Digital subtraction angiography: can we reduce the dose maintaining enough image quality?

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Purpose

The purpose of this work is to present a method for quality control of digital subtraction angiography (DSA) and propose a procedure to adjust the dose to the required level of image quality.

The method is exemplified using the phantoms described in the IEC/DIN standards, HPA and NEMA standards.

Methods and materials

Series of images using digital subtraction angiography (DSA) were obtained simulating two different patient thicknesses. Three commercially available phantoms following IEC/DIN, HPA and NEMA standard were used to assess the features of digital subtraction following the corresponding standards. In addition, image quality was quantified using measurements of signal-difference-to-noise ratio (SDNR) for low and high attenuation conditions.

The experimental set-up is shown in Fig. 1 on page 3 for the IEC/DIN phantom.

Dose measurements

Phantom entrance surface air kerma (ESAK) was measured with an ionisation chamber (20X6-60 E; S/N: 32263, Ref. 22195, electrometer 22195, Radcal Corp. Monrovia, CA) and phantom incident air kerma (IAK) (without backscatter) was measured with a solid state detector (Dido 2100k, QUART GmbH, Zorneding, Germany). The position of the detectors can be seen in Fig. 2 on page 3 a.

Descriptions of the phantoms can be found in the IEC, HPA and NEMA standard documents.

Data analysis

Regions including between 60 and 225 pixels were selected to measure the mean grey level of the background $x_b$ (dashed ROI in Fig. 3), and ROIs within the aluminium strips were selected to measure the mean grey level $x_s$ and standard deviation $s_s$ of the signal (solid ROIs in Fig. 3). Values of SDNR were obtained as
\[ SDNR = \frac{(x_s - x_b)}{s_s} \]

An overall score SDNR₃ has been calculated as addition of the SDNR measured in three different regions (the maximum number of ROIs available in the NEMA phantom) for each phantom (Fig. 3)

**Images for this section:**

**Fig. 1:** Left) The fluoroscopy device and the IEC/DIN phantom on the patient couch. Right) Set-up including additional 20 cm of PMMA. Note that the couch was lowered to keep the phantom in the isocentre.

**Fig. 2:** a.) DICOM image of the IEC/DIN phantom before generation of the mask. Observe the copper wedge steps (horizontal stripes producing darkening towards the top of the image) and the presence of the ionisation chamber (solid arrow) and the solid state
detector (dashed arrow). b.) Image right after mask creation and subtraction. The window level has been adjusted to search for potential artefacts in the homogeneous image. c.) Image of the DSA phantom after insertion of the slider containing the aluminium strips. Observe that the seven regions of the copper wedge can be separately analysed thanks to thin, horizontal black lines which separate the regions corresponding to each step.

**Fig. 3:** Post-contrast images of the IEC/DIN (left), HPA (middle) and NEMA (right) phantoms. The dashed ROI indicates the region used to obtain the background signal $x_b$. The solid ROIs indicate the three ROIs used to obtain the signal averages $x_s$ and standard deviations. The arrows indicate the fourth step of the copper wedge in the IEC/DIN phantom.
Results

The need to include objective measures of image quality and the method to calculate SDNR for the different methods have been proved. A method to reduce dose and maintain image quality is thus suggested below.

Need for objective evlautions:

Visually assessing the visibility of the vessels is a very subjective task. For example one cannot know if all steps of the thinnest vessel in the IEC/DIN phantom are correctly visualized or if they are only assumed to be there because we know they have to be there.

To further illustrate this point, Fig. 4 on page 6 shows the corresponding profiles of the four vessels at the 4th step of the copper wedge for the case of large attenuation. The profiles show that indeed the thinnest vessel is almost indistinguishable from the background noise. For this reason it is useful to calculate the SDNR, which provides an objective measure of the visibility of this vessel against the quantum noise of the background. The measured values of SDNR for each step of every vessel are shown above the corresponding profiles.

Measurements of SDNR for different phantoms

Fig. 5 on page 6 shows that it is indeed possible to obtain reasonable measurements of SDNR with any of these phantoms. Each one has its particular materials and thus produce SDNR values in different ranges, but the values show that it is possible to perform objective measurements of image quality and cobine them with simultaneous measurements of dose to optimize and compare DSA protocols.

Procedure for dose optimization

Our results show that different values of SDNR can be assigned to different exposure modes depending on the image quality required for a specific clinical task. For example, an SDNR equal to 0.20 seems to correspond to low visibility, but still provides enough visibility of a thin vessel so that it can be followed against a homogeneous background (Fig. 4 on page 6). Therefore, an SDNR equal to 0.20 could be used to define a low-dose exposure mode that can be used by the radiologist when high image quality is not required (for example to follow a guidewire within a big vessel). On the other hand, an SDNR equal to 0.5 can be used to define a high-quality exposure mode for clinical tasks that require very good image quality.
Similarly, the SDNR measured for different vessel portions or in other positions within other phantoms could be used to define objective acceptance criteria in national and international standards. For example, an overall score obtained by agreement with all stakeholders could be considered as intervention or suspension level in DSA applications.

Images for this section:

![Profile of step 4 within the IEC/DIN phantom. The SDNR corresponding to each simulated vessel is displayed above the profile. The profile of the thinnest simulated vessel is framed.](image)

**Fig. 4:** Profiles of step 4 within the IEC/DIN phantom. The SDNR corresponding to each simulated vessel is displayed above the profile. The profile of the thinnest simulated vessel is framed.

<table>
<thead>
<tr>
<th>Phantom:</th>
<th>IEC / DIN</th>
<th>HPA</th>
<th>NEMA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>1</td>
<td>0.25 ± 0.01</td>
<td>0.20 ± 0.01</td>
<td>4.5 ± 0.2</td>
</tr>
<tr>
<td>2</td>
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<td>0.22 ± 0.01</td>
<td>8.37 ± 0.3</td>
</tr>
<tr>
<td>3</td>
<td>0.52 ± 0.01</td>
<td>0.37 ± 0.01</td>
<td>12.2 ± 0.4</td>
</tr>
<tr>
<td>SDNR 3</td>
<td>1.055 ± 0.011</td>
<td>0.79 ± 0.01</td>
<td>25.1 ± 0.5</td>
</tr>
</tbody>
</table>

**Fig. 5:** Measurements of signal difference-to-noise ratio using three signals with three different phantoms for DSA.
Conclusion

We have demonstrated a method to calculate an image quality score based in SDNR measurements on subtracted images. This objective quantification of image quality could serve to pre-define, adjust and compare exposure modes that may be chosen by the radiologist depending on the required task.

In addition, this work includes criteria for image quality evaluations in digital subtraction angiography, which have not been discussed in the recent European guidelines for quality control of x-ray equipment.

Personal information

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Conflict of interest statement

H. de las Heras works part-time as consultant for QUART GmbH, the company that manufactures one phantom included in this paper. The other authors have no conflict of interest and have always shared access to all data related to this work.

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