% for the infratentorial brain, 19% for the eyes, 28% for the lungs, 25% for the stomach, and 22% for the liver compared with those in the 0-position.

In head CT, regression analysis revealed that the radiation dose to the eyes decreased linearly and to the brain increased linearly with increasing table height (Fig. 1b). Scatter radiation (measured at the thyroid) did not show a significant dependency on patient position and demonstrated a maximum increase of 9.7% compared with that on the 0-position ($p = 0.21$). After normalizing the organ dose to the mean TCTP, the relation between organ doses and patient vertical position remained unchanged. The relation between image noise and patient position was approximately linear, but inverse to the relation found for organ dose. Depending on off-centering, image noise per mGy ranged from 0.12 to 0.23 HU/mGy for the supratentorial brain, 0.14 to 0.3 HU/mGy for the infratentorial brain, and 0.07 to 0.15 HU/mGy for the eyes.

In thoracoabdominal CT, regression analysis demonstrated an approximately quadratic relation of organ dose to patient position, with highest doses measured at the 0-position and decreasing doses with increasing off-centering to lower or higher positions (Fig. 1c). After normalization, the relative dose differences at different patient positions were more greatly affected compared with head CT. The relation between image noise and patient position was approximately quadratic but inverse to the relation found for organ dose. Depending on off-centering, image noise per mGy ranged from 2.2 to 3.4 HU/mGy for the thyroid, 2 to 3 HU/mGy for the right lung, 2 to 3.4 HU/mGy for the left lung, 2.4 to 4.4 HU/mGy for the stomach, and 2.4 to 4.1 HU/mGy for the liver.

Discussion

Our study indicates that in pediatric CT, ATCM, organ radiation doses, and image noise were substantially affected by vertical patient off-centering, with radiation dose differences of up to 34% compared with the 0-position. Our results extend the current body of literature for pediatric head and thoracoabdominal CT by the following main findings: (*i*) the impact of patient off-centering depends on the body region and location of each individual organ within the body; (*ii*) the differences in organ dose and image

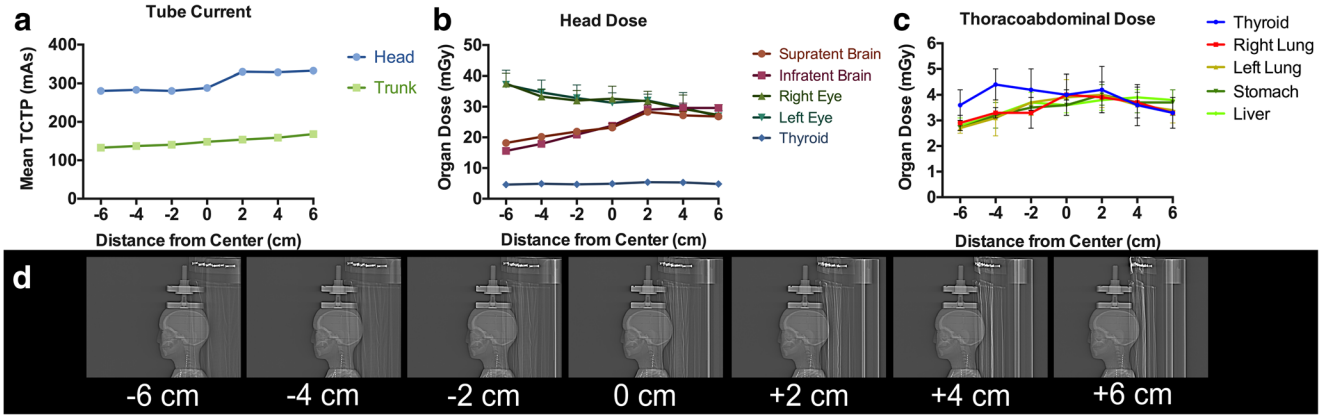

Fig. 1 Impact of patient off-centering on ATCM and organ radiation doses. **a** The mean TCTP as a function of patient off-centering. In thoracoabdominal CT, TCTP increased linearly with increasing table height. In head CT, two table height ranges demonstrated approximately constant TCTP (− 6 cm to 0 cm and + 2 cm to + 6 cm). **b**, **c** The linear relation between organ radiation doses and patient off-centering in head CT (**b**) and approximately quadratic relation in thoracoabdominal CT (**c**). Data is plotted as mean ± standard deviation. Scatter radiation, as indicated by the organ dose of the thyroid, did not show significant dependency on patient position. **d** The lateral scouts of head CT for each patient position. Higher attenuating structures of the table were absent or only partly present in scout images at lower table heights (− 6 cm to 0 cm) while they were fully present at higher table heights (+ 2 cm to + 6 cm). This additional attenuation increased the TCTP at higher table positions

noise are caused by both ATCM and bowtie filter in thoracoabdominal CT, but are mainly affected by the bowtie filter alone in head CT; (*iii*) scatter radiation to the thyroid is not significantly related to patient off-centering; and (*iv*) the CT table on lateral scout images can negatively impact dose modulation by ATCM.

Similar to previous studies, we found an overestimation of the patient size by ATCM if the phantom was off-centered in thoracoabdominal CT [4, 6, 7]. This is due to magnification effects in scout images that are acquired in posteroanterior or anteroposterior projection. In head CT, however, we did not expect a modulation of the TCTP by ATCM because of the lateral scout image, which should not be affected by magnification effects. Interestingly, we observed that the CT scanner table unintentionally increased the overall presumed attenuation of the patient, which triggered the ATCM to apply higher TCTPs. This finding emphasizes that the orientation of the scout image can have an unnecessarily strong influence on ATCM, eventually leading to increased radiation doses.

Interestingly, we found that the change in image noise per radiation dose unit (HU per mGy) depended on patient position and body region. We hypothesize that due to the changes in the thickness of the bowtie filter, the shape and quality of the x-ray spectra differed dependent on patient position. These differences in the x-ray spectra lead to altered absorption effects, ultimately affecting image noise.

Further discussion of our results, the impact of bowtie-filters in head and thoracoabdominal CT as well as the limitations of our study can be found in the Supplementary Material.

Conclusion

In conclusion, patient off-centering demonstrated substantial impact on organ radiation doses and image noise in pediatric head and thoracoabdominal CT with dose differences of up to 34%. The impact of ATCM and bowtie filter on dose and noise differed between the two body regions. CT scanner table can negatively impact dose modulation by ATCM if lateral scout images are acquired.

Funding The authors state that this work has not received any funding.

Compliance with ethical standards

Guarantor The scientific guarantor of this publication is André Euler.

Conflict of interest The authors of this manuscript declare no relationships with any companies, whose products or services may be related to the subject matter of the article.

Statistics and biometry One of the authors has significant statistical expertise.

Informed consent Not needed because of the design as a phantom study.

Ethical approval Institutional Review Board approval was not required because of the design as a phantom study.

Methodology
- prospective
- experimental
- performed at one institution

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