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Anja Stüssi*, Marta Bogowicz, Verena Weichselbaumer, Patrick Veit-Haibach, Oliver Riesterer, Matthias Guckenberger and Stephanie Tanadini-Lang

Optimizing a perfusion CT protocol for head and neck cancer

Abstract: Perfusion computed tomography (CTP) images tumor angiogenesis and can assess tumor aggressiveness. However, the CTP examinations are dose intensive. This study aimed to optimize a routinely used CTP protocol for the head and neck region in oncology in order to reduce the effective dose to the patient and simultaneously achieve the same image quality.

The Alderson phantom was scanned on a GE Revolution CT scanner. A scan with our standard protocol for head and neck cancer patients was used (100kV, 80mAs, 5mm slice thickness and backprojection algorithm) and in seven predefined regions (ROI) the signal to noise ratio (SNR) was measured. For the dose optimized protocol, the tube voltage was lowered and the mAs adaptation protocol was used. To improve image quality different percentage of an adaptive statistical iterative reconstruction (ASiR) was applied. For a better resolution we set the slice thickness to 2.5 mm. The mAs adaption range and the percentage of the ASiR reconstruction were varied until we found a combination with the same median SNR in the seven defined ROIs as for our old protocol. For the old and the optimized protocol dose measurements were performed using 25 LiF-TLDs. Organ doses were calculated and the effective dose was determined based on the weighting factors of ICRP103.

The optimized scanning protocol used a voltage of 80kV, a mAs range between 15 and 80, a noise level of 10%, and 50% ASiR reconstruction. The median SNR ratio was slightly better (14% better SNR) with the new protocol. An effective dose of 8 mSv was measured with the original protocol and 4 mSv with the optimized scanning protocol. For organs in the scanning field the dose was reduced by a factor of 2 and outside the field by a factor of 2.2.

Advanced reconstruction algorithms allow a significant dose reduction and an improvement of image resolution, while maintaining the image quality.

Keywords: Perfusion CT imaging, head and neck cancer, effective dose

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*Corresponding author: Anja Stüssi[#]: Department of Radiation Oncology, University Hospital Zurich, Rämistrasse 100, 8091 Zurich, Switzerland, e-mail: anja.stuessi@usz.ch
Marta Bogowicz[#], Oliver Riesterer, Matthias Guckenberger, Stephanie Tanadini-Lang: Department of Radiation Oncology, University Hospital Zurich, Rämistrasse 100, 8091 Zurich, Switzerland
Verena Weichselbaumer, Patrick Veit-Haibach: Department of Nuclear Medicine, University Hospital Zurich, Rämistrasse 100, 8091 Zurich, Switzerland
[#]AS and MB contributed equally

1 Introduction

Perfusion computed tomography (CTP) is a non invasive functional imaging technique to assess the tissue blood circulation, which is associated with tumor angiogenesis. In head and neck tumors CTP imaging has been shown to be a promising tool for treatment prognosis, differentiation of different tumor histologies and differentiation between malignant and benign tumors. [1-4]

The number of CT examinations is continuously increasing, and the average lifetime cancer risk due to medical radiation exposure has been estimated to be as high as 2% [5]. It might be even higher for patients receiving CTP, which consists of repetitive CT scans. Therefore, dose reduction is an important topic, especially for patients with benign tumors and long term survivors.

The current CT technology implements several dose reduction methods, such as automated tube current modulation and iterative reconstruction. These methods have successfully been applied to conventional CT imaging [6] as well as for CTP imaging in the brain region [7]. However their potential to reduce dose for CTP imaging of head and neck cancer has not yet been investigated.

This study was performed to optimize a routinely used CTP protocol for the head and neck region in order to reduce the effective dose to the patient and simultaneously achieve an equal image quality. New iterative reconstruction technology and automated tube current modulation were evaluated for dose reduction. The effective dose was estimated based on TLD measurements.

2 Materials and methods

2.1 Scanning protocols and dose optimization

A routinely used protocol suggested by the vendor (Protocol R) was the starting point for our dose optimization process (see **Table 1**). For dose reduction the tube voltage was lowered from 100 to 80 kVp. The milliampere-second (mAs) was adapted based on the attenuation of the body region that was analysed in the scout. The level of adaptation depends on the set noise index, i.e. image noise which influences image quality. We set the noise index to 10%, which was a comparable noise to the images from Protocol R. Such a dose reduction results in a worse image quality. To compensate for that an adaptive statistical iterative reconstruction algorithm (ASiR), provided from GE, was applied. The percentage of ASiR was varied until an optimal setting was found. Additionally, for a better resolution we set the slice thickness to 2.5 mm.

2.2 Image quality measurements

To compare the image quality we measured the signal to noise ratio (SNR) in seven predefined regions (ROI 1-7). The images were registered in the MIMVISTA (MIM Software Inc., Cleveland, OH, USA), which is a registration and contouring tool. The ROIs were drawn as circles of 2 cm diameter, equally distributed over the head and neck region. The ROIs were propagated from CTP of Protocol R to CTP of Protocol O (see **Figure 1**).

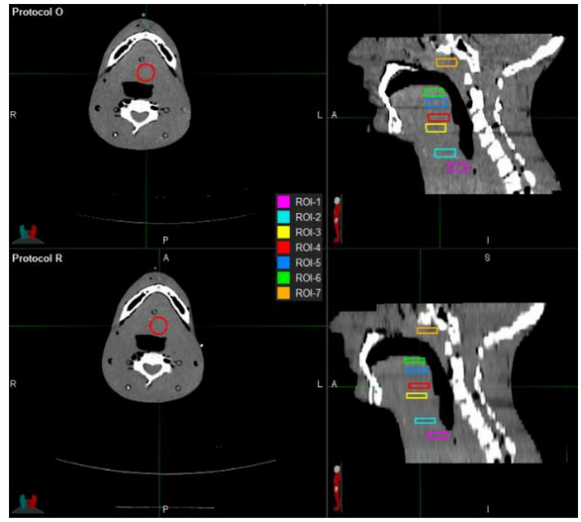

Figure 1: Location of 7 regions of interest (ROI) that were used to evaluate the image quality in the two CTP of protocols: R - routine and O - optimized.

2.3 Dose measurements and effective dose calculation

A tissue equivalent anthropomorphic phantom (Alderson Rando Phantom, Radiology Support Devices, CA, USA) was scanned on a GE Revolution CT scanner (GE Healthcare Technologies, Waukesha, Wisconsin, USA) with both protocols (Protocol R and Protocol O). Dose measurements were performed with LiF-TLD. For each scan, 25 TLDs were distributed over the multiple slices of the phantom inside and outside the scanning field (see **Figure 2**). The allocation of the TLDs was chosen to measure the corresponding organ doses necessary for the effective dose calculation. Additionally, the dose to the eye lenses, a radiation sensitive organ in the scanning field, was measured. The dose to organs in the scanning field was measured using two TLDs, whereas the dose to organs outside of the field was measured with a single TLD. Moreover, for organs located partially in the scanning field (i.e. for brain, oesophagus, skin, bone), the final dose was a result of a weighted average from corresponding TLDs placed in and out of the field.

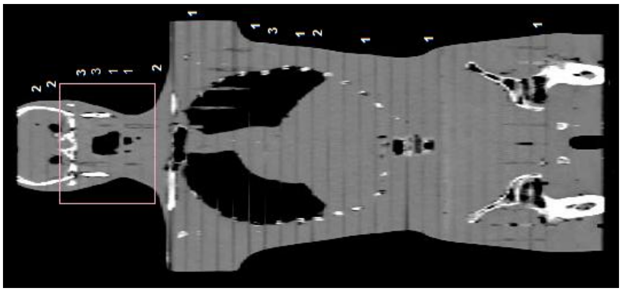

Figure 2: Alderson Phantom with TLDs in the corresponding slice (25 TLDs in total). The red rectangle marks the scanning field with a size of 16 cm.

In the effective dose calculation the weighting factors given by ICRP103 [8] were applied. The fraction of bone marrow distribution inside and outside of the scanning region was estimated based on Cristy et al. [9].

Additionally, the TLD-based effective dose was compared with the effective dose based on the scanner estimation of $CTDI_{vol}$. Dose length product (DLP) was calculated and the effective dose was estimated according to the AAPM 96 [10] using a conversion factor of 0.0031 (for adults for head and neck).

3 Results

The 50% of ASiR was found to provide as good image quality as the Protocol R and consecutively was used in the new optimized protocol (Protocol O) (see **Table 1**).

	Protocol R	Protocol O
scan length [cm]	16	16
number of scans	45	45
kV	100	80
mAs	80	----
mAs adaptation [mAs]	----	15-80
noise [%]	----	10
slice thickness [mm]	5	2.5
iterative recon ASiR [%]	0	50

Table 1: CTP parameters for the optimized scanning protocol (Protocol O) and the old in our clinic routinely used protocol (Protocol R).

The median SNR ratio (over all 7 segments) was slightly better (14% better SNR) with the new protocol (see **Figure 3**). ROI 1 shows the largest improvement with 2.5 times better SNR. The Wilcoxon rank sum test showed no significant difference between the two protocols (p>0.1).

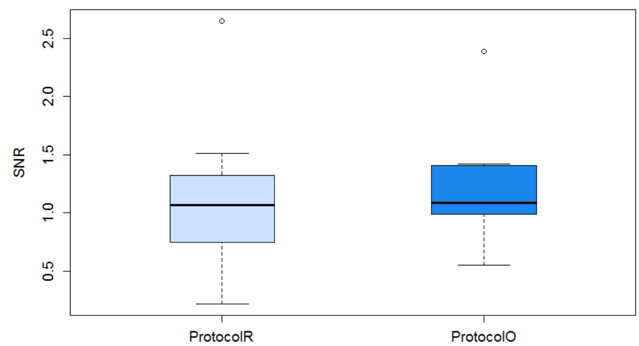

Figure 3: Boxplot of the SNR measurements for the ROI 1 – 7 for both protocols.

The measured organ doses, the effective dose based on the TLD measurements and based on the DLP are shown in **Figure 4** for both protocols (Protocol R, Protocol O). The effective dose decreased with the new protocol. For organs in the scanning field the median dose was reduced by a factor of 2 and outside the field by a factor of 2.2. Additionally, the dose to the eye lenses was reduced by a factor of 1.6. Based on TLD measurements, the Protocol R delivered 8 mSv, whereas the Protocol O delivered only 4 mSv. The effective dose calculated out of DLP was 9 mSv and 5 mSv for the protocol R and protocol O, respectively.

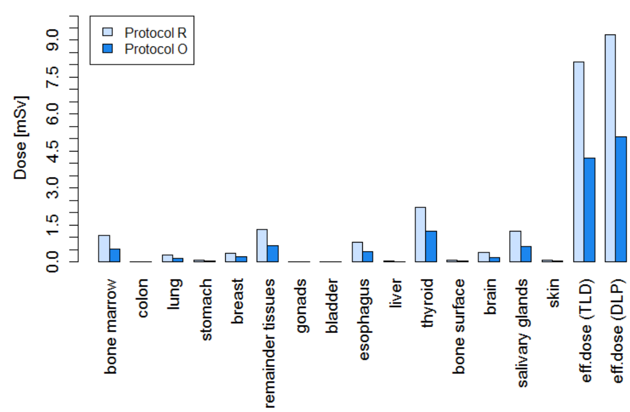

Figure 4: Organ doses, effective doses based on TLD measurements and based on the DLP calculation for protocol R and protocol O.

4 Discussion

In this study we showed that the decreased tube voltage and tube current in combination with iterative reconstruction allowed for an effective dose reduction by a factor of 2 and the preservation of the image quality in the CTP head and neck scan. Additionally, our new protocol improved the out-plane resolution by a factor of 2.

The organ dose comparison showed a dose reduction of 43% to 61% with the new protocol. This is in agreement with the study published by Niesten et al [7], which showed a 50% dose reduction for cerebral brain perfusion imaging. In our study, exceptions were colon and bladder, where the dose was equal. However, these organs were far off the scanning field and the delivered doses were minimal. Generally, for organs in the scanning field the median dose was reduced by a factor of 2 and outside field by a factor of 2.2.

The use of the iterative algorithm ASiR allowed not only the maintenance of image quality but also a slight improvement of the median SNR as well as an improvement in the out-plane resolution. The median SNR increased by 14% over all the analyzed ROIs. The slice thickness was reduced from 5 mm to 2.5 mm.

The effective dose to the patient was measured using TLD measurements and we additionally calculated the dose based on the DLP given by the scanner. The effective dose estimated from the DLP was slightly higher compared to our TLD measurements. This is in agreement with the study of Bauhs et al [11], who showed that CTDI overestimates the dose in perfusion CT imaging up to 50%, but contradicts studies on conventional CT, which often show that the DLP based method underestimates the effective dose [12]. The TLD measurements enabled us to give an organ specific estimation of the doses.

A limitation of the study is that we assumed an equal image quality in the phantom without contrast agent will result in a similar quality of the calculated perfusion parameters and that no perfusion parameters were calculated in the frame of this study.

5 Conclusion

Iterative reconstruction algorithms such as ASiR allow a significant dose reduction while maintaining the image quality. Therefore CTP protocols should be adapted if iterative reconstruction algorithms are available. The optimized scanning protocol used a voltage of 80kV, a mAs range between 15 and 80 with a noise level of 10%, and 50% ASiR reconstruction.

Author's Statement
Research funding: This study was supported by the Clinical Research Priority Program Tumor Oxygenation of the University of Zurich. Conflict of interest: Authors state no conflict of interest. Informed consent: Informed consent is not applicable. Ethical approval: The conducted research is not related to either human or animals use

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