RESEARCH ARTICLE

Reaching for better image quality and lower radiation dose in head and neck CT: advanced modeled and sinogram-affirmed iterative reconstruction in combination with tube voltage adaptation

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Objectives: The aim of this study was to evaluate image quality and radiation dose in low-dose head and neck CT comparing two different commercially available iterative reconstruction algorithms: sinogram-affirmed iterative reconstruction (SAFIRE) and advanced modeled iterative reconstruction (ADMIRE) with fixed and automated tube voltage adaptation (TVA).

Methods: CT examinations of 103 patients were analysed. 58 patients were examined on a single-source CT at fixed tube voltage of 120 kV and reconstructed with filtered back projection (FBP) and SAFIRE (Strength Level 3). 45 patients were examined in a single-source mode on a dual-source CT with automated TVA and reconstructed with FBP and ADMIRE (Strength Levels 2 and 3). Image noise was calculated in seven anatomical volumes of interest. Subjective evaluation of the CT images was performed using a four-grade scale.

Results: Mean CT numbers of FBP and the corresponding iterative reconstruction did not differ significantly ($p = 0.74\text{--}0.99$). Image noise was lower with both iterative reconstruction techniques than with FBP (SAFIRE 3: -22.3% ; ADMIRE 2: -14.9% ; ADMIRE 3: -24.2% ; all $p < 0.05$); hence, the signal-to-noise ratio and the contrast-to-noise values were higher. Subjective image quality revealed a more favourable result for the iterative reconstruction. ADMIRE 3 in combination with automated TVA showed 14.4% ($p < 0.05$) less image noise with a 7.5% lower radiation dose than SAFIRE 3 with fixed tube voltage.

Conclusions: Higher image quality at lower radiation dose can be achieved using ADMIRE in combination with automated TVA.

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Keywords: computed tomography; head and neck; image quality enhancement; radiation dose; iterative reconstruction

Introduction

Justification, optimization of protection and dose limitation are the three fundamental principles of the International Commission on Radiological Protection.¹

Obtaining improved image quality with a radiation dose “as low as reasonably achievable” is a hot topic in research and technical development in CT.² The number of CT examinations increased steadily in the past two decades. For certain indications, CT is preferable to MRI or ultrasound imaging, although associated with radiation exposure and possible risks for the patient.^{3,4} The individual risk of one single imaging examination is

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very small, but repeated procedures can lead to a high lifetime exposure. The lifetime cancer risk for CT usage has been estimated to be as high as 1.5–2.0%,⁵ although this topic remains highly controversial.⁶ For some tumours, significant radiation dose–response relationships were found, *e.g.* breast cancer.³ X-ray-induced DNA damage such as an increase of double-strand breaks caused by radiation exposure can directly be measured in *in vitro* and *in vivo* experiments.⁷ Dose awareness and individualized CT protocols must be considered by the radiological medical practitioner. Recent technical solutions such as iterative reconstruction contribute to lower image noise, better image quality and dose reduction strategies.^{8–11} A variety of iterative techniques has been launched by different scanner manufacturers.¹² Although the principle of lower image noise and better resolution is a feature of all these techniques, there are major algorithmic differences and different parameter settings, which influence the results. Iterative reconstruction techniques in CT have been applied in a large variety of indications and body regions.^{13–18} Furthermore, tube potential (kV) adjustments such as automated tube voltage adaptation (TVA) can contribute in combination with attenuation-based tube current adaptation to better image results and dose optimization, especially when combined with iterative techniques.^{16,19,20} In our study, we performed a clinical comparison of two groups in head and neck CT: the first with sinogram-affirmed iterative reconstruction (SAFIRE) at a fixed tube voltage and the second with advanced modeled iterative reconstruction (ADMIRE) in combination with automated kV selection.

The objectives of this study were to evaluate image noise, diagnostic quality and radiation dose of the two protocols.

Methods and materials

Patient examination

103 patients with indication for contrast-enhanced CT of the head and neck performed within 11 months were included. Written informed consent was obtained from all patients. Tumour staging was the predominant indication for imaging. Two groups were evaluated: 58 patients were examined on a 128-slice single-source CT (Somatom[®] Definition AS+; Siemens Healthcare, Forchheim, Germany) with automated exposure control at a fixed tube voltage of 120 kV and 116 quality reference mAs with automated mAs modulation (CARE Dose 4D[®]; Siemens Healthcare, Erlangen, Germany); 45 patients were examined using attenuation-based kV selection, automated TVA (range 80–120 kV, 10-kV steps) with automated mAs adaptation [CARE kV[®] (Siemens Healthcare) and CARE Dose 4D] and 116 quality reference mAs at 120 reference kV on a third-generation 192-slice dual-source CT (Somatom Force; Siemens Healthcare, Forchheim, Germany), operated in single-source mode.

Table 1 Patient characteristics

Group	1	2
n (patients)	58	45
Age (years, av $\pm$ SD)	57.8 $\pm$ 15.5	58.5 $\pm$ 11.6
Sex		
Female	22	19
Male	36	26
Indication (n)		
Tumour staging	28	25
Tumour follow-up	13	15
Abscess	9	2
Osteonecrosis	4	2
Others	4	1

av, average; SD, standard deviation.

Patient characteristics and scan parameters are given in [Tables 1](#) and [2](#).

Data reconstruction

Image reconstruction parameters were as follows: slice-thickness was 0.75 mm, slice increment was 0.5 mm, a soft-tissue convolution kernel (B31) was used with filtered back projection (FBP), the corresponding convolution kernel (I31) with SAFIRE, Strength Level 3 (Group 1). The corresponding soft-tissue convolution kernel for the dual-source CT system was Br40 for FBP and ADMIRE, Strength Levels 2 and 3 (Group 2). Briefly, the SAFIRE algorithm uses two reconstruction loops, the first iteration loop in raw data domain contributes to reduce image artefacts (*e.g.* cone beam artefacts) and the second in the image domain contributes to reduce image noise.²¹ ADMIRE uses, in comparison to SAFIRE, additional processing steps with larger anatomical neighbourhood data to analyse image information and noise with multiple forward and backward reconstructions. Higher strength levels of the iterative reconstruction correlate with a higher noise reduction.²²

Image analyses

The images were evaluated in random distribution. The two corresponding image data sets—on the one side, FBP, and on the other side, the iterative reconstructions—were displayed with a pre-set soft-tissue window (width 400 HU; centre 50 HU), which could be manually adapted on a three-dimensional post-processing workstation (iNtuition[®]; TeraRecon, Foster City, CA).

Table 2 Scan parameters

Group	1	2
Tube voltage (kV)	120	93.3 $\pm$ 8.3
Tube current (ref. mAs)	116	116 at 120 kV
CTDI _{vol} (mGy)	8.63 $\pm$ 0.99	7.99 $\pm$ 1.50
DLP (mGy cm)	261.23 $\pm$ 37.68	254.42 $\pm$ 57.90

CTDI_{vol}, volume CT dose index; DLP, dose–length product; ref. mAs, reference milliamper second.

CTDI_{vol} and DLP are both referenced to a 32-cm phantom in the patient protocol; tube voltage in Group 2: 80 kV (*n* = 4), 90 kV (*n* = 26), 100 kV (*n* = 13) and 120 kV (*n* = 2).

Anatomical volumes of interest (VOIs) were defined within the jugular vein (avoiding the vessel wall), the superficial part of the masseter muscle, the subcutaneous fatty tissue of the cheeks, the palatine tonsils, the submandibular gland, the spinal canal (homogeneous area within the spinal canal, avoiding bone artefacts of the vertebral body) and the pathological lesion (tumour tissue, necrosis or abscess, if existing) and were transferred by copy-and-paste to ensure identical measurement locations. The VOIs had a spherical volume and were defined manually as large as possible, whereas inhomogeneous areas, *e.g.* caused by plaques, small vessels or artefacts (motion, dental hardware) were avoided as far as possible. In all VOIs, the mean CT values (in Hounsfield units) and its standard deviation were determined. The standard deviation of the CT values was used as a measure of image noise. The signal-to-noise ratio [SNR, Equation (1)] and the contrast-to-noise ratio [CNR, Equation (2)] were calculated. The CNR was analysed for the jugular veins, masseter muscles and fatty tissue.

$$\text{SNR} = \frac{\text{mean CT value}(x)}{\text{SD}(x)} \quad (1)$$

$$\text{CNR} = \frac{\text{mean CT value}(x) - \text{mean CT value}(y)}{\text{SD}(\text{Fat})} \quad (2)$$

According to the European Guidelines on Quality Criteria in CT,²³ a subjective evaluation of image quality was performed by two examiners (senior radiologist with more than 15 years' experience and dentist in medical training for maxillofacial surgery with 4 years' experience in head and neck imaging). Image noise, definition of small anatomical structures, image artefacts, detection and edge sharpness of pathologic findings if existing were graded on a four-point scale (1, inadequate; 2, poor; 3, good; and 4, excellent). The general image quality was evaluated on the basis of the subjective overall image noise and the spatial resolution comprising the detailed definition of small anatomical internal structures. Windmill, streak and truncation artefacts as well as coarse pixel appearance were assessed; artefacts caused by dental hardware were excluded. The detectability and edge sharpness of pathological findings, such as tumour, abscess, necrosis or pathological lymph nodes were evaluated.

Radiation dose evaluation

The volume CT dose index (CTDI_{vol}) was used to assess radiation dose. Radiation dose reduction in Group 2 was calculated by dividing CTDI_{vol} values of Group 2 by the CTDI_{vol} values of Group 1. We did not use the dose-length product for evaluation of the radiation dose because the volumes differed in the two groups.

Statistical analyses

Values are expressed as mean ($\pm$ standard deviation). Statistical analyses were performed with the software packages SigmaStat[®] and SigmaPlot[®] (Systat Software, San Jose, CA) and SPSS[®] v. 23 (IBM Corp., New York, NY; formerly SPSS Inc., Chicago, IL). Descriptive statistics was calculated, and normality was tested using the Kolmogorov–Smirnov test. If this test was passed, a *t*-test was performed; otherwise, a Mann–Whitney *U* test was performed. $p < 0.05$ was supposed to be a statistically significant difference. Interobserver agreement was calculated using Cohen's weighted kappa.

Ethical standards and patient consent

All human studies have been approved by the institutional review board of the University of Erlangen-Nuremberg and have been performed in accordance with the ethical standards (1964 Declaration of Helsinki and its revisions). All patients gave informed consent prior to inclusion in this study.

Results

Objective image quality

The CT values of the FBP and the different corresponding iterative reconstruction techniques and settings were similar (FBP–SAFIRE, $p = 0.80$ – 0.99 ; FBP–ADMIRE, $p = 0.74$ – 0.99 ; ADMIRE 2–ADMIRE 3, $p = 0.76$ – 1.00).

Comparing images of Group 1 (fixed kV setting at 120 kV) and Group 2 (adjusted kV setting), we found higher CT values in Group 2 (FBP Group 1–FBP Group 2, $p = 0.002$; SAFIRE 3–ADMIRE 3, $p < 0.001$), particularly in the VOIs of the jugular vein and the submandibular gland.

Image noise was 12.3% lower in Group 2 using FBP (FBP 1–FBP 2, $p < 0.05$). Image noise in Group 1 was 22.3% lower with SAFIRE 3 than with FBP ($p < 0.001$), whereas image noise in Group 2 was 14.9% lower with ADMIRE 2 ($p < 0.05$) and 24.2% lower with ADMIRE 3 ($p < 0.05$) than with FBP. Image noise in Group 2 with ADMIRE 3 and automated TVA was 14.4% lower than in Group 1 with SAFIRE 3 and fixed tube voltage ($p = 0.004$).

The SNR and CNR values of Group 2 were consistently higher than Group 1 using FBP (FBP 1–FBP 2: SNR + 44.4%, $p < 0.001$; CNR + 31.7%, $p < 0.001$). The SNR and CNR increased accordingly with iterative reconstruction (FBP 1–SAFIRE 3: SNR + 36.8%, $p < 0.001$; CNR + 36.6%, $p < 0.001$; FBP 2–ADMIRE 2: SNR + 19.4%, $p = 0.01$; CNR + 17.7%, $p = 0.051$; FBP 2–ADMIRE 3: SNR + 41.7%, $p < 0.001$; CNR + 34.6%, $p < 0.001$; ADMIRE 2–ADMIRE 3, SNR + 18.7%, $p = 0.013$; CNR + 14.3%, $p = 0.1$; SAFIRE 3–ADMIRE 3: SNR + 49.6%, $p < 0.001$; CNR + 29.6%, $p < 0.001$).

A detailed overview of the objective image quality results is given in Table 3.

Table 3 Objective image quality

Group	1				2			
		CT value (HU)	Image noise (HU)	SNR		CT value (HU)	Image noise (HU)	SNR
Jugular vein	FBP	166.8	13.6	12.9	FBP	234.1	10.9	22.6
	SAFIRE	166.8	9.4 ^a	18.6 ^a	ADMIRE 2	234.8	9.1 ^a	27.4
Masseter muscle	FBP	77.4	16.3	4.9	ADMIRE 3	234.8	8.1 ^a	30.8 ^b
	SAFIRE	77.3	11.8 ^a	6.9 ^a	FBP	90.5	16.2	5.8
Fat	FBP	−95.8	15.6	−6.4	ADMIRE 2	90.4	13.7 ^b	6.9 ^b
	SAFIRE	−92.5	11.5 ^a	−8.7 ^a	ADMIRE 3	90.8	12.3 ^a	7.7 ^a
Tonsils	FBP	74.8	21.1	3.7	FBP	−106.5	15.4	−7.3
	SAFIRE	74.8	16.9 ^a	4.8 ^a	ADMIRE 2	−99.4	12.8 ^b	−8.1 ^b
Submandibular gland	FBP	92.1	17.6	5.7	ADMIRE 3	−98.7	11.1 ^a	−9.2 ^a
	SAFIRE	91.7	13.6 ^a	7.6 ^b	FBP	101.4	20.2	5.3
Spinal canal	FBP	47.0	17.9	3.0	ADMIRE 2	101.7	17.7	6.1 ^b
	SAFIRE	46.7	15.3 ^a	4.0 ^a	ADMIRE 3	101.4	16.1 ^b	6.7 ^b
Tumour	FBP	71.2	22.7	3.3	FBP	138.3	15.4	9.2
	SAFIRE	71.3	19.1 ^b	4.1	ADMIRE 2	138.6	13.3 ^b	10.7 ^b
Jugular vein–fat	FBP	17.8			ADMIRE 3	139.2	11.4 ^a	12.5 ^a
	SAFIRE	24.6 ^a			FBP	42.7	13.5	3.4
Masseter muscle–fat	FBP	11.6			ADMIRE 2	42.1	11.3 ^b	4.0 ^b
	SAFIRE	15.9 ^a			ADMIRE 3	42.1	10.4 ^a	4.4 ^b
Jugular vein–masseter muscle	FBP	6.2			FBP	87.7	16.8	4.8
	SAFIRE	8.7 ^a			ADMIRE 2	86.6	14.6	5.7
					ADMIRE 3	84.3	14.5	6.2
						CNR		
					FBP	23.3		
					ADMIRE 2	27.5		
					ADMIRE 3	31.4 ^a		
					FBP	13.4		
					ADMIRE 2	15.5 ^b		
					ADMIRE 3	17.8 ^a		
					FBP	9.9		
					ADMIRE 2	12.0		
					ADMIRE 3	13.6 ^b		

ADMIRE, advanced modeled iterative reconstruction; CNR, contrast-to-noise ratio; FBP, filtered back projection; SAFIRE, sinogram-affirmed iterative reconstruction; SNR, signal-to-noise ratio; VOI, volume of interest.

Mean value is given for every VOI: jugular vein, masseter muscle, fat, tonsils, submandibular gland, spinal canal, tumour or other pathological structure. *p*-values of the iterative reconstruction for the statistical difference between the FBP and the respective iterative reconstruction (SAFIRE and ADMIRE) are >0.05.

^a*p* ≤ 0.001 denotes highly significant difference.

^b*p* ≤ 0.05 denotes significant difference.

Subjective image quality

The image texture in iteratively reconstructed images differed from the image texture of FBP images (Figures 1–3). Image quality was rated significantly higher with iterative reconstruction (SAFIRE, ADMIRE 2 and ADMIRE 3) images than with FBP images because of a lower noise level (*p* ≤ 0.001). Lower image noise of the iterative reconstructed images led to a more homogeneous appearance of the anatomical structures. The definition of small anatomical structures and the edge sharpness of pathologies was also rated superior with SAFIRE and ADMIRE. No significant differences were found for the definition of small anatomical structures and edge sharpness of pathologies between ADMIRE 2 and ADMIRE 3. There were no significant differences of the FBP and the SAFIRE or ADMIRE images regarding artefacts and lesion detection.

Comparing image quality of the FBP images in both groups, we found less image noise, a better definition of anatomical details and a better edge sharpness of pathologies in the second group (TVA), but lesion detection remained similar.

A detailed overview of the subjective image quality results is given in Table 4.

Interobserver agreement was substantial ($\kappa = 0.71$).

Radiation dose

Applying TVA, 120 kV was used in a minority of cases only, the average tube voltage was 93.3 ± 8.3 kV (80 kV: *n* = 4, 8.9%; 90 kV: *n* = 26, 57.8%; 100 kV: *n* = 13, 28.9%; 120 kV: *n* = 2, 4.4%). Although the reference setting of both protocols had identical parameters and CTDI_{vol} (7.8 mGy), the values for the actual CTDI_{vol} in the patient examinations were CTDI_{vol} = 8.63 ± 0.99 mGy in Group 1 and CTDI_{vol} = 7.99 ± 1.50 mGy in Group 2 (*p* = 0.011) (Table 2).

Discussion

In our study, we found that the highest image noise reduction was possible with ADMIRE 3 (−24.2% compared with FBP). The best subjective evaluation was achieved with ADMIRE 3 in comparison to

Figure 1 A 64-year-old female, squamous cell carcinoma infiltrating the right parotid and masticator space with peripheral contrast enhancement (white arrows), examined on a 128-slice single-source CT at fixed tube voltage of 120 kV. (a) Filtered back projection image with higher image noise. (b) Sinogram-affirmed iterative reconstruction 3 with more homogeneous appearance, clear definition and good edge sharpness of the tumour.

SAFIRE 3 and ADMIRE 2. Comparison of SAFIRE 3 at fixed tube voltage and ADMIRE 3 with TVA yielded 14.4% less image noise with better image quality at 7.5% lower radiation dose using ADMIRE 3. According to our knowledge, a comparison of the two different iterative techniques SAFIRE and ADMIRE in combination with fixed tube voltage and automated TVA in head and neck CT has not been reported in a clinical study yet.

Both SAFIRE and ADMIRE demonstrated a reduction of image noise without affecting the average CT values, hence higher SNR and CNR values resulted than with FBP. These general results agree well with the results of current literature about iterative reconstruction techniques. Because small anatomical structures with similar attenuation in the head and neck region and

lesions, such as tumor, lymph nodes or inflammatory lesions may not differ greatly in attenuation from the surrounding tissue, high spatial and contrast resolution as well as a low level of image noise are required.¹⁹ With conventional reconstruction techniques (FBP and three-dimensional adaptive filtering), lower image noise and higher radiation exposure are correlated. For many years, FBP has been the standard image reconstruction algorithm in CT because of relatively low computational demand and short reconstruction time. However, nowadays high-performance computers allow performing complex iterative reconstruction loops in a relatively short time and such algorithms are increasingly used in clinical routine.²⁴ Abundant data have been published to address noise reduction with iterative reconstruction and the potential to reduce dose for different organ systems

Figure 2 A 46-year-old male, extensive cervical lymph node metastases white arrows and hypopharyngeal squamous cell carcinoma (cT3) on the right side, examined on a 192-slice dual-source CT with automated tube voltage adaptation at 90 kV. (a) Filtered back projection image with some higher image noise. (b) Advanced modeled iterative reconstruction 2 with more homogeneous appearance, improved definition of the pathological structures.

Figure 3 An 80-year-old female, staging in marginal zone lymphoma, no pathology in the head and neck region, examined on a 192-slice dual-source CT with automated tube voltage adaptation at 90 kV. (a) Filtered back projection image with higher image noise as the reference standard. (b) Advanced modeled iterative reconstruction 2 (ADMIRE 2) and (c) ADMIRE 3 with the smoothest texture.

but only little data are available to demonstrate the real extent of dose reduction at identical image quality,^{25,26} an increase in accuracy²⁷ and differences between various iterative reconstruction algorithms.^{28,29}

Lower image noise levels of the iterative reconstruction enable to compensate the higher noise levels of lower tube voltage acquisition. Thus, iterative reconstruction techniques contribute to dose-saving strategies. Willemink et al²⁹ demonstrated in a chest phantom that dose reduction of 27–54% at similar image quality is possible with hybrid iterative reconstruction techniques and dose reduction of up to 80% with model-based iterative reconstruction techniques. This

corresponds to our findings. We received better objective and subjective image quality at lower radiation dose with the model-based iterative reconstruction (ADMIRE) than with SAFIRE.

In our study, image noise was 22.3% lower with SAFIRE 3, 14.9% and 24.2% lower with ADMIRE 2 and 3 than with FBP. Similar noise reduction (27% with ADMIRE 3; 63% with ADMIRE 5 compared with FBP; and 50% with ADMIRE 5 compared with ADMIRE 3) was reported previously.²² Five different iterative reconstruction techniques were evaluated on an anthropomorphic liver phantom by Jensen et al.²⁸ They reported that all iterative methods led to an image noise decrease in a range of 10–71% and an improved CNR, but only two of the five iterative algorithms (SAFIRE and Veo®, GE Healthcare, Waukesha, WI) improved lesion detection compared to FBP. Our subjective evaluation of image quality revealed improvements in image noise and the definition of small anatomical details, but only a slight non-significant improvement in lesion detection with the iterative reconstruction compared with FBP images. The non-significant improvement in lesion detection in our study may be explained by the fact that the scan protocols were not optimized for maximum dose reduction but the reference scan parameters were kept identical to our previously used standard protocol.

Comparing SAFIRE 3 and ADMIRE 3 in our study, we found a decrease of 14.4% of image noise with significantly higher SNR (+49.6%) and CNR (+29.6%) values. The advantages of combination of automated TVA and an iterative reconstruction technique were investigated and compared with automated TVA and FBP or fixed tube voltage and FBP in previous literature. Similar to our findings, studies of Scholtz et al^{16,20} (ADMIRE and automated TVA) and Song et al³⁰ (SAFIRE and automated TVA) also showed good image quality with reduced image

Table 4 Subjective image quality

Group		1	2
Image noise	FBP	2.1	FBP 2.3
	SAFIRE	2.9 ^a	ADMIRE 2 3.0 ^a ADMIRE 3 3.7 ^a
Definition small structures	FBP	2.5	FBP 2.9
	SAFIRE	2.9 ^b	ADMIRE 2 3.1 ADMIRE 3 3.1
Artefacts	FBP	2.7	FBP 2.6
	SAFIRE	2.8	ADMIRE 2 2.8 ADMIRE 3 3.0 ^b
Detection pathology	FBP	3.2	FBP 2.8
	SAFIRE	3.4	ADMIRE 2 2.9 ADMIRE 3 3.2
Edge sharpness pathology	FBP	2.6	FBP 2.8
	SAFIRE	3.0 ^b	ADMIRE 2 2.8 ADMIRE 3 3.0

ADMIRE, advanced modeled iterative reconstruction; FBP, filtered back projection; SAFIRE, sinogram-affirmed iterative reconstruction. Mean values of each quality grade (1, inadequate; 2, poor; 3, good; and 4, excellent) are given.

p-values of the iterative reconstruction for the statistical difference between the FBP and the respective iterative reconstruction (SAFIRE and ADMIRE) are >0.05.

^a*p* ≤ 0.001 denotes highly significant difference.

^b*p* ≤ 0.05 denotes significant difference.

noise and increased SNR and CNR, whereas reduced radiation dose. Using TVA, lower radiation dose at lower tube voltage is possible in most cases. In our study, we compared examinations with a fixed tube voltage of 120 kV (reference standard) with examinations with automated tube voltage and tube current adaptation. Although the average tube voltage in the second group was 93 kV, and 120 kV was applied only in a minority of patients ($n = 2$), image noise in the FBP images was 12.3% lower than that in the first group (reference group). This noise reduction of the FBP images in Group 2 is multifactorial. It is influenced for example by the CT scanner configuration and the TVA algorithm adapting the tube current. Because of the higher iodine enhancement at lower kV settings, the SNR and CNR increased significantly. As expected, tissues with high iodine uptake or rich vascularization had higher CT values in the lower kV group.

$CTDI_{vol}$ is proportional to the tube voltage to the power of 2.6 and therefore low-kV techniques have a strong effect in reducing radiation exposure.³¹ But there are various other factors besides kV influencing the radiation dose for the patient, e.g. the effective mAs, pre-filtration, scanner geometry, detector technology, and patient size.^{32,33} Several studies investigated low tube voltage CT of the neck and reported adequate image quality.^{34–37} Low tube voltage acquisitions induce a higher iodine contrast, but also lead to higher image noise because of lower photon energy.³⁸ Wichmann *et al*³⁴ compared 80 kV and 120 kV acquisitions of the neck and reported sufficient image quality and high sensitivity for the 80-kV scans with increased signal and improved contrast of pathological structures. Gnannt *et al*³⁵ also reported improved image quality at 70 kV in comparison to the 120-kV acquisition, but they noted degraded image quality in the lower third of the neck, especially the lower cervical spine in the 70-kV acquisition.

A study focusing on automated TVA in head and neck CT allowing 100 and 120 kV only, found a radiation dose reduction of 7–8% within 100-kV acquisition, although with an increase of image noise and lower SNR values at maintained image quality.¹⁹ Our study setup differed in this aspect because our protocols were designed to have identical $CTDI_{vol}$ values at the reference setting. Still, we had a dose reduction of 7.5% in

Group 2 but improved image quality and also improved SNR and CNR.

The higher tube capacity and the larger range of selectable kV values (in 10-kV steps) in Group 2 improve individual adaptation of the settings to the patient's anatomy.

Some limitations of our study should be mentioned. A systematic intraindividual comparison of the two reconstruction techniques (SAFIRE and ADMIRE) could not be performed because both algorithms were not available on the same scanner and scanning one patient twice just for the purpose of research is ethically unacceptable. Pathological findings varied in size, localization or texture in the two groups. This could potentially have influenced the results in the subjective evaluation of lesion detection or edge sharpness. With both SAFIRE and ADMIRE, different strength levels could be chosen, which correlate with the degree of noise reduction. We used SAFIRE at Level 3 and ADMIRE at Levels 2 and 3 only, as these are the settings that are routinely used at our institution and provide a balance between noise reduction and alteration of the visual aspect of the images.

Conclusions

Using ADMIRE in combination with automated TVA, it is possible to obtain higher image quality with lower image noise and high diagnostic resolution at a 7.5% lower radiation dose than using SAFIRE at fixed tube voltage of 120 kV. Superior results in noise reduction, SNR and CNR were obtained with ADMIRE, Strength Level 3, followed by ADMIRE 2 and SAFIRE 3 compared with the reference FBP images.

Conflicts of interest

The author Michael M Lell has received speaker honorarium from Bayer, Bracco, Guerbet and Siemens. The author Michael M Lell has received speaker honorarium from Bayer, Bracco, Guerbet and Siemens and research grants from Bayer and Siemens.

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