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Original article

Abdominal Computed Tomography Angiography at 80kV: feasibility study

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Summary. *Purpose:* Preliminary evaluation of different dose reduction algorithms in abdominal Computed Tomography Angiography (CTA) with standard scan protocols at 120kV vs. 80kV. *Materials and Methods:* Prospective, randomized, crossover study. 60 consecutive patients who underwent CTA of the abdomen (Sensation 64, Siemens; Iomeprol 400 mgl/ml Bracco) for suspected or diagnosed Abdominal Aortic Aneurysm (AAA) were enrolled in the study. A standard 120kV/200mAs scan protocol was acquired in all patients (reference tube current modulated with Automatic Exposure Control). In each patient a second scan with 80kV/300mAs (Group 1; n. 20), 80kV/400mAs (Group 2; n. 20), 80kV/500mAs (Group 3; n. 20) was acquired. We used the same scan/reconstruction parameters with the same amount and kind of contrast medium. The radiation dose, the aortic attenuation values, the noise and the signal/noise ratio (S/N) were evaluated. *Results:* The mean dose was 9.7±2.7mSv for 120kV (all patients), 3.6±0.8mSv in Group1 (80kV), 5.0±0.6mSv in Group 2 (80kV) and 5.9±1.2mSv in Group 3 (80kV), respectively. The aortic attenuation was 350±59HU (120kV) vs. 534±100HU (80kV), 12±3.5 (120kV) vs. 8.8±3.6 (80kV) for the whole population. Aortic attenuation and S/N were: 328±40HU (120kV) vs. 494±61HU (80kV), 11±2 (120kV) vs. 7±2 (80kV) in Group1; 353±77HU (120kV) vs. 551±117HU (80kV), 11±2.8HU (120kV) vs. 8.4±2.6 (80kV) in Group 2; 389±55HU (120kV) vs. 598±117HU (80kV), 15±5 (120kV) vs. 12±5 (80kV) in Group 3, respectively ($p<0.05$). *Conclusion:* In abdominal CTA, the 80kV/400mAs scan protocol allows a radiation dose reduction of 50% without a significant reduction of S/N ratio. (www.actabiomedica.it)

Key words: Computed Tomography, Abdominal CT Angiography, radiation dose, 80kV; 120kV, signal, noise

Introduction

CTA is the non-invasive standard method for the evaluation of abdominal arteries (1-19). Thanks to recent technological advances in Multi-slice CT (MSCT), the abdominal arteries CTA currently represents a non-invasive extremely efficient and accurate diagnostic tool in vascular imaging.

However, the widespread use of its applications could result in an increase of the exams' number with a corresponding increase of the patient's radiation dose exposure which represents the main limit of this method (1-19). The aim of this study is to evaluate different scan protocols of abdominal CTA, ie different tube current (Kv) and voltage (mAs) in order to reduce the radiation dose preserving the image quality.

Materials and methods

Population

From April 2009 to September 2009 we prospectively enrolled 60 consecutive patients >60 years old (44 men; mean age: 74 yo) with clinical indication for abdominal CTA (i.e. suspected or known AAA).

All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008. Informed consent was obtained from all patients.

All patients were examined with the standard scan protocol characterized by 120kV/ref 200mAs (reference tube current modulated with Automatic Exposure Control AEC – CARE Dose4D, Siemens, Germany).

Every patient were subsequently randomly underwent to a second CTA scan with 80kV with different tube current values: reference current 300mAs (Group 1; n. 20), reference current 400mAs (Group 2; n. 20); reference current 500mAs (Group 3; n. 20). Patients with known allergy to iodinated contrast agents and renal failure (creatinine >1.5 mg/dL) were excluded. The study protocol was approved by the local Ethics Committee and all patients gave written and oral informed consent.

CTA scan protocol and imaging reconstruction

All scans were performed with a 64-slice CT scanner (Sensation 64, Siemens, Forchheim, Germany). The following parameters were used for every angiographic scan: detector collimation 24x1.2mm, gantry rotation time 500msec; effective temporal resolution 250msec; table feed/rot. 3.84mm; craniocaudal scan direction. For contrast enhancement, 80 ml of contrast medium (Iomeprol, Iomeron 400, Bracco S.p.A., Milan, Italy) was administered intravenously at 3 ml/sec (IDR/Iodine Delivery Rate = 1.2 gI/sec) flow rate, followed by 40 ml of saline chaser at same flow rate using an automatic dual-head CT injector (Stellant, MedRAD, Pittsburgh, PA, USA) attached to an 18- to 20-Gauge needle cannula positioned in an antecubital vein.

The bolus tracking technique (CARE bolus®, Siemens, Forchheim, Germany) for contrast bolus arrival and data acquisition synchronisation was used to optimize the arterial contrast enhancement. The anatomical coverage was extended from toraco-abdominal aortic passage to the pelvic ring. Angiography scan data were obtained during a single breath-hold (9±1s). Data-sets reconstructions were performed with the following parameters: effective slice thickness 1.5 mm; reconstruction increment 1 mm; standard medium-smooth convolution kernel (B30f).

Data analysis

All CT images were blinded evaluated by an expert operator (5 years of CTA). We obtained 120 complete data-sets, 60 acquired with standard CTA protocol (120kV) and 60 with low-dose CTA protocol (80kV).

The data-sets were transferred to a dedicated workstation (Leonardo, Siemens, Forchheim, Germany) and processed with conventional algorithms of imaging visualization: axial images cine-scrolling; multiplanar reconstruction (MPR); curved multiplanar reconstruction (cMPR) along longitudinal axis of abdominal aorta; maximum intensity projections (MIP); volume rendering (VR).

To quantify the CT vascular attenuation value [expressed in Hounsfield units (HU)] for each scan, five regions of interest (ROIs) along aortic axis were placed in different anatomic levels: celiac trunk, origin of renal arteries, origin of inferior mesenteric artery, aortic bifurcation and iliac bifurcation. For data analysis the mean of attenuations values was calculated.

CT attenuation values and density were also calculated at the level of the psoas muscle and the abdominal fat. The image noise was defined as the standard deviation value of pixel density measured in a circular ROI (region of interest) placed in the surrounding patient air included in the scan FOV. Signal to noise ratio (S/N) and contrast to noise ratio (C/N) were calculated as it follows:

- S/N = AA density/noise
- C/N = AA-Psoas density/noise

Statistical Analysis

Normal distribution was described as mean values ± standard deviation [mean±SD]. The relationship between the standard-dose scan protocol (120kV) and the low-dose scan protocol (80kV) was evaluated. We compared the values and the differences of CT attenuation measured in AA, psoas muscle and abdominal fat. The image quality was quantatively evaluated as S/N and C/N ratio. The comparisons between the different groups of data were obtained with Student's t-test for paired samples, setting a significant p-value cut-off less than 0.05. The agreements between different methods were explored using Pearson's correlation coefficient (r).

Evaluation of Radiation Dose

The effective radiation dose (mSv) evaluation was based on DLP dose index (dose-length-product) using the conversion coefficient for abdominal exams (0.015 mSv/mGy cm). At the end of every acquisition DLP dose' values were calculated by CT scan software. The dose reduction was calculated as percentage obtained dividing the effective dose of the standard-dose protocol for the effective dose of the low-dose scan protocol.

Results

No complications neither adverse event related to the contrast agent administration were reported during CT scans. All datasets provide adequate image for the study. No datasets were excluded for pulse-related motion artifacts or poor enhancement. Demographic characteristics of the study population are summarized in Table 1. The Student's t test for paired data showed no statistically significant difference (p>0.05) between the three groups in terms of age, gender distribution, BMI and BSA. The CT attenuation mean value and its standard deviation are showed in Table 2-3. The mean value of CT intravascular attenuation and its standard deviation, of the noise and S/N was 350±59HU (120kV) vs. 534±100HU (80kV), 30±5.1HU (120kV) vs. 65±15HU (80kV), 12±3.5 (120kV) vs. 8.8±3.6 (80kV) for the entire population. While the corresponding mean values in the three groups were: 328±40HU (120kV) vs. 494±61HU (80kV), 30±4HU (120kV) vs. 69±15HU (80kV), 11±2 (120kV) vs. 7±2 (80kV) in Group 1, 353±77HU (120kV) vs.

Table 1. Population demographic data

Population	Total
Number of patients	60
Age (years; mean ±SD)	74±9
Male/Female	41/19
Cardiovascular risk factors	
Weight (kg; mean±SD)	78±12
Height (cm; mean±SD)	171±7
BMI (Kg/m^2; mean±SD)	26.6±3.7
BSA (m^2; mean±SD)	2.8±1.0
Abdominal circumference (cm)	97±17

Abbreviations: SD = Standard Deviation; BSA = Body Surface Area; BMI = Body Mass Index

Table 2. Summary results

		Group 1	Group 2	Group 3
PROT 1	mAs	135.5±27.6	176.7±21.7	173.0±59.7
100kVp	CTDIvol	9.2±1.9	11.9±1.5	11.7±4.0
	DLP	557.5±119.8	753.7±158.9	718.2±214.6
	Ed (mSv)	8.4±1.8	11.3±2.4	10.8±3.2
	S/N	11.2±2.3	11.1±2.8	14.7±4.9
PROT 2	mAs	245.4±45.2	364.8±22.6	409.4±49.0
80kVp	CTDIvol	4.4±0.8	6.6±0.4	7.4±0.9
	DLP	237.9±55.3	332.5±36.6	391.4±77.4
	Ed (mSv)	3.6±0.8	5.0±0.5	5.9±1.2
	S/N	7.4±1.8	8.3±2.6	11.8±5.3

Summary results for the two protocols in the three groups. The values are indicated as mean and standard deviation.
Abbreviations: SD = Standard Deviation; kVp = kilovolt ; mAs = milliAmpere ; CTDIvol = CTDI volumetric; DLP = Dose Length Product; Ed = Effective dose (milliSievert)

Table 3. Detailed results

		Group 1	Group 2	Group 3
PROT 1	Celiac Trunk	328.6±39.8	353.6±77.3	389.1±55.5
120 kVp	Renal Arteries	331.2±44.0	355.2±74.7	381.3±49.8
	Inferior Mesenteric Artery	335.0±50.7	350.0±82.6	393.6±60.7
	Aortic Bifurcation	340.1±46.5	358.2±81.5	393.3±59.7
	Iliac Bifurcation	322.9±92.1	353.8±83.2	405.1±52.8
	Psoas M.	38.3±30.9	37.9±6.8	47.5±8.6
	Fat	-93.5±33.9	-98.3±16.6	-82.7±34.5
	Air	13.9±3.8	15.3±3.5	12.7±6.3
	THROMBUS	38.0±22.8	39.4±8.3	67.0±79.8
	SD	26.6±9.2	23.6±6.5	22.5±7.2
PROT 2	Celiac Trunk	493.8±61.2	551.2±117.1	597.6±117.0
80 kVp	Renal Arteries	496.4±62.5	555.0±111.4	620.0±100.4
	Inferior Mesenteric Artery	496.9±65.5	546.8±129.2	587.5±84.3
	Aortic Bifurcation	505.2±63.9	567.6±112.1	611.9±106.8
	Iliac Bifurcation	474.7±128.6	560.8±105.1	617.2±105.7
	Psoas M.	57.3±38.1	60.6±10.8	68.2±13.9
	Fat	-100.5±35.7	-43.0±220.6	-106.9±14.0
	Air	22.9±4.2	22.4±7.2	20.6±9.6
	THROMBUS	48.9±22.7	50.0±13.9	104.7±135.9
	SD	48.6±16.2	52.2±17.1	45.2±21.5

Summary results for the two protocols in the three groups. Values are indicated as mean and standard deviation. Detailed results of vascular attenuation, of other tissues attenuation and signal-to-noise ratio.
Abbreviations: SD = Standard Deviation; S/N = Signal-to-noise ratio

551±117HU (80kV), 32±4HU (120kV) vs. 68±10HU (80kV), 11±2.8H (120kV) vs. 8.4±2.6 (80kV) in Group 2, 389±55HU (120kV) vs. 598±117HU (80kV), 29±7.1HU (120kV) vs. 57±17HU (80kV), 15±5 (120kV) vs. 12±5 (80kV) in Group 3, respectively (Figure 1-4).

All data obtained showed a statistically significant difference ($p < 0.05$). A discrete correlation between the S/N ratio and BMI values was observed (r=-0.46 at 120kV; r=-0.43 at 80kV) while there was a good correlation between the S/N ratio and the body weight (r=-0.58 at 120kV; r=-0.53 at 80kV). No statistically significant correlation between the S/N ratio and BSA nor S/N ratio and height was found.

The mean effective dose value was 9.7±2.7 mSv in the standard-dose scan protocol (120kV) (total population) and 3.6±0.8 mSv in Group 1 (80kV/300 mAs), 5.0±0.6 mSv in Group 2 (80kV/400 mAs) and 5.9±1.2 mSv in Group 3 (80kV/500 mAs), respectively.

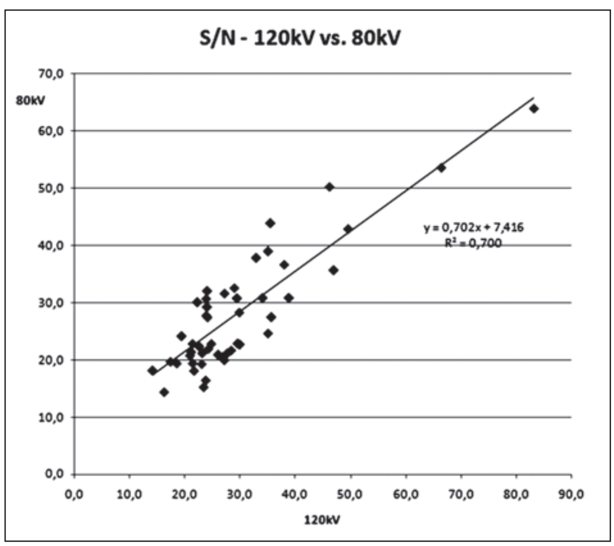

Figure 1. Signal-to-noise ratio correlation – 120kV vs. 80kV. Summary results about overall signal-to-noise ratio between 120kV and 80kV scans.
Abbreviations: S/N = Signal/Noise

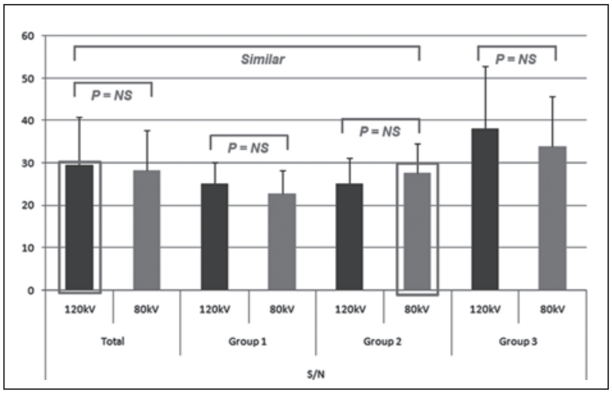

Figure 2. Signal-to-noise ratio - Absolute values. Summary results related to absolute values of the overall signal-to-noise ratio between the 120kV (dark grey columns) and 80kV (light gray columns) scans in the total population and in the three groups with different tube current setting. In each group 1-3 (300mAs-400mAs-500mAs) no significant changes in S/N are observed. A signal-to-noise ratio value similar to the mean value of the protocols at 120kV/200mAs is obtained with 80kV in Group 2, that is 400mAs.
Abbreviations: NS = Not significant; S/N = signal-to-noise ratio

Discussion

The radiation dose reduction is one of the key aims of the radiology protocol optimization. Considering the extensive and repeated CT use and the improving scanner performance a radiation dose reduction using only what is strictly necessary for diagnostic purposes is necessary (1-19).

In the last years different strategies for reducing the CT radiation dose were tried. Possible approaches are based both on the direct modification of the scanning parameters (i.e. reduction of mAs, kVp, pitch, etc..) and on exposure dose modulation based on individual patients' characteristics (with semi-automatic or also automatic techniques).

For example, a fundamental aim of scientific research and all CT scan manufacturers is the patient exposure limitation maintaining adequate diagnostic image quality using automated dose limitation systems (i.e. AEC, automatic exposure control systems) that allow a tube current intensity modulation based on patients' individual characteristic.

The tube current reduction results in a linear dose reduction. The kilovoltage reduction results in an exponential dose reduction.

CT vascular applications benefit more than others of the low kilovoltage settings (80-100kVp) that allow a better visualization of the high contrast enhancement anatomical structures (the arterial district Vs the surrounding tissues). Since the intra-vascular attenuation is enhanced by the iodinated contrast agent administration, the different iodine attenuation spectrum between the soft tissues and the other adjacent structures could be used.

X rays generated by a 80 kV tube potential have a mean energy significantly lower than the x rays generated by a 120kV tube potential, more similare to

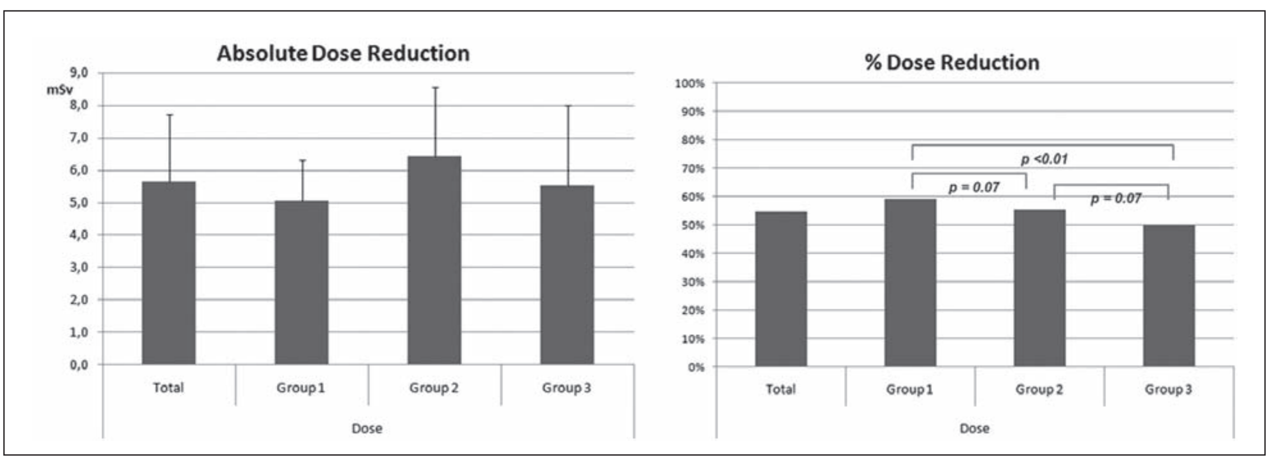

Figure 3. Absolute and relative dose reduction. Summary results related to the absolute and relative variation of effective dose for the two protocols in the three groups. The greater absolute dose reduction (>6mSv; superior panel) is obtained in Group 2 and corresponds to a relative reduction slightly superior than 50% (inferior panel)

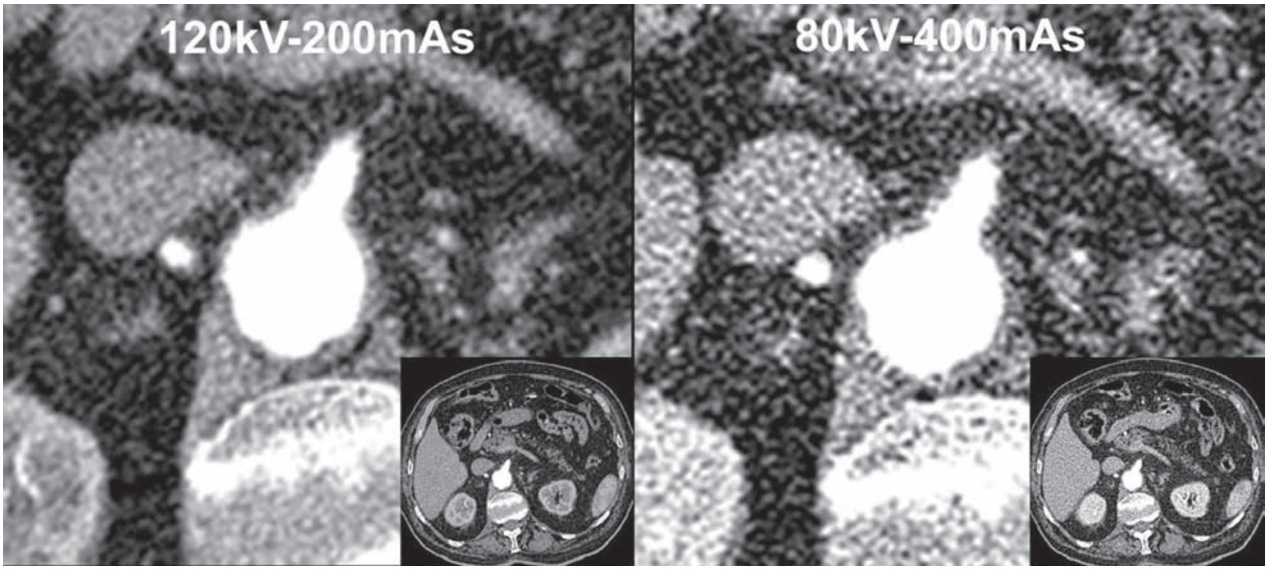

Figure 4. Abdominal CT angiography example. The figure shows axial images reconstructed with 1.5 mm of thickness at the level of the origin of superior mesenteric artery. On the right side there is the standard scan at 120kV and 200mAs of reference current and on the left side there is the scan at 80kV and 400mAs of reference current. The images are alike and the image noise increase at 80kV is compensated by an high intravascular attenuation

iodine k-edge (33.2keV). With low kilovoltages the incidence of Compton interaction is reduced while the photoelectric effect of high atomic number structures as iodine increase esponentially. This leads to a better contrast agent yield in terms of densitometry and then in a better, or at least equal, vessel visualization at the same iodine concentration injected and at the same or even lower radiation doses.

In our study with the low-dose scan protocol (80kV) we registered a clear increase of intravascular attenuation mean values (signal) and an unavoidable non linear increase of the images noise. However, analyzing the signal-to-noise ratio there was no statistically significant difference between the standard and the low-dose scan protocol (in particular Group 2-80 kV/400 mAs). Moreover, the most surprising results were obtained in terms of dose reduction, ≥ 50% compared to the standard both in the global population and in the three subgroups.

For this purpose, the use of high iodine concentration contrast agents could represent a valid aid as confirmed by Iezzi et al (20-21) studies, which demonstrated the feasibility of low-dose protocols (low kV and mAs) for the follow-up of patients undergoing EVAR and with aorta and lower limbs AOC. In these patients the noise increase was compensated, in terms of image quality, by the high concentration contrast agents (400 mgI/ml) administration, obtaining a total dose reduction always higher than 50%.

Finally, the use of iterative reconstructions markedly reduces the image noise without sacrificing spatial resolution (22-23) extending the use of low-dose scan protocol to overweight/obese patients.

Compared to traditional FBP reconstructions, the association of low tube voltage and the iterative reconstructions reducing significantly the quantum noise could represent a further strategy to optimize the radiation dose preserving the image quality to the point that it can be used also for abdominal CT scans, in which the soft tissue contrast is lower.

The results obtained from the various studies may be useful in order to combine the use of the low and high kilovoltage. The new generations of double-tube CT scanners (dual-source CT, DSCT), permit the use of dual-energy scanning protocols (dual energy, DE) which allow a dose reduction simultaneously maintaining the images quality.

Operating the two tubes at different voltages, these protocols have the added value of exploiting the difference in the profile of attenuation between iodine and other tissues, allowing the tissue characterization. For example with the virtual non-contrast imaging technique (VNC) the evaluation of the iodine contribution to the density of each voxel is possible. It can then be removed from the entire data volume obtaining virtual images without contrast avoiding the baseline scan and reducing the radiation dose.

Discriminating different structures such as iodine and calcium this technique allows to remove the vascular calcification along the arteries (automatic bone removal). This notably facilitates the vessels evaluation especially in districts characterized by small vessels (i.e. brain, lower limbs, etc.) (27).

Study Limitations

The comparison between the standard scan protocol (120kV) vs. the low-dose scan protocol (80kV) was performed only in quantitative terms. Further analysis are currently in progress in order to obtain an adequate qualitative assessment for completing this preliminary data.

The study caused to the enrolled patients an additional dose administration of both contrast agent and ionizing radiation, even in small quantities, compared to a conventional abdominal CTA.

Moreover, for all angiographic scans we used the same contrast agent compound/concentration. Further investigations are currently in progress to evaluate the impact of contrast agent different iodine concentration on intra-vascular attenuation and on the possibility of the radiation dose reduction.

Conclusions

Our study demonstrates the feasibility of low kilovoltage protocols (80kVp) for abdominal CTA. This allows to halve the radiation dose preserving a good S/N ratio. Also the major manufacturers seem to follow this direction experimenting new automated tube voltage regulation system (such as CARE kV, Siemens Healthcare, Forchheim, Germany) based on patient attenuation calculated on the scanogram and on the kind of exam, as shown by the preliminary experience of Niemann et al (24). In the prospective CTA follow-up of patients undergoing Endovascular Abdominal Aortic Aneurysm Repair, Goetti et al (25) observed an image quality and a S/N ratio similar to the standard protocol with 120 kV.

According to Yu et al (26) this new algorithm could reduce in the future the volume of the injected contrast medium. It could be useful in patients with impaired renal function or with difficult intravenous access.

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