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FULL PAPER

The use of adaptive statistical iterative reconstruction (ASiR) technique in evaluation of patients with cervical spine trauma: impact on radiation dose reduction and image quality

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This study was presented in the Adaptive Statistical Iterative Reconstruction 2014: American Society of Spine Radiology Annual Symposium, 13–16 February 2014, Miami Beach, FL, USA, and received the best paper award in the oral presentation category.

Objective: The aim of this study was to evaluate the impact of adaptive statistical iterative reconstruction (ASiR) technique on the image quality and radiation dose reduction. The comparison was made with the traditional filtered back projection (FBP) technique.

Methods: We retrospectively reviewed 78 patients, who underwent cervical spine CT for blunt cervical trauma between 1 June 2010 and 30 November 2010. 48 patients were imaged using traditional FBP technique and the remaining 30 patients were imaged using the ASiR technique. The patient demographics, radiation dose, objective image signal and noise were recorded; while subjective noise, sharpness, diagnostic acceptability and artefacts were graded by two radiologists blinded to the techniques.

Results: We found that the ASiR technique was able to reduce the volume CT dose index, dose-length product and

effective dose by 36%, 36.5% and 36.5%, respectively, compared with the FBP technique. There was no significant difference in the image noise ($p = 0.39$), signal ($p = 0.82$) and signal-to-noise ratio ($p = 0.56$) between the groups. The subjective image quality was minimally better in the ASiR group but not statistically significant. There was excellent interobserver agreement on the subjective image quality and diagnostic acceptability for both groups.

Conclusion: The use of ASiR technique allowed approximately 36% radiation dose reduction in the evaluation of cervical spine without degrading the image quality.

Advances in knowledge: The present study highlights that the ASiR technique is extremely helpful in reducing the patient radiation exposure while maintaining the image quality. It is highly recommended to utilize this novel technique in CT imaging of different body regions.

INTRODUCTION

CT has now become one of the main modalities for routine imaging. The number of CT procedures has significantly increased in recent times with a growth rate of 10% every year.¹ Previous studies have shown that number of CT examinations accounts for only 15% of all imaging procedures but contributes around 75% of total radiation exposure to the general population.^{2,3} Therefore, it is imperative that radiologists, radiation technologists and the CT vendors make every possible effort to reduce patients' radiation exposure.

Various approaches have been devised to reduce CT radiation doses. Primarily, appropriate use of CT scans must be

encouraged by evidence-based recommendations that balance the benefits vs risks, as well as consider the cost of the scans.⁴ Other complementary approach is related to the development of various CT dose reduction techniques with the goal of preserving the image quality while reducing radiation exposure. These strategies include optimization of CT parameters (tube current, tube voltage, reconstructed section thickness and pitch), use of dual-energy CT to decrease the number of acquisitions and automated tube current modulation according to the patient's body habitus.^{5,6}

Iterative reconstruction (IR) is a newer image post-processing method that uses different mathematical

algorithms for CT reconstruction to improve image quality by reducing image noise and artefacts. Adaptive statistical IR (ASiR; GE Healthcare, Waukesha, WI) is one such post-acquisition image-processing technique that selectively identifies and removes noise from the low-dose CT images.^{7,8} It applies mathematical models to correct the image data by changing the photon statistics in X-ray attenuation.⁹ Noise is iteratively reduced in the image domain.¹⁰ There are very limited numbers of studies in the literature focusing on the role of ASiR in cervical spine CT.^{9,11,12} In the present study, we compared the subjective image quality, image noise and radiation dose of cervical spine CT images using reduced dose protocol with ASiR *vs* reference dose protocol without ASiR.

METHODS AND MATERIALS

The Ottawa health science network research ethics board approved this retrospective study. Informed consent was waived by the institutional review board.

Patient demography and CT protocol

At our institution, the ASiR technique was introduced with our 64-slice CT scanner (LightSpeed® VCT®; GE Healthcare, Milwaukee, WI) towards the end of September 2010. We analysed a cohort of patients who had cervical CT scans using ASiR method with a group of patients who had cervical CT scans using the standard filtered back projection (FBP) technique. The inclusion criterion for the study was adult patients presented with suspected spinal trauma. The scans with significant movement artefacts and/or showing significant streak artefacts caused by foreign bodies and metallic surgical objects were excluded. A total of 78 consecutive patients with acute trauma who underwent cervical spine CT in the same scanner during the period of 1 June 2010 to 30 November 2010 were assessed retrospectively in this study.

The total patient population was divided into FBP and ASiR groups. (1) The FBP group comprising 48 patients had

traditional reconstruction algorithm (FBP) protocol before implementation of ASiR in the same scanner and (2) the ASiR group comprising 30 patients who had reduced dose acquisition with ASiR (30%). As per the vendor's suggestion and our initial experience of using ASiR in CT head scans, we chose 30% of ASiR in our new low-dose cervical spine protocol.

Scanning parameters

For patients with FBP technique, the following scan protocol was used: detector configuration of 64×0.625 and tube current–time product (mAs) ranging from 100 to 650 mAs using Auto-mA function. The scanner noise index (NI) for the FBP group was 18. For the ASiR group, the scan protocol was almost similar; however, the NI was increased to 22.8 (27% increase compared with FBP), which helped us in decreasing the tube current range to 81–451 mAs. The difference in NI setting was based on external recommendations and our initial experience with the ASiR technique.⁸ The slice thickness (3 mm) and tube voltage (120 kV) were similar in both the groups. The scanning range for both groups extended from the level of external auditory canal to the upper margin of the sternum (Table 1).

Radiation dose parameters

The two standard radiation dose indicators, volume CT dose index (CTDI_{vol}) and dose–length product (DLP) were derived from the dose result page of each of the FBP and ASiR studies, which were automatically prepared by the scanner and were available in the picture archiving and communication system. The CTDI_{vol} represents the average dose delivered within the scanned area, whereas the DLP corresponds to the overall radiation burden of a given examination. DLP is the product of the CTDI_{vol} and scan length. The effective radiation exposure (mSv) was calculated by multiplying the DLP with the conversion factor of $0.0054 \text{ mSv mGy}^{-1} \text{ cm}^{-1}$.¹³ The accuracy of the displayed CTDI_{vol} and DLP of the manufacturer was regularly assessed as a part of the quality control program of the institution.

Table 1. Imaging protocol

Scan protocol	FBP	ASiR
Detector configuration	64×0.625	64×0.625
Slice thickness (mm)	3	3
Reconstruction interval	0.5	0.5
Pitch	0.984	0.984
Rotation time	0.7	0.7
Peak voltage (kVp)	120	120
Minimal tube current (mAs)	100	81
Maximal tube current (mAs)	650	451
Noise index	18	22.8
Reconstruction algorithm	FBP	ASiR: 30% + FBP: 70%
Matrix	512×512	512×512
Pixel size	0.625 mm	0.625 mm

ASiR, adaptive statistical iterative reconstruction; FBP, filtered back projection; kVp, peak kilovoltage; mAs, milliampere seconds.

Table 2. Dose parameters

Parameter mean (SD)	FBP	ASiR	<i>p</i> -value
CTDI _{vol} (mGy)	16.80 (5.34)	10.74 (4.46)	<0.001
Scan length (cm)	19.18 (2.67)	18.87 (2.09)	<0.001
DLP (mGy × cm)	404.47 (143.47)	256.62 (117.48)	<0.001
Effective dose (mSv)	2.38 (0.77)	1.51 (0.63)	<0.001

ASiR, adaptive statistical iterative reconstruction; CTDI_{vol}, volume CT dose index; DLP, dose length product; FBP, filtered back projection; mGy, milligray; mSv, millisievert; SD, standard deviation.

Conversion factor for effective dose calculation: 0.0054.

Quantitative analysis

A region of interest (40 mm²) was placed in the spinal cord at Levels C3 or C4, with minimum streak artefacts. We selected the spinal cord as this is within the bony spinal canal and most susceptible to image degradation related to the surrounding bones. This is also a very important area of interest in spinal trauma.⁵ Image signal is defined by the mean CT number (CTn) in Hounsfield units, and image noise is the standard deviation (SD) of the mean CTn within the region of interest.^{14,15} This was performed by the same radiologist (SP) in all studies and there was consistent placement and sizing of the region of interest for both groups. CTn and SD values were recorded for each examination. The signal-to-noise ratio (SNR) was calculated by dividing the CTn by the SD.

Qualitative analysis

For qualitative analysis, a midline sagittal image (slice thickness, 3 mm) reconstructed in both soft-tissue and bone reconstructions from each study was anonymized by removing all displayed technical and personal identifiable information. As our present study is not targeted for detection of pathology or fractures, only a midline sagittal image was used for simplicity of qualitative assessment. These images were then evaluated on the picture archiving and communication system station by a neuroradiologist and an emergency radiologist (SC, 10 years' experience; AS, 8 years' experience) in a random manner, working independently and blinded to the scan protocol, ASiR usage and date. The readers were allowed to change window settings during their assessment.

Specific criteria were used to judge the subjective image quality, and these were based on the scale used in previous studies.^{14,16} Subjective image noise was graded on a 4-point scale: 1, little noise (below average noise); 2, optimum noise (average noise); 3, noisy but permits evaluation (above average noise); and 4, too much noise, which degrades the image quality so much that no diagnostic information can be gathered. Image sharpness was graded on

a 5-point scale: 1, structures are well defined with sharp contours (above average sharpness); 2, structures seen but contours are not fully sharp (average sharpness); 3, structures can be seen, contours are sharp enough, diagnostic information can be retrieved (below average sharpness); 4, structures can be visualized but not enough for diagnostic reporting, contours are blurred; and 5, structures cannot be identified or defined. Diagnostic acceptability was graded on a 4-point scale: 1, fully acceptable; 2, probably acceptable; 3, only acceptable under limited conditions; and 4, unacceptable.

Statistical analysis

The quantitative image noise measurements and radiation doses were compared by using the independent sample *t* test. The subjective analysis of image noise, sharpness and diagnostic acceptability were compared between the FBP and ASiR studies by using the Wilcoxon rank-sum (Mann–Whitney *U*) test. *p* < 0.05 was considered to indicate a statistically significant difference. The interobserver agreement was assessed by using reader's percentage agreement and Fisher's exact test. We calculated percentage of agreement between readers after dichotomising the scores (1–2 and 3–4) for the subjective assessment of image noise and diagnostic acceptability and (1–2 and 3–5) for the subjective assessment of image sharpness. We also compared between FBP and ASiR groups. The data analysis was performed using SAS® software v. 9.3 of the SAS System for Windows. Copyright © 2013 SAS Institute Inc., Cary, NC.

RESULTS

Patients

48 patients (16 females and 32 males) were included in the FBP group; their age range was 18–97 years. 30 patients (12 females and 18 males) were included in the ASiR group with the age range of 27–91 years. There were no significant differences between patients' age and gender distribution. The original radiology reports confirmed nine patients in the FBP group and six patients in the ASiR group with fractures, although these fractures were not evaluated as part of this study.

Table 3. Quantitative measurements

Measurements mean (SD)	FBP	ASiR	<i>p</i> -value
Image noise (HU)	09.42 (3.02)	08.88 (1.84)	0.39
Image signal (HU)	48.40 (6.47)	48.76 (6.94)	0.82
SNR	05.13 (2.14)	05.50 (3.77)	0.56

ASiR, adaptive statistical iterative reconstruction; FBP, filtered back projection; HU, Hounsfield unit; SD, standard deviation; SNR, signal-to-noise ratio.

Table 4. Interobserver agreement

Subjective measurements	FBP		ASiR		<i>p</i> -value
	Agreement (%)	Disagreement (%)	Agreement (%)	Disagreement (%)	
Noise	83.8	16.2	87.5	12.5	0.7436
Sharpness	90.3	9.7	95.8	4.2	0.3755
Soft-tissue diagnostic acceptability	93.5	6.5	97.8	2.2	0.5614
Bone diagnostic acceptability	96.7	3.3	97.7	2.3	1.0000

ASiR, adaptive statistical iterative reconstruction; FBP, filtered back projection.

Radiation dose

The detailed values of the total scan radiation exposure between the groups are summarized in Table 2. In the ASiR group, the mean CTDI_{vol} and DLP were reduced by 36% and 36.5%, respectively ($p < 0.001$), compared with the standard protocol. There was no significant difference in the scan length between the two groups. Similarly, the effective dose was reduced by 36.5%.

Signal and noise measurements

There was no significant difference in the image noise ($p = 0.39$), signal ($p = 0.82$) and SNR ($p = 0.56$) suggesting non-inferiority of the images between the groups. The image noise was slightly lower in the ASiR group; also, the image signal and SNR were slightly better in the ASiR group than in the FBP group (Table 3).

Subjective image quality

The subjective rating of the image quality was minimally better in the ASiR group but not statistically different between the two groups. The percentages of agreement between readers were calculated after dichotomising the scores (1–2 and 3–4) for the subjective assessment of image noise and diagnostic acceptability and (1–2 and 3–5) for the subjective assessment of image sharpness. We also compared between the FBP and ASiR groups. There is a strong agreement between observers within both FBP and ASiR groups with a tendency for better agreement in the ASiR group (Table 4) (percentage agreement between 83% and 97%). However, there was no statistically significant (p -values > 0.05) difference in percentage agreement between the FBP and ASiR groups suggesting non-inferiority of images during subjective assessment. No significant difference in the artefacts is noted between the two groups, and none of the examinations produced any diagnostically unacceptable images. An appendix has been added to show the number of ASiR and FBP cases under different subjective image quality scores in each domain assessed (Appendix A).

DISCUSSION

It is a well-known fact that accurate and fast imaging assessment of the traumatized spine is essential to evaluate spinal stability and integrity of the neural elements.¹⁷ There is ample evidence that CT outperforms plain radiography in many aspects.^{18–21} According to previous studies, the radiation dose is reported up to 10 times higher than that in conventional plain radiography in two planes (mean effective dose is 0.9–4.0 mSv).^{18,22} It is essential to modify CT techniques and protocols to reduce the radiation dose without compromising the image quality.

Traditionally, the CT image reconstruction algorithm is FBP, which is fast and robust.²³ This is an adequate reconstruction method in most situations at the routine level of radiation dose, particularly in non-obese patients. However, when the radiation dose is lowered and in cases of overweight/obese patients, FBP produces noisy images and artefacts.²⁴ Mathematical algorithms have been developed to smoothen the images, thereby improving the diagnostic quality of the noisy images, acquired with low amounts of radiation.

IR technique has long been used as a principal method of processing the images in nuclear medicine such as single-photon emission CT and positron emission tomography; however, owing to large amount of data in CT imaging and cumbersome mathematical processing, it has been impractical for clinical purposes. With recent advances in computing power, the data-processing capability of IR techniques has significantly improved and made it a feasible option in CT imaging. These techniques allow radiation dose reduction without compromising the image quality. Each vendor has their own uniquely named iteration method, which range from less computationally demanding algorithms, reconstructing in the image data domain, to more advanced IR algorithms, reconstructing in the raw data domain. IR in image space (Siemens Medical Solutions, Forchheim, Germany) is an IR technique iterating in the image domain alone. Sinogram-affirmed IR (Siemens Medical Solutions), adaptive iterative dose reduction 3D (Toshiba Medical Systems, Tokyo, Japan) and iDose⁴ (Philips Healthcare, Best, Netherlands) iterate in both the raw data domain and image domain, and ASiR and model-based IR (GE Healthcare) fully iterate with forward and backward reconstruction steps.¹⁰ Each of the IR techniques works in a different way. Further discussion on these techniques other than ASiR is out of scope of this article. ASiR is one of the post-acquisition image-processing algorithms, which unlike FBP, performs a hybrid iterative process of mathematical and statistical modelling to identify and selectively reduce noise of an image.^{7,8} ASiR transforms repeatedly the pixel Hounsfield values of an image until they converge on a final value by using matrix algebra.¹² Noise is inversely proportional to the square root of dose. By lowering image noise, this method allows tube current reduction, thus decreasing radiation dose, with recovery of image quality. The degree of ASiR ranging from 0% (100% FBP) to 100% (0% FBP) can be chosen by the radiologist to reconstruct CT images. A 0% ASiR setting would produce a CT scan using the traditional FBP method and a 100% ASiR setting would produce a CT scan with no noise but correspondingly an image with “plastic” texture, having very limited diagnostic value.^{12,15} At higher

Figure 1. (a, b) Sagittal CT reconstruction in both bone and soft-tissue windows of a cervical spine study in a 36-year-old female patient using adaptive statistical iterative reconstruction (ASiR) method. (c, d) Sagittal CT reconstruction in both bone and soft-tissue windows of cervical spine study in a 51-year-old male patient without using ASiR method (filtered back projection).

level ASiR, the contours of the objects begin to blur and make the images shinier with a more glazed appearance.^{9,25} Most protocols use a blend of ASiR and FBP with 10–40% ASiR settings.¹² In the present study, we chose 30% of ASiR in our low-dose cervical spine protocol based on our initial experience and consensus among the radiologists. Various studies have reported the benefits of using ASiR techniques in the abdomen, the chest, coronary CT angiography, the head and cervical spine.^{7,12,14,15,26,27}

ASiR allows the use of a higher scanner NI, which helps in reducing the tube current and radiation exposure.^{12,14,15} In the present study, the NI could be increased by 27% after implementation of ASiR in CT scan of patients with blunt cervical spine trauma. Our study confirmed that use of ASiR resulted in significant reduction in radiation dose (approximately one-third) with no statistically significant difference in image noise and subjective image quality compared with the FBP technique (Figure 1).

A recent study on the use of CT ASiR technique in evaluation of patients with cervical spine trauma showed considerable reduction in radiation dose (55.3% for CTDI and 53.7% for DLP) in the ASiR group compared with the FBP group; but there was lack of detailed evaluation of subjective image quality.¹¹ Another recent study by Komlosi et al⁹ looked at the effect of ASiR on different neuroradiology CT studies. In their study, they could achieve approximately 17.9% radiation dose reduction in CT studies of the cervical spine without compromising the image quality. A study by Maxfield et al, showed overall reduction of radiation exposure by 19%. In this article, CT studies of both brain and cervical spine were lumped together with over 100 patients in each arm. The breakdown between the CT brain and c-spine studies is not reported in the paper, so it is not possible to know for sure how many c-spines were performed.¹² Our study has adequate number of patients in both groups for better comparison of the radiation dose and image quality in greater details. Results of our study are encouraging with overall 36% reduction of radiation dose without any compromise in the image quality.

Our study has the following limitations. First, it is a retrospective study and may suffer from selection bias. We did not include and evaluate the patients with significant motion and streak artefacts caused by metallic or surgical implants, a potential selection bias and one of the limitations of our study. We evaluated the patients with only one type of CT scanner from a single manufacturer. As we did not compare the radiation dose

reduction and image quality between different techniques from the same vendor or from different vendors, it is difficult to comment on how this ASiR method fares in comparison to other similar available techniques. We did not look at the impact of body mass index on the radiation dose. Different regions such as the paraspinal muscles, spinal cord and surrounding air were selected by different studies for placing the region of interest to quantify objective image assessment.^{5,25} In the present study, we preferred the spinal cord for placing the region of interest, as this is within the bony spinal canal and most susceptible to image degradation related to the surrounding bones. This is also one of the areas of interest in spinal trauma. A small region of interest (40 mm² for the spinal cord) as in our study is a limitation, but this was necessary due to a lack of space in and around the spinal cord. We did not evaluate the blinded reader's ability to guess whether studies were performed with ASiR, which may have corrected for this potential bias. We did not assess the diagnostic accuracy or the effect of ASiR in the detection of fractures and other pathology, although this is being planned for a future study.

CONCLUSION

The results of our study showed that use of ASiR post-processing as a radiation dose reduction tool for the CT examinations of the cervical spine resulted in a substantial reduction (approximately 36%) in radiation dose while the image quality, both subjective and objective measurements, was maintained.

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APPENDIX A

Table A1. Subjective image quality assessment scores by each reader in all domains assessed

Subjective image parameters	Score ^a	FBP (<i>n</i> = 48)		ASiR (<i>n</i> = 30)	
		Reader SC	Reader AS	Reader SC	Reader AS
Subjective noise	1	16	17	11	15
	2	26	23	11	6
	3	6	8	7	9
	4	0	0	1	0
Sharpness	1	33	32	17	19
	2	12	16	9	10
	3	1	0	2	1
	4	2	0	2	0
	5	0	0	0	0
Soft tissue diagnostic acceptability	1	39	35	22	19
	2	8	13	6	10
	3	1	0	2	1
	4	0	0	0	0
Bone diagnostic acceptability	1	46	38	28	20
	2	2	10	2	9
	3	0	0	0	1
	4	0	0	0	0

^aSubjective image quality assessment scores.