COMPUTED TOMOGRAPHY

Head CT: Image quality improvement of posterior fossa and radiation dose reduction with ASiR - comparative studies of CT head examinations

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Abstract

Objectives To evaluate head CT protocol developed to improve visibility of the brainstem and cerebellum, lower bone-related artefacts in the posterior fossa and maintain patient radioprotection.

Methods A paired comparison of head CT performed without Adaptive Statistical Iterative Reconstruction (ASiR) and a clinically indicated follow-up with 40 % ASiR was acquired in one group of 55 patients. Patients were scanned in the axial mode with different scanner settings for the brain and the posterior fossa. Objective image quality analysis was performed with signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR). Subjective image quality analysis was based on brain structure visibility and evaluation of the artefacts.

Results We achieved 19 % reduction of total DLP and significantly better image quality of posterior fossa structures. SNR for white and grey matter in the cerebellum were 34 % to 36 % higher, respectively, CNR was improved by 142 % and subjective analyses were better for images with ASiR.

Conclusions When imaging parameters are set independently for the brain and the posterior fossa imaging, ASiR has a great potential to improve CT performance: image quality of the brainstem and cerebellum is improved, and radiation dose for the brain as well as total radiation dose are reduced.

Key Points

- With ASiR it is possible to lower radiation dose or improve image quality
- Sequential imaging allows setting scan parameters for brain and posterior-fossa independently
- We improved visibility of brainstem structures and decreased radiation dose
- Total radiation dose (DLP) was decreased by 19 %

Keywords Brain diseases/radiography · Radiation dosage · Radiation protection methods · Computer-assisted methods · Tomography, X-ray computed methods

Introduction

From the introduction of computer tomography (CT) into clinical practice in 1972, the filtered back projection (FBP) algorithm has been used for image reconstruction [1]. Within the next few decades, many advances in CT technology were made. Simultaneously the number of indications for CT has markedly increased. Widening the scope of CT application has resulted in an increase in the number of CT examinations performed each year and thus in higher population doses from medical sources [2]. On the other hand, widespread interest in radiation protection has increased with the aim of lowering the possible hazards associated with radiation exposure [3, 4]. For this reason several CT protocols have been developed that aimed to lower radiation dose. Many of them are based on modification of scanning parameters and decreasing the tube current-time product as well as lowering tube voltage.
In recent years the Adaptive Statistical Iterative Reconstruction (ASiR, GE Healthcare, Milwaukee, WI, USA) method has been introduced into CT. The final image is the result of multiple repeated steps in which the image quality is improved with statistical methods. Previous studies have shown that ASiR improves the image quality in abdominal CT and has a potential for a reduction in radiation dose while maintaining diagnostic acceptability [5, 6].

Earlier studies on ASiR in head CT showed similar results [7–10]. However, to our knowledge all of them were performed in two distinct groups of patients. In our study we compared ASiR and FBP protocols in one group of patients who underwent head CT twice for clinically indicated purposes.

Another purpose of this study was to better fit scanning protocols to the posterior fossa structures in order to decrease the scatter noise and the beam hardening artefacts. We performed head CT scanning in the axial mode with different scanning parameters for the brain and the posterior fossa while previous studies have reported on helical scanning mode with one scanner setting for the whole head. Thus, we also aimed to improve the brainstem and the posterior fossa visibility without increasing exposure to the brain. To our knowledge, previously published papers did not describe the impact of ASiR on the posterior fossa imaging.

Methods and materials

Study group

In this Institutional Review Board approved study we retrospectively examined patients who underwent two clinically indicated head CTs during one period of hospitalization. We reviewed 355 consecutive patients who underwent head CT in the Emergency Department. We included patients who underwent clinically indicated follow-up head CT. The exclusion criteria were: (1) neurosurgical treatment (clipping, coiling, drainage, etc.), (2) motion artefacts and (3) mass effect (severe haematoma, oedema, neoplasms, etc.). Exclusion criteria were carefully evaluated in order to avoid image quality degradation caused by artefacts from foreign bodies, surgery and severe disturbances in brain morphology.

The first CT examination was performed in the Emergency Department with a VCT Lightspeed, 64-row scanner (GE Healthcare) with FBP reconstruction. The subsequent head CT was performed with a Discovery 750 HD (GE Healthcare) and images were reconstructed with 40 % ASiR.

Scanning was performed in sequential mode. All patients were positioned supine; tube voltage was 120 kVp; beam collimation was at 2.5 mm for the posterior fossa and 5 mm for the cerebrum; scan range was 14 ± 1 cm; scan rotation time was 1 s. Automatic exposure control (AEC) was activated. The noise index (NI) was increased from 2.8 to 4.0 for ASiR and the maximum mA increased from 303 in the initial examination to 320 in the follow-up ASiR examination. Radiation dose descriptors were derived from the dose report automatically stored in PACS (Picture Archiving and Communication Systems). CT dose index volume (CTDIs), dose length product (DLP) and scan range were recorded for both the FBP and ASiR groups.

Subjective image quality

Image pairs were reviewed independently by two radiologists with 8 and 10 years’ experience, respectively, in neuroradiology. The readers were blinded to the scanning protocols. Images were displayed in the brain window (80 W, 40 L) on an Advantage Workstation AW 4.6 (GE Healthcare). In the subjective image quality assessment the image noise, posterior fossa artefacts and diagnostic acceptability were taken into account.

The readers were instructed to evaluate the image sharpness, the grey and white matter differentiation, and the visibility of the basal ganglia, pons, cerebellum and ventricular system. Images of excellent quality were graded 3; images of good quality were graded 2; images of poor quality but adequate for evaluation were graded 1. The image quality assessment was done according to European Guidelines on Quality Criteria for Computed Tomography [11].

Objective image quality

In the objective image quality assessment, the signal-to-noise (SNR) and contrast-to-noise (CNR) ratios were analysed. For each data-set five regions-of-interest (ROIs) were manually positioned. The ROI area varied from 20–30 mm² to encompass homogeneity of measured tissues. The first two ROIs were set in the white matter of the posterior limb of the internal capsule and grey matter of the caudate nucleus. The other two ROIs were set in the white and grey matter of the cerebellum.

The fifth ROI was drawn in cerebrospinal fluid of the fourth ventricle (Figs. 1 and 2). The mean attenuation value (mean) within the ROI and the standard deviation (SD) were considered for signal level and noise.

The SNR was then calculated as the mean divided by the SD. The CNR was calculated for ROIs of white and grey matter with the following formula where the difference in means are divided by the square root of the sum of the squared noise in two ROIs:

\[
\text{CNR} = \frac{\text{Mean}_1 - \text{Mean}_2}{\sqrt{\text{SD}_1^2 + \text{SD}_2^2}}
\]
Statistics

Statistical analysis was performed using R Statistical Software (R Foundation for Statistical Computing, Vienna, Austria) [12].

Differences in SNR and CNR measurements between image pairs were tested using the paired t-test with Welsh modification for unequal variances. To reduce the possibility of significance due to chance because of multiple statistical testing, the Bonferroni correction was applied to the p-value. Significance was assumed only when the p-value was less than 0.01.

The paired t-test was used to compare subjective image quality assessments between image pairs with a 0.05 level of significance.

Results

We included in the study 55 patients who underwent the head CT twice: once each with ASiR and FBP. Using ASiR we

| Table 1 | Objective image quality assessment of head CT: Adaptive Statistical Iterative Reconstruction (ASiR) compared to filtered back projection (FBP) |
|---------|--------------------------------------------------------------------------------|
|         | ASiR                      | FBP                      | ASiR vs. FBP | p-value |
| Cerebrum|                           |                          |              |         |
| SNR GM  | 11.6 ± 2.8                | 9.7 ± 1.9                | +20 %        | NS      |
| SNR WM  | 8.7 ± 2.5                 | 7.3 ± 1.7                | +19 %        | NS      |
| CNR     | 0.12 ± 0.09               | 0.08 ± 0.05              | +50 %        | NS      |
| Posterior fossa |                |                          |              |         |
| SNR GM  | 13.5 ± 3.6                | 9.9 ± 2.5                | +36 %        | <0.0001 |
| SNR WM  | 9.5 ± 2.9                 | 7.1 ± 1.7                | +34 %        | <0.0001 |
| CNR     | 0.17 ± 0.10               | 0.07 ± 0.04              | +142 %       | <0.0001 |
| Fourth ventricle |                |                          |              |         |
| SNR     | 1.7 ± 0.8                 | 1.4 ± 0.7                | +21 %        | NS      |

Values are given as mean ± SD

SNR signal-to-noise ratio, CNR contrast-to-noise ratio, GM grey matter, WM white matter
achieved a statistically significant improvement in posterior fossa imaging. In the objective image quality analysis the SNR of both white and grey matter in the cerebellum was 34 % and 36 % higher. We also achieved a 142 % increase in the CNR of the posterior fossa. All SNR and CNR measurements for the brain and the posterior fossa are presented in Table 1. In the subjective image quality analysis two researchers reported a slightly better quality of ASiR images, but there was no significant difference in overall subjective image quality assessment: 2.7 versus 2.8 for the ASiR protocol for the first observer and 2.6 versus 2.8 for the second observer (Figs. 3 and 4).

In the ASiR protocol we achieved a 30 % decrease in radiation dose (DLP) for the brain, and a 19 % decrease in overall radiation dose from head CT, whereas the scan range in the two cohorts did not differ significantly. The DLP for the posterior fossa in the ASiR protocol increased by 9 %. CTDI\textsubscript{vol} in the brain and in the posterior fossa were 36.2 and 59.7 mGy, respectively. Radiation dose descriptors for ASiR and FBP protocols are shown in Table 2.

Attenuation value of white and grey matter and cerebrospinal fluid remained at the same level in both cohorts; no statistically significant difference was noted. These results are presented in Table 3.

**Discussion**

In our study we investigated head CT in terms of an image reconstruction algorithm (i.e. ASiR and FBP protocols) as well as radiation dose to the brain and the posterior fossa. The advantage of this study was that we gathered paired sets of ASiR and FBP examinations from one group of patients and we were able to perform paired comparisons of the acquired images. To our knowledge all other published studies compared ASIR and non-ASiR CT protocols in two separate groups of patients and thus might have been confounded by differences in the subjects’ brain morphology [7–10].

As ASiR application optimises noise in the reconstructed images [13], it may serve two general purposes: (1) to lower radiation dose without compromising image quality and (2) to improve the image quality maintaining radiation dose. This first approach, i.e. reducing the radiation dose with ASiR, is applied in the majority of published papers. However, we decided to scan the posterior fossa with ASiR and the same radiation dose (DLP) as in the previous protocol with FBP in order to improve the image quality of the posterior fossa structures. For this reason we performed head CT in which the brain and the posterior fossa are scanned with different scanner settings. As a result, with the introduction of ASiR we maintained the radiation-dose level in the posterior fossa and we achieved a 34–36 % increase in SNR in white and grey matter, and a 142 % increase in CNR. Our results have clinical importance because images of the cerebellum, pons and medulla were always compromised by artefacts resulting from skull base bones [14, 15].

**Table 2** Radiation dose in head CT: Adaptive Statistical Iterative Reconstruction (ASiR) compared to filtered back projection (FBP)

|                | ASiR  | FBP   | ASiR vs. FBP | p-value |
|----------------|-------|-------|--------------|---------|
| **DLP (mGy*cm)** |       |       |              |         |
| Overall        | 654.5 ± 77.0 | 804.2 ± 52.3 | -19 % | <0.0001 |
| Cerebrum       | 390.3 ± 75.5 | 560.6 ± 51.8 | -30 % | <0.0001 |
| Posterior fossa| 264.2 ± 31.9 | 243.6 ± 5.5  | +8 %  | <0.0001 |
| **CTDI\textsubscript{vol} (mGy)** |       |       |              |         |
| Cerebrum       | 36.2 ± 4.5  | 51.5 ± 3.0  | -30 % | <0.0001 |
| Posterior fossa| 59.7 ± 3.7  | 55.9 ± 2.5  | +7 %  | <0.0001 |
| Scan range (cm) | 14.3 ± 1.1  | 14.6 ± 1.1  | +2 %  | NS      |

*DLP* dose-length product, *CTDI\textsubscript{vol}* volumetric CT dose index
In our study the mean CTDIvol to the brain and the posterior fossa were 36.2 and 59.7 mGy, respectively, and were well below the routine diagnostic reference head level which is 75 mGy [16]. For comparison (Table 4) the head CT protocol designed by the American Association of Physicists in Medicine in the same GE Discovery scanner as used in our institution has a CTDIvol for brain and posterior fossa of 41.9 and 69.7 mGy [16].

The mean DLP in our study was 654 mGy*cm, whereas in other studies on ASiR and non-ASiR protocols of Kilic et al. [7], Rapalino et al. [8] and Komlosi et al. [10], DLP was 748, 932 and 1,191 mGy*cm, respectively. On the other hand, Ren et al. [17] reported a mean DLP of routine head 559 mGy*cm that was 15% lower than in our study. However, in Ren et al.’s study the posterior fossa was scanned in helical mode with CTDIvol 38.1, whereas in our study the CTDIvol of the posterior fossa was 59.2 mGy. This is very important for image quality of the brainstem and cerebellum because as the radiation dose decreases, the images are noisier and more susceptible to artefacts.

It should be emphasized that the head CT protocol in the axial mode employed for a routine head CT examination in our institution allows us to scan the brain with a lower CTDIvol and a lower current time product (mA*s) as compared to that for the posterior fossa slices. It is important because in helical mode the whole head is scanned in the same mAs settings, thus it should be a compromise between the brain and posterior fossa, where the cerebellum and the brainstem may be degraded by bone related artefacts. Kilic et al. [7] investigated an axial head protocol with CTDIvol of the posterior fossa of 93.5 mGy and could have achieved posterior fossa slices of better quality than in our study. In the studies of Rapalino et al. [8] and Komlosi et al. [9] the heads were scanned in helical mode with CTDIvol values similar to our study, but using helical mode and constant scanner settings for the brain and posterior fossa they achieved a total DLP 1.5–2 times greater.

With the axial scanning we also avoided the over-ranging phenomenon associated with helical scanning. In helical scan mode every reconstructed section is obtained with interpolation of projection data from neighbouring rotations, thus irradiation of neighbouring tissues is inevitable in helical scanning [18–20].

In order to reduce eye lens exposure, we set the scanned volume border at the line between the supraorbital ridge and posterior margin of the foramen magnum [16]. Precise gantry angulation has an additional advantage. In posterior fossa imaging the beam hardening artefacts have their origin in the relatively large amount of bones in the base of the skull that are thicker than bones that surround the brain. When the margin of the scanned volume is set to the basis of the occipital bone, the lowest imaged slices of cerebellum are adjacent and parallel to the skull base. As a consequence, the beam hardening effects of the x-ray beam are reduced and the number of bony artefacts is decreased.

In our institution ASiR was introduced with a new high definition scanner with a unique Gemstone detector (GD). Thus, we are not able to assess how reconstruction algorithm

| Table 3 Attenuation value in head CT: Adaptive Statistical Iterative Reconstruction (ASiR) compared to filtered back projection (FBP) |
|---|---|---|
| Cerebrum | ASiR | FBP | p-value |
| Attenuation GM | 32.6 ± 3.0 | 32.5 ± 2.4 | NS |
| Attenuation WM | 23.8 ± 1.7 | 24.1 ± 1.8 | NS |
| Posterior fossa | | | |
| Attenuation GM | 39.2 ± 2.7 | 38.6 ± 3.2 | NS |
| Attenuation WM | 26.2 ± 2.3 | 27.5 ± 2.8 | NS |
| Fourth ventricle | | | |
| Attenuation CSF | 3.9 ± 1.8 | 5.4 ± 2.6 | NS |

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| Table 4 Comparison of radiation-dose from head CT examinations with Adaptive Statistical Iterative Reconstruction (ASiR) image reconstruction |
|---|---|---|---|
| Head CT protocols with ASiR | Scan mode | CTDIvol | Total DLP |
| | | Posterior fossa | Brain |
| Our study | Axial | 59.2 | 36.4 | 654.5 |
| Kilic et al. 2011 [7] | Axial | 93.5 | 38.6 | 748.5 |
| Ren et al. 2012 [17] | Helical | 38.1 | | 559.0 |
| Rapalino et al. 2012 [8] | Helical | 49.7 | | 932.2 |
| Komlosi et al. 2014 [9] | Helical | 57.1 | | 1,190.9 |
| AAPM 2012 [16] | Axial | 69.7 | 41.9 | Not provided |
| | Helical | 38.4 | | Not provided |

1 The collection of routine head CT protocols by the American Association of Physicists in Medicine for different scanner vendors and models. Radiation doses for GE Discovery 750 HD with are ASiR provided here.

CTDIvol volume CT dose index, DLP dose length product
and detector technology contribute to the dose reduction and image quality improvement that we achieved. As GD has a better performance compared to the older detectors (e.g. the afterglow time is significantly shorter), we think that using the new detector influenced the results.

Another limitation is that in objective image quality assessment we used SNR and CNR values that were questioned by some authors, because IR algorithms gain SNR optimisation [21]. However, this approach for the image quality assessment is widely used in other studies that evaluate iterative reconstruction algorithms and model-based techniques [10, 22–24].

In conclusion, in our study we found advantages in using ASiR in head CT protocols. Axial mode provides the possibility of adjusting scanning parameters for the brain and posterior fossa. With the new protocol we improved image quality of the brainstem and cerebellum as well as reducing the total radiation dose. This scanning protocol has been introduced in our Institution for routine head CT. However, head CT protocols require a thorough evaluation in terms of scanning mode (axial vs. helical), reconstruction algorithm, current time product (mAs) and radiation dose delivered (CTDivol and DLP). Further studies are needed in this field.

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