ORIGINAL ARTICLE

Comparison of image quality and radiation dose in computed tomography angiography of the peripheral arteries using tube voltage of 80 kV versus 100 kV


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Received 24 March 2012; accepted 28 June 2012

KEYWORDS
Peripheral arterial disease; Multidetector computed tomography; Dose of radiation

Abstract
Objective: To compare the image quality and dose of radiation in two groups of patients undergoing CT angiography of the lower limbs, one with tube voltage of 80 kV and the other with tube voltage of 100 kV.

Materials and methods: We performed CT angiography of the lower limbs in 60 patients with suspected peripheral arterial disease. Patients were randomly assigned to one of the two groups; in one group, CT angiography was performed using a tube voltage of 80 kV, whereas in the other it was performed using 100 kV. The remaining acquisition parameters were the same in both groups. The images were analyzed by quantifying vascular density (VD) and noise (N) and by calculating the quotients density/noise (QVDN) and contrast/noise (QCN). Two radiologists working independently evaluated the subjective quality of the images. We calculated the estimated effective dose (EED) based on the dose-length product (DLP).

Results: In the group studied at 80 kV, VD was significantly higher (462.5 UH ± 95.6 vs 372 UH ± 100.9; P < .001), QVDN was significantly higher (241.9 ± 48.1 vs 194.3 ± 49.6; P < .001), and there were trends toward higher N (21.3 UH ± 13 vs 16.3 UH ± 3.5; P = .098) and toward higher QCN (21.4 ± 12.1 vs 22.9 ± 9.1; P = .15). No significant differences were found in the subjective quality of the images. The EED was significantly lower in the group studied at 80 kV (4.73 mSv ± 1.1 vs 9.6 mSv ± 2.2; P < .001).

Conclusion: Using 80 kV instead of 100 kV for CT angiography of the lower limbs reduces the dose of radiation without affecting the diagnostic efficacy of the study.

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PALABRAS CLAVE
Enfermedad arterial periférica; Tomografía computarizada multidetector; Dosis de radiación

Comparación de la calidad de imagen y dosis de radiación en angio-tomografía computarizada de arterias periféricas con 80 y 100 kV

Resumen
Objetivo: Comparar la calidad de imagen y la dosis de radiación en 2 grupos de pacientes a los que se realiza angio-TC de extremidades inferiores con 80 y 100 kV.

Material y métodos: Se realizó angio-TC de miembros inferiores a 60 pacientes con sospecha de enfermedad arterial periférica aleatorizados en 2 grupos, en uno la TC se realizó con 80 kV y en el otro con 100 kV. Los demás parámetros de adquisición se mantuvieron constantes. Se analizaron las imágenes cuantificando la densidad vascular (DV) y el ruido (R), y se calcularon los cocientes densidad vascular/ruido (CDVR) y contraste/ruido (CCR). Dos radiólogos evaluaron independientemente la calidad subjetiva de las imágenes. Se calculó la dosis efectiva estimada (DEE) basada en el producto dosis-longitud (DLP).

Resultados: El grupo de 80 kV presentó valores significativamente más elevados de la DV (462.5 UH ± 95.6 vs. 372 UH ± 100.9; \( p < 0.001 \)) y del CDVR (241.9 ± 48.1 vs. 194.3 ± 49.6; \( p < 0.001 \)) y diferencias no significativas del R (21.3 UH ± 13 vs. 16.3 UH ± 3.5; \( p = 0.098 \)) y el CCR (21.4 ± 12.1 vs. 22.9 ± 9.1; \( p = 0.15 \)). No hubo diferencias significativas en la calidad subjetiva de la imagen y la dosis efectiva fue significativamente menor en el grupo de 80 kV (4,73 mSv ± 1,1 vs. 9,6 mSv ± 2,2; \( p < 0.001 \)).

Conclusión: La utilización de 80 kV en el estudio de angio-TC de miembros inferiores disminuye la dosis de radiación sin afectar a la eficacia diagnóstica del estudio respecto a la utilización de 100 kV.

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Introduction

Peripheral artery disease (PAD) whose etiopathological factor is arterosclerosis is a serious health condition. Its prevalence is high: it affects 12% of adult population and 20% of people <70 years old.1,2 Its diagnosis is based on clinical criteria and image modalities that help us plan the appropriate therapy. Traditionally the assessment of pretreatment has been performed through conventional angiographies yet this modality is not free from complications.1 Angio-CT has proven to be an efficient exploratory tool to diagnose PAD in lower limbs. Several studies confirm the high diagnostic security of this modality when exploring the peripheral arterial system as easier less bloody more widely available test than digital angiography. For all these reasons angio-CT is more and more used to diagnose PAD while accounting for 5% of all planned explorations and 0.1% of scanning emergencies.4-12

Recently it has been proven that 64-detector row angio-CT equals conventional angiography both for the diagnosis and planning of therapy in patients with PAD.13 Yet angio-CT has several drawbacks like its poor diagnostic capacity when in the presence of calcification, its low profitability in stenoses <50% and above all due its radiation dose up to 12–13 mSv due to large anatomical volumes included and acquisitions that performed through thinner cuts.14 The idea of reducing the radiation dose of CT up to reasonable limits still stands today.15,16 There are studies on other vascular territories showing that it is possible to reduce the dose of radiation with protocols of fewer kW without affecting the quality of the diagnostic images acquired17 yet there are few studies showing how to optimize the radiation dose when studying lower limbs through angio-CT18–none of them just by reducing kW. Reducing kW not only reduces the radiation dose but also increases vascular enhancement. This is due to the fact that the level of maximum iodine attenuation (K-edge) is 33 kW, i.e. with energies of 80 kW the attenuation is >100 kW.19,20

Hence our goal is to check if there are differences in the diagnostic quality of angio-CT of lower limbs and in radiation dose while reducing kW.

Materials and methods

Patients

We did a prospective observational study where 60 randomized patients in two (2) groups during a period of five (5) months were analyzed. The study was approved by the hospital ethical committee and all patients signed prior written informed consent.

The criterion to do the test was the request of one angio-CT of lower limbs due to suspicion of acute or chronic peripheral artery disease. Exclusion criteria were contrast allergies, pregnancy, hyperthyroidism or renal failure (glomerular filtration rate below 35 ml/min/m²), age <18 years old and not signing the aforementioned informed consent. Patients were randomized in two (2) groups through a computed generated list with the program Excel® 2007 (Microsoft®) that randomly assigned kilovoltage to every patient. In group A the 100 kW protocol was used and in group B the 80 kW protocol was used. In group A 32 males and 7 women of an average 65.9 ± 16.5 years of age were included. In group B 23 males and 7 women of an average 65.8 ± 12.6 years of age were included.

Computed angio-tomography of lower limbs

All studies were done through a 64-detector row angio-CT (Somatom Sensation 64®; Siemens Medical Systems,
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Patients were examined in the decubitus supinatus position with their arms above their heads. Frontal topogram with 100 kV and 35 mA was acquired. The study was done in cranial-caudal direction with a coverage spanning from the diaphragm to the heels. The CT parameters were 64 mm × 0.6 mm collimation, gantry rotation speed 0.33 s, table speed 40 mm/s, pitch factor 0.9, reference tube current 170mAS with tube modulation modality in a 170–230 mAs range (Care Dose® Siemens Medical Systems, Erlangen, Germany). Based on the group a different kilovoltage was used (100 kV for group A and 80 kV for group B) while the remaining parameters remained stable including the reference tube current. For the administration of contrast the antecubital vein was canialized to introduce 120 ml of iopromide (Ultravist 300® Bayer Schering Pharma, Berlin, Germany) followed by 40 ml of saline solution at a constant flow of 4 ml/s using a Stellant Dual® injector (Medrad Inc., PA, USA).

For an adequate vascular enhancement the contrast optimization technique "bolus tracking" was used by placing one ROI in the abdominal aorta at the level of renal arteries and with a trigger threshold of 150 HU. A 15 s additional delay was added to guarantee the stain of the more distal arteries. In an effort to homogenize the technique this protocol was applied in the same way in all patients regardless of their clinical manifestations. During post-processing 1.5 mm thick cuts were done with reconstruction increase of 1 mm and soft tissue filter B20f. Final analysis was done with axial images with V reconstructions—volume rendering.

Image analysis

Measurements of vascular density (VD) were acquired in w Leonardo® working station (Siemens Medical Systems; Erlangen, Germany) along the arteries of lower limbs including 11 different levels (Fig. 1): aorta at the level of renal arteries, external left and right iliac arteries, proximal left and right superficial femoral arteries, proximal left and right deep femoral arteries, left and right popliteal arteries, posterior left and right tibial arteries. To that end one ROI was free-hand drawn of a diameter as big as the vascular lumen area and the HU density was measured. The vascular lumen area was considered exclusively as the visible surface with contrast of which wall thrombi or plaques calcified at wall level were excluded.

Based on these measurements the average VD was obtained. In those cases where we could not measure all segments—occlusion, prosthesis or amputation the average VD was limited to the assessed vessels.

The average muscle density (MD) was estimated by measuring density with a 0.25 in.-ROI in the central region of the right paraspinal muscle and the anterior rectum of left quadriceps from which the measurement was obtained.

Measurement of the average noise (N) was estimated through the standard deviation of a 0.25 in.-ROI in the surrounding air of three (3) regions in front of the patient's body (right, central and left) at the level of the belly button. The average values were used to estimate the final noise.

Based on these measurements the vascular density-noise ratio (VDNR) and the contrast-noise ratio (CNR) were estimated according to the following equations: VDNR = VD/N and CNR = (VD − MD)/N.

Also the subjective quality of image was assessed by two (2) explorers (CDS and CTL) with 12 and 11 years of experience in CT respectively by using axial cuts and volume rendering reconstructions (Fig. 2). To that end a five (5) point-scale was used: 5 excellent; optimal homogenous vascular enhancement allowing us to evaluate all possible vascular lesions with high diagnostic safety and without any artifacts; 4: good; good vascular nearly homogeneous enhancement allowing us to evaluate all possible vascular lesions with high diagnostic safety and without any significant artifacts; 3: moderate; good; heterogeneous vascular enhancement allowing us to evaluate all possible vascular lesions with moderate diagnostic safety or artifacts affecting the interpretation of images; 2: poor quality but diagnostic; heterogeneous vascular enhancement allowing us to evaluate all possible vascular lesions with low diagnostic safety or artifacts affecting the interpretation of images; 1: non-diagnostic; poor diagnostic information that does not allow us to find or discard vascular lesions with artifacts definitely affecting the interpretation of images.

Evaluation of the estimated effective radiation dose

The effective radiation dose (ERD) was estimated by multiplying the longitudinal product dose (LPD) by a conversion factor for the studied anatomical region. This conversion factor in abdomen and pelvis is 0.01 mSv/mGy.cm.
LPD was obtained according to the proportionate figure in the exploration protocol given by the equipment.

Statistical analysis

The outcomes of the measurements of VD, VDNR, CNR, subjective image quality, LPD and ERD are expressed according to the average ± standard deviation with ranges between brackets. Normalcy in the distribution of the sample could be confirmed through the Kolmogorov–Smirnov test. The characteristics of both groups—age, sex, body mass index [BMI]—could be compared by using Student’s t test for separate samples as well as the Chi-square test. The variables exploration length and measurements of VD, VDNR, CNR, subjective image quality, LPD and ERD were compared between both groups by using Student’s t test for unpaired samples as well as the Chi-square test. Statistical significance was considered to be a value of $P < 0.05$. The Kappa coefficient was used to measure the inter-observer concordance while assessing the subjective quality of images. All estimates were done through a standard PC with the SPSS® software for Windows® v. 15.0 (SPSS® Chicago, IL, USA).

Results

Subjects

The demographic variables of both groups showed normal distribution and the comparison between both groups of patients did not show statistically significant differences in age, sex, BMI or length of acquisition (Table 1).

Image parameters

All variables followed normal distribution. The average VD in subjects from group B was greater than that in subjects from group A ($462.5 \pm 95.6$ vs $372.3 \pm 100.9; P < 0.001$). Also a detailed analysis for each and every vessel showed a greater VD in all vessels of patients from group B than in patients from group A without exemption and with significant differences too. There were no statistically significant differences in the average MD ($50.1 \pm 11.2$ vs $51.3 \pm 8.8; P = 0.54$). The average N was greater in patients from group B ($21.3 \pm 13.4$) than in patients from group A ($16.3 \pm 3.5$) with no statistically significant differences ($P = 0.098$). There

Figure 2 Volume rendering reconstructions with the identical algorithm to that of angio-CT of peripheral arteries of two (2) different patients of 82 kg of weight both. The patient who underwent the 80 kV protocol shows occlusion of the right external iliac artery (hollow arrow) and bilateral femoropopliteal artery recanalizing through collaterals distally. The patient studied with 100 kV shows the occlusion of the left popliteal artery (arrow). See the optimal quality of the image obtained with both protocols.
Comparison of image quality and radiation dose in computed tomography angiography

Table 1  Characteristics of patients and parameters of acquisition.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Patients from group A</th>
<th>Patients from group B</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>65 ± 12 (27-92)</td>
<td>66 ± 16 (41-86)</td>
<td>0.97</td>
</tr>
<tr>
<td>Ratio men: women</td>
<td>23:7</td>
<td>23:7</td>
<td>1</td>
</tr>
<tr>
<td>BMI</td>
<td>28 ± 4 (19-35)</td>
<td>28 ± 5 (20-47)</td>
<td>0.86</td>
</tr>
<tr>
<td>Length of scan (mm)</td>
<td>1.320 ± 100 (1.184-1.594)</td>
<td>1.278 ± 99 (1.039-1.536)</td>
<td>0.10</td>
</tr>
<tr>
<td>Collimation (mm)</td>
<td>0.6</td>
<td>0.6</td>
<td>NA</td>
</tr>
<tr>
<td>Rotation speed (s)</td>
<td>0.33</td>
<td>0.33</td>
<td>NA</td>
</tr>
<tr>
<td>Pitch</td>
<td>0.9</td>
<td>0.9</td>
<td>NA</td>
</tr>
<tr>
<td>Tube current (mA)</td>
<td>170</td>
<td>170</td>
<td>NA</td>
</tr>
<tr>
<td>Kilovoltage (kVp)</td>
<td>100</td>
<td>80</td>
<td>NA</td>
</tr>
<tr>
<td>BMI, body mass index; NA, non applicable value.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The data are the average ± standard deviation with ranges between brackets.

were statistically significant differences between patients from group A and B when it comes to the VDNR (194.3 ± 49.6 vs 241.9 ± 48.1; P < 0.001) yet no statistically significant differences in CNR (21.4 ± 12.1 vs 22.9 ± 9.1; P = 0.15). The assessment of the subjective quality of images showed an average value in patients from group A of 4.27 ± 0.82 (CDS) and 4.37 ± 0.71 (CTL) and for patients from group B of 4.0 ± 0.91 (CDS) and 4 ± 0.87 (CTL) P = 0.3, with a K-correlation of 0.93 ± 0.075 (Table 2).

Radiation dose

There were statistically significant differences both in the longitudinal product dose (LPD) (570.1 mGy cm ± 131.5 vs 278.6 mGy cm ± 64.9; P < 0.001) and in the effective radiation dose (ERD) (9.6 mSv ± 2.2 vs 4.7 mSv ± 1.1; P < 0.001) between the two groups (Table 2).

Discussion

The results of this study confirm that it is feasible to reduce the radiation dose in studies of angio-CT of lower limbs using a low dose-protocol of 80 kV without affecting the quality of image.

Recently it has been confirmed that 64-detector row angio-CT endows a great diagnostic safety similar to that of conventional arteriography for the diagnosis and planning of therapy in patients with PAD.13 However, the most important limitation in this type of studies is the radiation dose. Some authors claim that the radiation dose is not a major issue in patients with PAD since the radiation dose does not increase the possibility of developing neoplasms or other conditions when life expectancy is shorter than the latency period needed to develop such conditions.21 Yet despite this several official bodies following the ALARA (as low as reasonably achievable) criterion insist in the need for reducing the radiation in all radiologic tests to the reasonable minimum and patients to levels of unnecessary exposure.15,16 In the attempt to constantly reduce the radiation dose modifications in the acquisition parameters of equipments are planned. Modifying the tube current, varying the pitch factor, the angle between the tube and the table or the distance of the tube with respect to the patient have been proceedings used to achieve the aforementioned optimization.22 The most significant setback in the strategies aimed at diminishing the dose is the reduction

Table 2  Measurements of vascular density, subjective quality of image and radiation dose.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Patients from group A 100 kV</th>
<th>Patients from group B 80 kV</th>
<th>Difference percentage between protocol A and B</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>VD (HU)</td>
<td>372.3 ± 100.9</td>
<td>462.5 ± 95.6</td>
<td>±0.19</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>MD (HU)</td>
<td>51.3 ± 8.8</td>
<td>50.1 ± 11.2</td>
<td>±0.02</td>
<td>0.54</td>
</tr>
<tr>
<td>Background noise (HU)</td>
<td>16.3 ± 3.5</td>
<td>21.3 ± 13.4</td>
<td>±0.23</td>
<td>&lt;0.098</td>
</tr>
<tr>
<td>VDNR</td>
<td>194.3 ± 49.6</td>
<td>241.9 ± 48.1</td>
<td>±0.19</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>CNR</td>
<td>21.4 ± 12.1</td>
<td>22.9 ± 9.1</td>
<td>±0.06</td>
<td>0.152</td>
</tr>
<tr>
<td>Subjective quality of image</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reader#1</td>
<td>4.27 ± 0.82</td>
<td>4 ± 0.91</td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td>Reader#2</td>
<td>4.37 ± 0.71</td>
<td>4 ± 0.87</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LPD (mGy cm)</td>
<td>570.1 ± 131.5</td>
<td>278.6 ± 64.9</td>
<td>−0.51</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>ERD (mSv)</td>
<td>9.6 ± 2.2</td>
<td>4.7 ± 1.1</td>
<td>−0.51</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

CNR, contrast-noise ratio; VDNR, vascular density-noise ratio; ERD, effective radiation dose; LPD, longitudinal product dose; MD, muscular density; VD, vascular density; HU, Hounsfield units.
of the diagnostic ability due to an increase in image noise and worsening of the quality of the very test.\(^6\) In the study of Frailoli et al.,\(^6\) when the tube current was reduced from 130 to 100 mAs and to 50 mAs in the artery studies of lower limbs the radiation dose was reduced 40–74% respectively without affectation on the diagnostic safety of the test. In another study–Heyer et al.\(^7\) only by modifying the tube kilovoltage from 120 to 100 kV they achieved a reduction of up to 40% in the radiation dose without affectation of the image quality in angio-CT for the diagnosis of lung thromboembolism. Similarly Wintersperger et al.\(^2\) showed that the reduction of kilovoltage from 120 to 100 kV did not influence the relation between VD and N or the overall quality of image in angio-CT of the aortoiliac region. In our study we tried to show that by reducing kilovoltage to 80 kV we still can acquire arterial maps of lower limbs with enough quality to perform diagnostic explorations.

One of the reasons is due to the fact that the iodine attenuation (K-edge) is maximum at 33 kV which means it is closer to 80 than 100 kV so it presents a greater enhancement in the studies performed at 80 kV.\(^5,6\) Indeed our results were consistent with the studies published to date in other anatomical regions and with the recent study by Lezzi et al.\(^4\) in the lower limbs. Studies performed at 80 kV proved that the VD is significantly greater than studies done at 100 kV. However there were not significant differences in MD or N even though the latter showed a certain growing trend toward significance. N was greater in studies at 80 kV yet the VDNR image quality gauge showed a significantly greater result in the 80 kV group. This indicates that VD increase is proportionately greater than N allowing us to analyze the arterial system adequately in studies at 80 kV. However, the CNR—that also assesses the MD too not only arterial enhancement did not show a significant difference between both groups. This fact can be interpreted by the greater amount of N in the 80 kV series images meaning that we need to be cautious when assessing other structures different from arteries in those studies.

Also it is also possible that a greater sample size conditions a significant increase of N that in turn could also condition a reduction of CNR. In any case in the sample a non-diagnostic study was found only that could be explained by the patient’s abnormal cardiac output that conditioned one insufficient vascular perfusion in the time of acquisition rather than the reduction of kV per se. Despite the systematic use of bolus tracking modality the variability among patients of hemodynamic features can explain the sporadic cases of inconclusive images above all in the more distal territories and the more stenosed-vessels. As a matter of fact this is one of the limitations of our study since trying to homogenize the modality to all patients the same amount of iodinated contrast was administered and the same 15 s-delay was used when the 150 HU threshold was achieved in the abdominal aorta without paying attention to the physical characteristics of each subject. However, with this protocol we did not find any other cases without stain of distal arteries due to delays in the arrival of contrast. The reasons why the distal arteries could not be assessed were occlusions, artifacts due to metallic prostheses or amputations of limbs.

This study has other limitations. We did not assess the radiation dose through direct method using phantoms yet the formula allowed us to obtain the dose through a protocol supplied by the team has proven to have a high concordance with the real doses in adult patients.\(^4\) On the other hand the exploration of abdomen with 80 kV can underestimate the extravascular findings that with 100 kV would be seen with greater reliability which limits its use to the strict vascular evaluation above all in patients with high BMI. Yet despite these drawbacks this study opens the door to new researches with the use of kilovoltage for the assessment of vascular territories through CT.

In sum we can say that using 80 kV in angio-CT studies of lower limbs reduces the radiation dose without affecting the diagnostic efficacy of the study with respect to the use of 100 kV.

### Ethical responsibilities

#### Protection of human and animal subjects. Authors confirm that all proceedings and experiments followed relate to the committee of responsible human experimentation ethical rules and regulations in compliance with the World Medical Association and the Declaration of Helsinki.

#### Confidentiality of data. Authors confirm that in this report there are no personal data of patients.

#### Right to privacy and informed consent. Authors confirm that in this report there are no personal data of patients.

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9. Manuscript critical review with intellectually relevant contributions: CTL, GTF, CTL, AFV, MGV and NSP.
10. Final Version Approval: ROP, CDS, AFV, NSP, MGV, CTL and GTF.

### Conflict of interest

The authors declare no conflict of interest.

### References

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