Low Kilovoltage CT of the Neck with 70 kVp: Comparison with a Standard Protocol

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BACKGROUND AND PURPOSE: CT protocols should aim for radiation doses being as low as reasonably achievable. The purpose of our study was to assess the image quality and radiation dose of neck CT at a tube potential of 70 kVp.

MATERIALS AND METHODS: Twenty patients (7 female, mean age 51.4 years, age range 19–81 years) underwent contrast-enhanced 64-section CT of the neck at 70 kVp (ATCM, effective tube current-time product 614 eff.mAs, range 467–713 eff.mAs). All 20 patients had a previous neck CT at 120 kVp on the same scanner. Two radiologists assessed image quality and artifacts in the upper, middle, and lower neck. Image noise and attenuation were measured, and the CNR was calculated. Effective radiation dose was calculated.

RESULTS: Interobserver agreement regarding image quality of soft tissue for 70-kVp and 120-kVp scans was good to excellent. At 70 kVp, soft tissues were of diagnostic image quality in all scans, whereas the lower cervical spine was not of diagnostic quality in 3 and 4 scans per both readers. No difference was found among 70-kVp and 120-kVp scans for soft tissue image quality in the upper neck, while image quality was significantly better in the middle at 70 kVp ($P < .05$) and better in the lower third at 120 kVp ($P < .05$). CNR was significantly higher at 70 kVp in all levels for both readers ($P < .001$). Effective radiation dose at 70 kVp was significantly lower (0.88 ± 0.2mSv) than at 120 kVp (1.33 ± 0.2mSv, $P < .001$).

CONCLUSIONS: CT of the cervical soft tissues at 70 kVp is feasible, provides diagnostic image quality with improved CNR, and reduces radiation dose by approximately 34% compared with a standard protocol at 120 kVp. In contrast, low kVp CT of the lower cervical spine suffers from compromised image quality.

ABBREVIATIONS: ATCM = automatic tube current modulation; BMI = body mass index; CNR = contrast-to-noise ratio; $CTDI_{vol}$ = volume computed tomography index; DLP = dose-length product; eGFR = estimated glomerular filtration rate; HU = Hounsfield Unit; ICC = intraclass correlation coefficient

The increase in the total number of CT studies performed over the past decades has raised concerns regarding the collective radiation burden to the general population.[1] The underlying reason is the assumed link between radiation dose levels associated with CT and the subsequent development of cancer.[2] In addition to reducing the total number of CT examinations to the lowest possible level, the radiation dose of each individual CT study should be kept as low as reasonably achievable.[3]

Radiation dose of multisection helical CT is determined by several scanning parameters, including the tube voltage, tube current, volume coverage, and pitch.[4] Any or all of these factors can be adapted and optimized to meet the needs of the type of CT study being performed.[5] One of the most widely used options for lowering the radiation dose in CT is ATCM, enabling the adjustment of the tube current in various planes (x-y and/or z) to the respective attenuation of the body region, aiming to maintain constant image quality.[4,6] In the neck region, several studies have shown radiation dose reduction of up to 34% when using ATCM.[7-9] Another approach for radiation dose reduction is lowering of the tube voltage from the standard 120 kVp to 100 kVp or 80 kVp, because the radiation dose roughly changes with the square of the tube voltage.[10] Lowering the tube voltage has the additional advantage of higher attenuation for iodinated contrast medium at lower x-ray tube voltages as a result of a greater photoelectric effect and decreased Compton scattering.[10] The downside of low tube voltage CT scanning, however, is the parallel increase in image noise, if the tube current-time product is not correspondingly increased.

Whereas ATCM is routinely used in daily practice for CT of many body regions, most CT examinations are nonetheless performed with a fixed tube potential of 120 kVp, irrespective of the body region and specific habitus of the patient, and so the potential option of lowering the tube voltage for radiation dose reduction is not leveraged. Very recently, a new x-ray tube for CT was developed that allows scanning with a tube voltage of 70 kVp. Although the main reason for the development of the 70-kVp-tube option was to achieve dose reduction for pediatric CT, it might also be well used in adult CT in body regions having relatively low attenuation levels. To our knowledge, no study so far has addressed the issue of low kV scanning for CT imaging of the neck, and, more specifically, no studies have assessed scanning at 70 kVp.

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The purpose of this study was to assess the feasibility, image quality, and radiation dose of low kilovoltage CT of the neck at a tube potential of 70 kVp. Our hypothesis was that a 70-kVp protocol would not be inferior to 120 kVp for imaging of the cervical soft tissues.

Materials and Methods

Patient Population

Between January and May 2011, 40 consecutive patients (23 male, 17 female, mean age 53.1 ± 15.7 years, age range 19–81 years) underwent a clinically indicated contrast-enhanced CT study of the neck at 70 kVp as part of a chest-abdominal CT study. Indications for neck, chest, and abdominal CT were known or suspected lymphoma (n = 25), carcinoma (n = 14), and tuberculosis (n = 1). No study was explicitly indicated for imaging of the cervical spine. General exclusion criteria for contrast-enhanced CT included impaired renal function (eGFR <30 mL/min), hypersensitivity to iodine-containing contrast media, and pregnancy. Twenty of these 40 patients (50%) had a previous CT study within 1 year, obtained with the same CT scanner at a fixed tube voltage of 120 kVp. Thus, the final study population included 20 patients (13 male, 7 female, mean age 51.4 ± 17.8 years, age range 19–81 years) who had CT studies at 2 different tube voltages for comparison.

The study had local institutional review board and ethics committee approval; written informed consent was waived because all studies were clinically indicated and were performed with a low-radiation-dose protocol.

CT Data Acquisition and Reconstruction

All CT scans were performed on a 64-section CT machine (Somatom Definition AS; Siemens Healthcare, Forchheim, Germany) equipped with the software package Somaris 7, VA40. This CT machine includes an x-ray tube, allowing for scanning with a potential of 70 kVp. In addition, its software package includes a newly developed algorithm (CarekV), which allows for the automated selection of the tube potential in each individual patient based on the attenuation of the scanned body region in the CT scanogram.[11] Early experience in our department showed that the software automatically selected a tube potential of 70 kVp in some patients for neck CT, yielding acceptable—that is, diagnostic—image quality. Thus, we initiated this study for systematically evaluating if this low tube potential would be feasible for neck CT in comparison with the standard protocol at 120 kVp.

After acquiring the contrast-enhanced thoracoabdominal CT scan following administration of 80 mL of nonionic iodinated contrast material (iopromidum, Ultravist 300, 300 mg iodine/mL; Bayer Schering Pharma, Berlin, Germany), an additional bolus of 40 mL contrast material, followed by 40 mL saline flush, was injected at a flow rate of 2.4 mL/s into an antecubital vein for contrast-enhanced neck CT with a scanning delay of 45 seconds. Contrast material injection protocols were identical for both 70-kVp and the previous 120-kVp scans. A craniocaudal scan direction was chosen.

Before scanning at 70 kVp, we selected our standard 120-kVp neck protocol (reference tube current-time product 165mAs with ATCM). We then manually switched the tube voltage to 70 kVp. The reference tube current-time product then automatically increased to an average of 738 mAs, with a mean effective tube current-time product of 576 mAs (range 440–669 eff. mAs with ATCM). The section acquisition was 64 × 0.6 mm using the z-flying focal spot, the gantry rotation time was 330 ms, and the pitch was 1.2.

The 20 previous neck CT scans were performed with the same 64-section CT machine at a fixed tube voltage of 120 kVp and using a reference tube current-time product of 165 mAs (mean effective tube current-time product 149 eff. mAs, range 130–178 eff. mAs wih ATCM).

All data were reconstructed with an axial section thickness of 2 mm, an increment of 1.7 mm, and a soft tissue convolution kernel (B30f; window width 450 HU, level 100 HU). Sagittal reconstructions of the cervical spine were performed directly from the raw data using a bone tissue convolution kernel (B50f; window width 2000 HU, level 500 HU). All data analysis was performed with the hospital PACS (Impax 5.3; Agfa, Moertel, Belgium).

Radiation Dose Estimations

For each CT scan, the $CTDI_{vol}$ and DLP were taken from the patient protocol, which summarizes all relevant dose information in each patient. The DLP represents the integrated radiation dose imparted by all sections of a CT examination.[12] The effective dose in mSv was estimated using a method proposed by the European Working Group for Guidelines on Quality Criteria in CT and was derived by multiplying the DLP with the region-specific conversion coefficient k (neck: 0.0059 $mSv*mGy^{-1}*cm^{-1}$).[13] The conversion coefficient is averaged between male and female models in Monte Carlo simulation. The effective dose is an estimate of the dose to patients during an ionizing radiation procedure and enables direct comparisons with other sources of radiation exposure by measuring the total amount of energy entering the body, and taking into account the different sensitivities of the irradiated organs.[14]

In addition, the scan length in the z-axis was extracted from the data to allow for meaningful comparisons of DLP and effective dose between the 2 follow-up CT scans.

CT Data Analysis

Diameter and Circumference Measurements. One radiologist not otherwise involved in the study readout measured the anteroposterior diameter and the circumference of the neck at the level of the right carotid bulb.

Image Quality. Two independent radiologists with 2 (reader 1 [R1]) and 3 years (reader 2 [R2]) of experience in imaging, respectively, assessed the overall image quality of the soft tissue and the cervical spine. The 2 readers were blinded to all clinical information, including patient names and scanning parameters.

All datasets were divided into 3 parts: 1) skull base to the hyoid bone, representing the upper third of the neck; 2) from the hyoid bone to the acromioclavicular joints, representing the middle third; and 3) from the acromioclavicular joints to the center of the humeral head, representing the lower third of the neck. Soft tissue image quality was assessed on the transverse CT images; image quality of the spine was assessed on the sagittal image data.

A 5-point scale was used by the readers for grading the overall image quality and artifacts as previously shown[7]: score 5 = excellent; score 4 = good; score 3 = acceptable, sufficient for diagnosis; score 2 = poor, diagnostic confidence significantly reduced; score 1 = very poor/nondiagnostic. For grading of artifacts, another 5-point scale was used by the same readers: score 5 = no perceivable artifacts; score 4 = minimal; score 3 = slight artifacts without interfering with diagnostic capability; score 2 = moderate, degrading diagnostic capability; score 1 = severe.

Factors compromising image quality, such as metallic or streak

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Table 1: Image quality and artifacts of the cervical soft tissues and bones at 70 kVp and 120 kVp

	70-kVp protocol (n = 20)		120-kVp protocol (n = 20)		P Value*	
	Reader 1	Reader 2	Reader 1	Reader 2	Reader 1	Reader 2
Image quality: soft tissue						
Overall	3.92 ± 1.05	3.85 ± 1.07	4.05 ± 0.77	3.86 ± 0.85	0.211	0.606
Upper third	3.20 ± 1.11	3.15 ± 1.09	3.45 ± 0.76	3.45 ± 0.76	0.135	0.055
Middle third	4.95 ± 0.22	4.95 ± 0.22	4.60 ± 0.50	4.40 ± 0.50	0.015	0.001
Lower third	3.60 ± 0.60	3.45 ± 0.60	4.00 ± 0.46	3.85 ± 0.49	0.017	0.008
Image quality: bone						
Overall	3.89 ± 1.18	3.51 ± 1.12	4.33 ± 0.70	4.19 ± 0.70	<0.001	<0.001
Upper third	4.35 ± 0.49	4.30 ± 0.47	4.42 ± 0.51	4.16 ± 0.68	0.578	0.414
Middle third	4.50 ± 0.51	4.45 ± 0.60	4.84 ± 0.38	4.68 ± 0.49	0.276	0.058
Lower third	2.75 ± 1.16	2.65 ± 1.16	3.74 ± 0.73	3.74 ± 0.65	<0.001	<0.001
Artifacts						
Soft tissue and spine	3.95 ± 1.04	3.70 ± 1.11	4.20 ± 0.82	4.03 ± 0.97	<0.001	<0.001
Upper third	3.15 ± 1.04	3.05 ± 1.00	3.55 ± 0.90	3.25 ± 1.03	0.509	0.09
Middle third	5.00 ± 0.00	5.00 ± 0.00	4.95 ± 0.23	5.00 ± 0.00	0.33	0.33
Lower third	3.55 ± 0.69	3.35 ± 0.49	4.10 ± 0.45	3.85 ± 0.49	0.002	0.042

* P values comparing 70-kVp and 120-kVp scans in the same 20 patients.

artifacts, were noted by the readers. Readers were instructed on the criteria of image grading on a test dataset not included in the study. The predefined settings of window level and width (see above) were not changed by the readers.

Noise, Attenuation, and Contrast-to-Noise. Image noise was defined as the standard deviation of attenuation measured in the air ventral to the cervical soft tissues in the 3 levels (circular region of interest, size 200 mm^2).

Attenuation measurements were performed by 2 other independent radiologists (with 5 years' experience in radiology each) to avoid any bias in data readout. These 2 readers were also blinded to all clinical information as well as to the patient names and scanning protocol. Attenuation was measured (in HU) in a circular region of interest in a vessel and in a muscle in the same 3 levels: internal right carotid artery and right masseter muscle (upper third), center of the right carotid bulb and in the middle part of the right sternocleidomastoid muscle (middle third), and right common carotid artery and in the lower part of the sternocleidomastoid muscle (lower third).

The vessel-to-muscle CNR was calculated as CNR = (region of interest_V-region of interest_M)/n, as previously shown.[15] Region of interest_V is the mean attenuation of the vessel, region of interest_M is the mean attenuation of the muscle, and n is noise.

Statistical Analysis

Continuous variables were reported as mean ± standard deviation (range) and categoric variables as frequencies or percentages. Cohen κ statistics were calculated for interobserver agreements of image quality of the soft tissue and the cervical spine, and for the artifact readouts. An excellent interobserver agreement was defined as a κ value of 0.81 or more; good, 0.61–0.80; moderate, 0.41–0.60; fair, 0.21–0.40; and poor, <0.20.

For image noise and attenuation, interreader agreement was assessed by calculating ICC coefficients. Agreement was substantial at an ICC value of 0.81–1.0, moderate at 0.61–0.80, fair at 0.41–0.60, slight at 0.11–0.40, and virtually none at 0.00–0.10.[16]

Radiation dose parameters and quantitative image parameters (noise, attenuation, ap-diameter, circumference measurement) of the 70-kVp and 120-kVp scans were tested for normal distribution with the Shapiro-Wilk *W* test. Normally distributed parameters were compared using the paired *t* test; nonparametric data were tested with the Wilcoxon signed rank test.

Statistical significance was inferred at a *P* value below .05. Statistical analysis was performed using SPSS (release 19.0 for Windows; SPSS, Chicago, Illinois).

Results

The mean BMI of the 40 patients was 24.1 ± 3.8 kg/m^2 (range 15.2–34.6 kg/m^2). There were no significant differences in BMI (P = .23), ap-diameter (P = .08), and neck circumference (P = .19) in the 20 patients between the 2 CT scans (1 at 120 kVp and 1 at 70 kVp).

Image Quality: Soft Tissue

Interobserver agreement regarding image quality of the cervical soft tissue (all 3 levels) was good, at 70 kVp (κ = 0.70), and excellent, at 120 kVp (κ = 0.86).

Details regarding the image quality readout are shown in Table 1. There was no significant difference regarding image quality comparing scans at 70 kVp and 120 kVp in the upper third of the neck for both readers. In the middle third, there was a slightly better image quality at 70 kVp compared with 120 kVp for both readers. In contrast, in the lower third of the neck there was a significantly better image quality at 120 kVp compared with 70 kVp for both readers. None of the datasets was judged as nondiagnostic (ie, score 1) regarding the cervical soft tissue (Fig 1).

Image Quality: Cervical Spine

Interobserver agreement regarding the overall image quality of the cervical spine was excellent, at 70 kVp (κ = 0.93), and good, at 120 kVp (κ = 0.67).

Image quality of the spine at the 3 anatomic levels was rated better in 120 kVp compared with 70 kVp scans by both readers. However, the difference did not reach significance in the upper and middle third of the cervical spine for both readers. In the lower neck, however, there was a clear statistically significant better image quality for patients scanned with 120 kVp compared with 70 kVp for both readers (Fig 2). Three

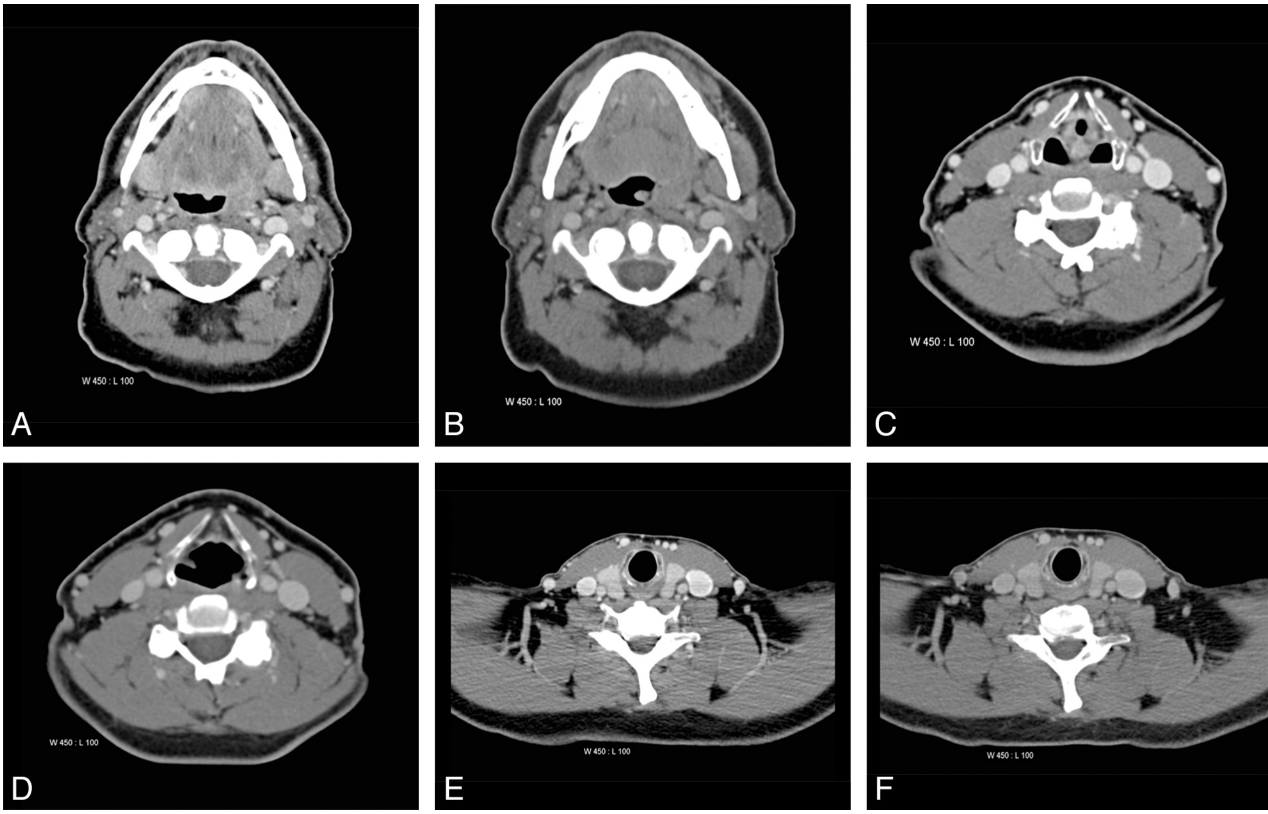

Fig 1. 37-year-old male patient with follow-up neck CT for lymphoma at 70 kVp (*A, C, E*) and corresponding previous CT at 120 kV (*B, D, F*) at 3 anatomical levels. Note the diagnostic image quality with a higher contrast-to-noise ratio of cervical soft tissues at 70 kVp at all levels.

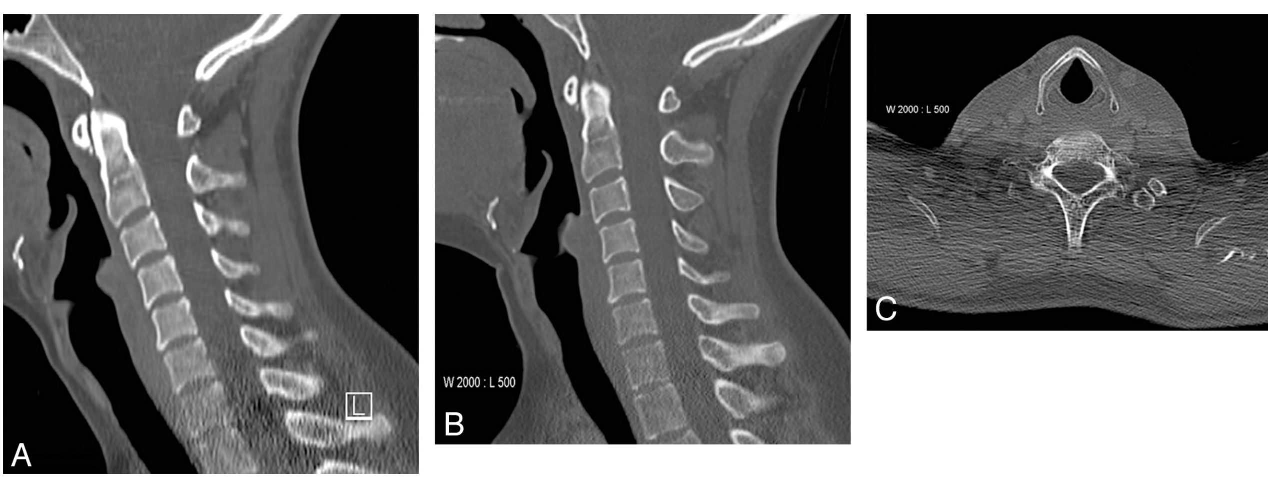

Fig 2. 42-year-old male patient with follow-up neck CT for lymphoma at 70 kVp (*A*) and corresponding previous CT at 120 kVp (*B*). Sagittal reconstructions of the cervical spine demonstrate more image noise in the lower spine at 70 kVp in comparison to 120 kVp. Corresponding axial images through the lower neck (level of C7) at 70 kVp (*C*).

of 20 (15%) 70-kVp datasets in the lower neck were judged as being of nondiagnostic image quality regarding the cervical spine by R1, and 4/20 (20%) by R2 (Table 1).

Artifacts

Interobserver agreement regarding image artifact readout (including all 3 levels) was fair at 70 kVp ($\kappa = 0.57$) and at 120 kVp ($\kappa = 0.60$).

Details regarding the artifact readout are shown in Table 1. There was no significant difference regarding artifacts comparing scans at 70 kVp and 120 kVp in the upper and middle third of the neck for both readers. In the lower third, there were significantly more artifacts at 70 kVp compared with 120 kVp for both readers.

Attenuation, Noise, and Contrast-to-Noise

Intraclass correlation between both readers regarding attenuation and image noise measurements was substantial at 70 kVp and 120 kVp (attenuation: ICC = 0.992, ICC = 0.998; noise: ICC = 0.86, ICC = 0.85). Because of the excellent interreader agreement, the mean from both readers was used for further analysis.

Attenuation in the muscle and vessel was significantly

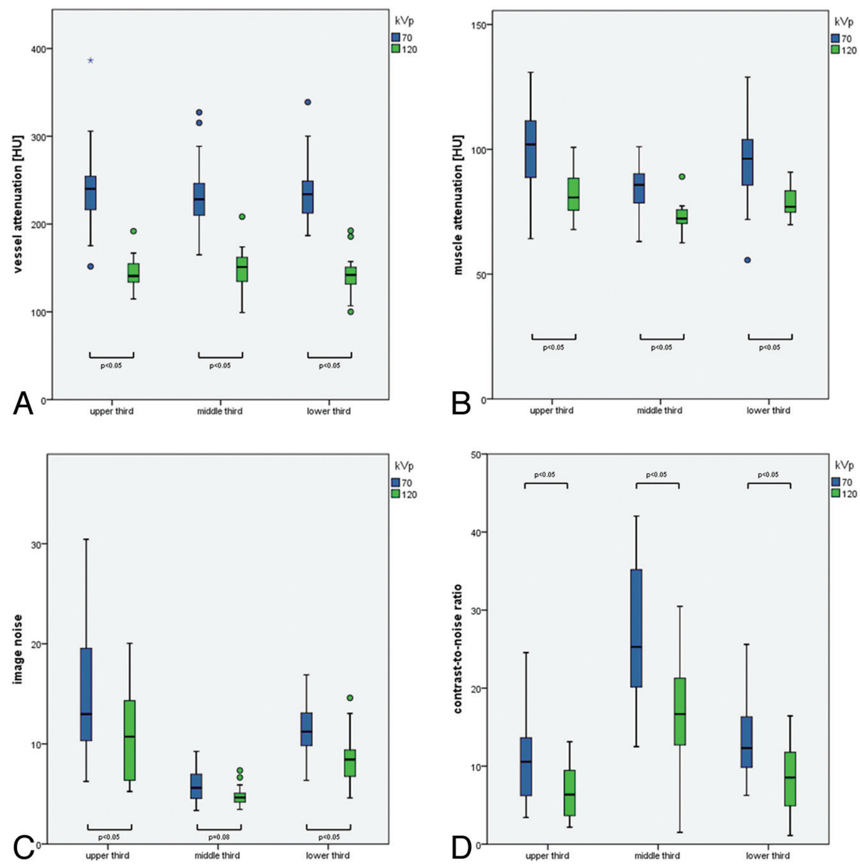

Fig 3. Measurements of cervical vessel (*A*) and muscle (*B*) attenuation, image noise (*C*), and the calculated contrast-to-noise ratio (*D*). Mean from both readers was taken for analysis.

higher at 70 kVp compared with 120 kVp at all 3 levels for both readers' measurements (all $P < .001$, Figs 3*A* and *B*).

In the upper third of the neck, there was significantly more image noise at 70 kVp compared with 120 kVp for both readers (R1, $P = .004$; R2, $P < .001$). In the middle third, there was no significant difference between 70 kVp and 120 kVp for both readers (R1, $P = .103$; R2, $P = .075$). At the lower neck, a significantly higher noise was found at 70 kVp compared with 120 kVp for both readers (R1, $P = .013$; R2, $P < .001$, Fig 3*C*).

The CNR was significantly higher at all 3 levels at 70 kVp compared with 120 kVp for both readers (all $P < .001$, Fig 3*D*).

Radiation Dose Estimates

Effective radiation dose at 70 kVp was significantly lower (0.88 ± 0.2 mSv) than that of 120 kVp (1.33 ± 0.2 mSv, $P < .001$), corresponding to a dose reduction by an average of 34%. There was no significant difference ($P = .74$) in scan length in the z-axis at 70 kVp and 120 kVp (Table 2).

Discussion

Our study assessed low kilovoltage CT scanning of the neck at 70 kVp compared with a standard dose of 120 kVp. Image quality of cervical soft tissues was of diagnostic image quality in all low-kV studies, whereas image quality of the lower cervical spine was not of diagnostic quality in up to 20% of the examinations scanned at 70 kVp. Moreover, the CNR in soft tissues was superior in all 3 levels of the neck, with the increase in attenuation exceeding the increase in image noise at low kVp. Most important, the 70-kVp protocol resulted in a 34% decrease in radiation dose compared with a standard protocol with 120-kVp settings.

Table 2: Comparison of $CTDI_{vol}$, DLP, scan length, and effective dose between 70-kVp and 120-kVp CT scans

	70 kVp (n = 20)	120 kVp (n = 20)	*P* Value*
$CTDI_{vol}$ (mGy)	7.27 ± 0.93	10.79 ± 0.86	<0.001
Scan length (cm)	18.32 ± 3.29	19.05 ± 1.88	0.74
DLP (mGy*cm)	144.23 ± 29.90	224.60 ± 35.15	<0.001
Eff dose (mSv)	0.85 ± 0.18	1.33 ± 0.21	<0.001

Note:—DLP is calculated by multiplying the $CTDI_{vol}$ by the scan length in the z-axis. Eff dose indicates effective radiation dose, calculated by multiplying the DLP by mSv*mGy-1*cm-1.[11]
**P* values comparing 70-kVp and 120-kVp scans.

In the past, CT systems allowed data acquisition with tube voltages ranging from 80–140 kVp. With the introduction of a new x-ray tube, voltages as low as 70 kVp can now be applied. What remains to be developed, however, is a technique that automatically modulates the tube voltage setting throughout the scan, similar to the technique of ATCM. When lowering the tube voltage, tube current typically has to be increased considerably to compensate for the increase in noise. Besides the reduction of radiation dose, lowering of the tube potential results in an increase in iodine signal intensity. Therefore, to maintain CNR (and hence image quality), higher noise levels requiring a more moderate increase in mAs levels are acceptable and still result in a substantial dose reduction.

There are only a few studies addressing the possibility of radiation dose reduction in CT scans of the neck soft tissues, all of which used ATCM.[7-9] By automatically maintaining the objective noise level in the z-axis at the same level, authors reported a dose reduction up to 34% compared with protocols using a fixed tube current; in addition, the tube voltage was kept constant at 120 kV in all these studies. In our study, we used ATCM in all CT examinations, and we additionally lowered the tube voltage to 70 kVp. This resulted in an average increase in tube current of 386% to compensate for the increase in image noise of low-kV scanning. By doing so, we were able to demonstrate that low-kV CTs can provide diagnostic image quality for the cervical soft tissues at all anatomic levels, despite the presence of more artifacts in the lower neck (at the level of the shoulders). With 70 kVp, the increase in attenuation in vessels and muscles was higher than the increase in image noise, resulting in a better CNR in all regions examined. Most importantly, radiation dose could be further reduced with the low-kV protocol to an average of 0.88 mSv, which is 34% lower than that of a standard 120-kV protocol. This decrease in radiation dose might be relevant considering the radio sensitivity of the thyroid gland, being at increased risk for the development of malignancies after irradiation.[17]

Mulkens and coauthors[18] evaluated, in a recent study, the image quality of low-dose CT of the cervical spine. By choosing combinations of low tube currents and low tube voltages, with the lowest $CTDI_{vol}$ of 12.48 mGy (100 kVp, 250 eff. mAs), the authors found only a small increase in image noise, without a difference in subjective image quality compared with a standard dose CT at 130 kVp, while dose could be substantially reduced. In our study employing a protocol with a $CTDI_{vol}$ of 7.27 mGy, we also found no difference in image quality of the upper and mid-cervical spine. The lower spine, however, showed a lower image quality at 70 kVp, with up to 20% of the studies being of nondiagnostic image quality. This increase in noise and artifacts in the lower neck at low kV can be explained by the high beam attenuation through the shoulders, resulting in greater scattering and hence greater noise. Based on our results, for imaging of the lower cervical spine, low-kV CT scanning at 70 kVp cannot be recommended.

The following study limitations must be acknowledged. First, a relatively small number of patients were available for comparison between 70-kVp and 120-kVp scans. Further studies are required to determine the best trade-off between low-kVp scanning and image quality that also results in diagnostic image quality of the lower cervical spine. Second, no assessment of diagnostic accuracy for different cervical pathologies was performed, as the aim of our study was to evaluate the overall image quality of the neck comparing 70 kVp and 120 kVp, regardless of any underlying neck pathology. Third, we chose the acromioclavicular joint and humeral head as landmarks for the lower neck. These anatomic structures are not fixed in relation to the neck, however, and a fixed point in reference to the neck might have been better. Finally, we did not evaluate other low-kV protocols employing 100-kV or 80-kV settings for imaging of the neck. Further work remains to be done to determine the optimal protocol that balances radiation dose against diagnostic image quality for cervical soft tissues and bones.

Conclusions

Our study shows that low-kV CT of the cervical soft tissues at 70 kVp is feasible, provides diagnostic image quality of cervical soft tissues with improved CNR, and reduces radiation dose by around 34% compared with a standard protocol with fixed 120-kVp settings. Low kilovoltage CT of the lower cervical spine at 70 kVp appears not feasible at present because of a compromised image quality.

Disclosures: Bernhard Schmidt—*UNRELATED: Employment:* Siemens AG.

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