ORIGINAL RESEARCH

Subjective and objective evaluation of image quality in biplane cerebral digital subtraction angiography following significant acquisition dose reduction in a clinical setting

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ABSTRACT

Objective Different technical and procedural methods have been introduced to develop low radiation dose protocols in neurointerventional examinations. We investigated the feasibility of minimizing radiation exposure dose by simply decreasing the detector dose during cerebral DSA and evaluated the comparative level of image quality using both subjective and objective methods.

Methods In a prospective study of patients undergoing diagnostic cerebral DSA, randomly selected vertebral arteries (VA) and/or internal carotid arteries and their contralateral equivalent arteries were injected. Detector dose of 3.6 and 1.2 μGy/frame were selected to acquire standard dose (SD) and low dose (LD) images, respectively. Subjective image quality assessment was performed by two neurointerventionalists using a 5 point scale. For objective image quality evaluation, circle of Willis vessels were categorized into conducting, primary, secondary, and side branch vessels. Two blinded observers performed arterial diameter measurements in each category. Only image series obtained from VA injections opacifying the identical posterior intracranial circulation were utilized for objective assessment.

Results No significant difference between SD and LD images was observed in subjective and objective image quality assessment in 22 image series obtained from 10 patients. Mean reference air kerma and kerma area product were significantly reduced by 61.28% and 61.24% in the LD protocol, respectively.

Conclusions Our study highlights the necessity for reconsidering radiation dose protocols in neurointerventional procedures, especially at the level of baseline factory settings.

INTRODUCTION

In adult and pediatric populations, fluoroscopically guided neurointerventional procedures have been increasingly used in the diagnosis and treatment of various neurovascular diseases.1 Radiation dose exposure to both patients and operators is concerning, especially in conditions of prolonged and complicated interventional procedures. The ALARA principle, ‘Image Wisely’, and ‘Image Gently’ campaigns, and a recent concept presented as ‘Image Intelligently’ have been developed to raise awareness regarding the need for development of techniques to reduce unnecessary radiation dose.2–4 Conversely, excessive reduction of radiation dose can result in poor image quality and noise, degrading the diagnostic value of the examination and potentially placing a patient at risk for repeat or additional diagnostic studies with or without radiation.

Different technical and procedural methods have been introduced to reduce radiation exposure and to develop low dose protocols in neurointerventional examinations, after which the diagnostic imaging value was demonstrated to be preserved.5–9 However, several questions remain with respect to clinical implementation, such as scale of dose reduction, image quality and noise, reproducibility, and flexibility for operators and technicians to reduce dose in complicated and long neurointerventional procedures.

Our purpose in this study was to investigate the feasibility of minimizing radiation exposure dose by simply decreasing the detector dose during routine cerebral biplane DSA. Additionally, we evaluated the comparative level of image quality with exposure dose reduction using both subjective and objective methods.

METHODS

Image acquisition

Following institutional review board approval and after obtaining informed consent, we performed a prospective study on patients undergoing diagnostic cerebral DSA using a biplane flat detector angiography suite (Artis Zee Flat Detector Biplane-Angiosuite, Siemens, Forchheim, Germany). Standard dose DSA images were acquired using predefined manufacturer factory settings with a detector dose of 3.6 μGy/frame. By manually reducing the detector dose to 1.2 μGy/frame, low dose DSA images were also acquired of the contralateral internal carotid (ICA) and/or vertebral (VA) arteries injections. As the system uses automatic exposure rate control, radiation output is adjusted to maintain image quality with patient specific adjustment of other acquisition parameters, including kVp, mA, and focal spot to conform within
the reduced detector dose settings, using a vendor’s proprietary algorithm.

Based on the preprocedural plan of the neurointerventionalist, using identical contrast agent, contrast injection rate, table/detector position, and acquisition time, randomly selected VA and/or ICA and their contralateral equivalent arteries were injected to obtain standard dose and low dose anteroposterior/lateral DSA images, respectively. Images were excluded from quality assessment if any technical/motion artifacts, flow limiting vascular stenosis/occlusion, or steal phenomenon from arteriovenous shunts obscured relative opacification of a vessel segment or distribution. Reference air kerma and kerma area product were obtained accordingly.

**Image analysis**

Image quality assessment was performed independently by two neurointerventionalists on a de-identified PACS workstation evaluating the low dose and standard dose images in pairs on randomly assigned adjacent monitors. A 5 point scale was developed for qualitative evaluation of arterial, capillary, and venous phases of DSA images, respectively. The qualitative grading scale is as follows: 5, very good: excellent large and small vessel visualization; 4, good: excellent large vessel and minimal compromise of small vessel visualization; 3, average: diagnostic value for large vessel, but compromised small vessel visualization; 2, poor: compromised large and small vessel visualization; and 1, non-diagnostic. Both observers were asked to focus on specific characteristics in each phase for grading, including discrimination of large, small, and crossing arteries in the arterial phase; capillary blush in the capillary phase; and sharpness of the venous system in the venous phase based on the previous criteria proposed by Söderman et al. The total cumulative score was defined as the overall diagnostic value. The individual scores of each phase as well as the overall diagnostic values assigned by each observer were compared after evaluation of the standard dose and low dose DSA images.

In an attempt for objective image quality evaluation, circle of Willis vessels were categorized into conducting vessels, primary vessels, secondary vessels, and side branch vessels based on the classification proposed by Pritz. Two blinded observers performed the arterial diameter measurements in each category. Only image series obtained from VA injections were utilized for objective assessment. The vertebral–basilar junctions were verified to be patent bilaterally before utilizing these images for objective assessment. VA injections provided the opportunity to opacify and measure the diameter of the identical posterior intracranial vascular distribution with either standard or low dose DSA. However, due to lack of inherent image scale in DSA images, an appropriate proportionality equation was used for correction. For a reference scale, average standard diameter of the basilar artery was used based on the values obtained from histopathological studies. The basilar artery diameter on DSA was measured using the digital caliper tool as the reference artery and the proportionality equation was set up to correct the diameter of all selected arteries measured on DSA images. Interobserver agreement was performed to determine the reliability of the diameter measurements. Subsequently, vessel diameters in standard and low dose images were compared to determine any significant difference in measurements suggesting image quality degradation.

**Statistical analysis**

Interobserver agreement for diameter measurements was evaluated using the intraclass correlation coefficient and values were interpreted as follows: >0.75=excellent; 0.40–0.75=fair to good; and <0.40=poor. The paired sample t test and Wilcoxon signed rank test were used for statistical analysis to compare the dosimetry parameters and qualitative scores, respectively. A p value of <0.05 was considered to be statistically significant. Statistical analysis was performed using SPSS statistical software (V20.0, SPSS Inc, Chicago, Illinois, USA).

**RESULTS**

Twenty-two image series were obtained from 10 patients (9 men and 1 woman; mean±SD age 64.4±10.04 years). Injection sites included 12 VAs and 10 ICAs. Reducing the detector dose resulted in reduction of acquisition parameters, including typical tube voltage, tube current, and focal spot size, as well as the addition of a 0.1 mm Cu filter. Mean reference air kerma and kerma area product were significantly reduced by 61.28% and 61.24% in the low dose protocol, respectively ($p<0.0001$, table 1).

In subjective evaluations of all DSA image series acquired from 22 injections by two neurointerventionalists, no significant difference was observed between image quality scores assigned by the observers while evaluating arterial, capillary, and venous phases of standard and low dose images. Additionally, there was no significant difference in overall diagnostic values assigned by the observers between standard and low dose DSA images (table 2, figure 1).

In objective evaluations, interobserver agreement was excellent in vessel diameter measurements performed by the observers on standard dose DSA images. Similarly, interobserver agreement was excellent and good in vessel diameter measurements performed by the observers on low dose DSA images. No significant difference was observed in vessel diameter measurements performed by the observers while comparing standard and low dose DSA images (table 3).

**DISCUSSION**

With the expanding indications and complexity of endovascular techniques in the treatment of cerebrovascular pathology, the frequency and duration of neurointerventional procedures are increasing. As the patient may acquire significant radiation

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**Table 1** Technical parameter and delivered radiation dose comparison in standard and low dose protocols

<table>
<thead>
<tr>
<th></th>
<th>Standard dose</th>
<th>Low dose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detector dose (μGy/frame)</td>
<td>3.6</td>
<td>1.2</td>
</tr>
<tr>
<td>Mean typical tube voltage (kVp)</td>
<td>77.5</td>
<td>71.9</td>
</tr>
<tr>
<td>Mean tube current (mA)</td>
<td>211.25</td>
<td>149.26</td>
</tr>
<tr>
<td>Focal spot size (mm)</td>
<td>0.6</td>
<td>0.3</td>
</tr>
<tr>
<td>Mean reference air kerma (mGy) (mean±SD)</td>
<td>72.97±47.59</td>
<td>28.25±21.06</td>
</tr>
<tr>
<td>Kerma area product (μGy/m²) (mean±SD)</td>
<td>1083.73±504.86</td>
<td>419.96±234.81</td>
</tr>
</tbody>
</table>

**Table 2** Qualitative image score difference between standard dose and low dose images

<table>
<thead>
<tr>
<th></th>
<th>Observer 1 (p value)</th>
<th>Observer 2 (p value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arterial phase</td>
<td>1.0</td>
<td>0.24</td>
</tr>
<tr>
<td>Capillary phase</td>
<td>0.54</td>
<td>0.30</td>
</tr>
<tr>
<td>Venous phase</td>
<td>0.14</td>
<td>0.70</td>
</tr>
<tr>
<td>Overall diagnostic value</td>
<td>0.34</td>
<td>0.80</td>
</tr>
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exposure, consequential adverse effects such as alopecia, skin epilation and desquamation, intraocular lens opacification, and potential for benign and malignant tumor development are concerning.13–17 A careful benefit–risk analysis should be considered in radiation dose reduction studies, particularly in novel medical imaging examinations. For example, the causal relationship between an increased risk of cancer and ionizing radiation exposure from medical imaging studies and interventional procedures has yet to be defined, and the plausibility of designing such a study would be difficult, especially in terms of feasibility, funding, and bioethical issues. Although theoretically described, no study has been published to demonstrate radiation induced carcinogenesis from medical imaging. In fact, most of our knowledge regarding specific cancers induced by radiation exposure and methodologies for risk estimation developed from studying survivors exposed to high doses of ionizing radiation in nuclear accidents or atomic bombs. This type of data was used in a major study to determine the lifetime cumulative risk of developing cancer secondary to diagnostic X-ray studies, estimated at 0.6–3%.18

Controversy persists regarding the hypothesis that there is a linear correlation between radiation exposure and an increased risk of cancer.19 Due to the relatively high baseline lifetime risk of developing cancer in any individual (1 in 2 men and 1 in 3
women), via interaction of multiple environmental and genetic factors, excessive radiation dose reduction can be detrimental if the diagnostic value of the examination is limited. Nevertheless, considering the cautious instruction in the ALARA principle, any effort to reduce radiation exposure to as low as reasonably achievable is valuable, especially in the absence of definitive data regarding the causal relationship between ionizing radiation exposure from interventional procedures and cancer risk. Significant reductions in radiation dose above factory defined standard doses may provide a benefit to minimize the deterministic and stochastic risks incurred during complicated and unexpectedly lengthy examinations, not uncommon in neurointerventional procedures.

Radiation dose delivery to the patient is extensively influenced by numerous factors, from operator expertise to image acquisition parameters. Additionally, radiation dose exposure varies significantly based on patient parameters, anatomic location, type of neurointerventional procedure, and underlying pathology, although both diagnostic and interventional procedures can result in excessive radiation exposure. Perhaps the most modifiable variables to reduce radiation exposure are avoiding unnecessary examinations and technical parameters that can be used to develop low dose protocols for utilization in various settings.

Several technical modifications have been proposed to reduce radiation dose exposure in neurointerventional procedures. Söderman et al combined image acquisition modifications and real time noise reduction algorithms to decrease the patient entrance dose by a factor of 4. In their subjective image quality evaluation of 20 patients, readers did not observe significant image quality inferiority in low dose versus standard dose images, but only a moderate interobserver agreement was achieved in low dose image quality assessment. In another study by the same group of investigators, they demonstrated that after applying a noise reduction algorithm protocol, 69% and 73% dose area product reduction in cerebral diagnostic and interventional procedures was achieved, respectively. However, they did not perform any specific image quality assessment after utilizing this low dose protocol. Pearl et al achieved 59% radiation dose reduction after implementing a guideline consisting of DSA frame rate modification, reduction of pulse rate during fluoroscopic and road map guidance, detector position and collimation configuration, and utilizing fluoroscopy instead of DSA in femoral artery access. In another study performed by Kahn et al, radiation exposure per pulse and radiation exposure per frame (from 3.6 to 1.2 μGy) were reduced during fluoroscopic and CINE image acquisition, respectively. Similar to the study by Pearl et al, they also utilized variable frame rates during DSA image acquisition with a 55% reduction in reference air kerma and 57% reduction in kerma area product achieved after implementation of the low dose protocol. Although the number of acquisition exposures and fluoroscopic times were slightly increased with the low dose protocol, it was not statistically significant and no major complications were encountered in various neurointerventional procedures, indirectly suggesting preserved image quality. In our study, we observed more than 60% reduction in both reference air kerma and kerma area product by switching the detector dose from 3.6 to 1.2 μGy during routine diagnostic cerebral DSA examinations with preservation of intraprocedural image quality confirmed by postprocedural subjective and objective image quality assessment.

Our study was prone to several limitations. As decreasing fluoroscopy time and reducing detector dose are the most efficient techniques in lowering procedure radiation exposure, both methods are subject to drawbacks as the former may not result in significant dose reduction and the latter may result in increasing the noise level to the extent that the diagnostic image quality is compromised. In our prospective study, our primary goal was to follow the identical clinical and operational steps utilized in a routine DSA study for both standard and low dose examinations, except for detector dose, which could be manually switched based on the condition of the operation and to achieve the greatest radiation dose reduction in the least amount of time. Similar to results by Söderman et al, reaching acceptable interobserver agreement in subjective scores assigned by the readers in our study had some limitations. Although we did not observe a significant reduction in subjective image quality scores of each reader while evaluating low dose images, we performed another image quality assessment for a more objective study regarding the level of diagnostic value loss after more than 60% radiation dose reduction. Not only was no significant diagnostic image quality compromised, but we also achieved substantial to excellent interobserver agreement in objective image quality evaluation. Furthermore, our study was limited to diagnostic studies without underlying vascular pathologies. The ability of low dose acquisition protocols to detect vascular lesions, especially subtle vascular pathologies, remains to be investigated. Therefore, it may be reasonable to prioritize low dose image acquisition to conditions where there is a minimal risk of missing potentially critical lesions. Separate studies to objectively assess the effects of low dose DSA protocols on diagnostic and interventional procedures in the setting of various neurovascular pathologies may be indicated.

CONCLUSIONS

Our study, in accordance with previous studies, highlights the necessity for reconsidering radiation dose protocols in neurointerventional procedures, especially at the level of baseline factory settings. The amount of radiation dose exposure can be reduced by at least twofold, as has been demonstrated in the majority of studies, without decreasing subjective or objective image quality as per our prospective evaluation of diagnostic cerebral DSA studies.
Contributors ARH: design of the study, patient enrollment, data acquisition, data analysis/interpretation, manuscript preparation, and revising the draft critically for important intellectual content. AS and MCH: substantial contributions, data acquisition, data analysis/interpretation, and manuscript revision. TP, FHS, CLS, MBP, and BSJ: substantial contributions, data acquisition, and data analysis/interpretation. SAA: conception and design, data acquisition, data analysis/interpretation, manuscript preparation, revising the draft critically for important intellectual content, and final approval of the version to be published.

Competing interests None declared.

Ethics approval The study was approved by the Northwestern University Ethics approval and manuscript preparation, revising the draft critically for important intellectual content, SAA: conception and design, data acquisition, data analysis/interpretation, and BSJ: substantial contributions, data acquisition, and data analysis/interpretation.

Contributors AS and MCH: substantial contributions, data analysis/interpretation, manuscript preparation, and revising the draft critically for important intellectual content. TP, FHS, CLS, MBP, and BSJ: substantial contributions, data acquisition, and data analysis/interpretation. SAA: conception and design, data acquisition, data analysis/interpretation, manuscript preparation, revising the draft critically for important intellectual content, and final approval of the version to be published.

Provenance and peer review Not commissioned; externally peer reviewed.

Data sharing statement Data for our study are available according to institutional review board approved methods of the Northwestern University.

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J NeuroIntervent Surg published online April 6, 2016

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