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ORIGINAL ARTICLE

Comparing CNR, SNR, and Image Quality of CT Images Reconstructed with Soft Kernel, Standard Kernel, and Standard Kernel plus ASIR 30% Techniques

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ABSTRACT

AIM: Compare effect of soft kernel (SK) and 30% adaptive statistical iterative reconstruction (ASIR) and standard kernel (StK) techniques on image quality.

MATERIALS AND METHODS:Three radiologists blinded to the type of reconstruction kernel used, independently reviewed 2.5mm-thick- axial abdominal CT-scans performed for 66-randomly selected patients, optimized for oncologic imaging. The filtered-back-projection images were reconstructed using: SK, ASIR 30% and StK. The Contrast to noise ratio (CNRs) and Signal to noise ration (SNRs) were calculated. The visibility and sharpness of abdominal structures were rated (qualitatively). Summary of pair-wise comparisons among series for CNRs and SNRs were performed. Estimates and standard-error were based on a linear mixed model. P values were adjusted using the Tukey-Kramer method to control overall type I error rate.

RESULTS: Image series reconstructed with SK or ASIR had higher CNRs than those with StK alone ($P < 0.009$ and 0.002, respectively). Qualitatively images reconstructed with ASIR or SK were better than with the StK ($P < 0.05$). SK produced significantly fewer artifacts than ASIR 30%. There was no difference in the SNR among series.

CONCLUSION: Images reconstructed with SK or ASIR had better image quality than StK. Scanners that cannot use ASIR may benefit from using the SK technique to improve image quality.

Key words: ASIR 30%; Soft kernel; Standard Kernel; CNR; SNR; Noise

Key points: 1. ASIR 30% and Soft kernels help in decreasing the image noise; 2. ASIR30% and Soft kernels have better CNRs than images reconstructed with standard kernel; 3. Using soft kernel on existing platforms will alleviate the need to purchase new generation scanners.

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Abbreviations:
CelTrunk: celiac trunk;
ExtHepPV: extra hepatic portal vein;
GBwall: gall bladder wall;
Liv Parenchyma HPV: liver parenchyma hepatic portal vein;
SplArt: splenic artery;
AOIVC: aorta and inferior vena cava;
CBD: common bile duct;
CHD: common hepatic duct;
Liv: liver;
ASIR: adaptive statistical iterative reconstruction;
CNR: contrast-to-noise ratio;
visibility; and mesent-Art is superior mesenteric artery.

INTRODUCTION

The widespread use of computed tomography (CT) has led to an increase in radiation exposure[1] and thus to a possible increased risk of carcinogenesis[2,3]. Owing to radiation dose concerns associated with CT, several efforts have been made in the radiology community to reduce radiation dose without compromising the quality of diagnostic information[4]. These efforts include lowering the tube current–time product; using automatic exposure control; reducing the peak kilovoltage; using a higher pitch; and shielding radiosensitive organs such as the breast, thyroid, and lenses of the eye[4]. Unfortunately, decreasing the tube current (dose) can lead to suboptimal or non-diagnostic studies, unless countermeasures to decrease image noise are taken[4]. For this reason, researchers and CT manufacturers have sought to provide ways to decrease image noise that would permit more aggressive reduction of radiation dose, while maintaining diagnostically acceptable image quality[5-8].

One factor that can affect image noise is a component of the CT image reconstruction software called a kernel. These reconstruction kernels, which have been available for the past 20-30 years, include standard, soft, and edge-enhancing techniques, are applied on to the raw CT image data and are able to enhance aspects of the CT image. To our knowledge, the differences in image quality among CT images created using filtered back projection (FBP) with applied soft kernel (SK), standard kernel (StK), and adaptive statistical iterative reconstruction (ASIR) techniques have not been described. The purpose of this study is to evaluate the effect of SK on image quality compared to ASIR 30% and StK techniques.

METHODS

Following institutional review board approval of our study, patients who had routine oncology surveillance CT scans between January 1, 2010, and February 28, 2011 were selected from the radiology database. Only patients, who had had their images reconstructed with all three reconstruction kernels, i.e. filtered back projection using Stk, SK, and ASIR 30% plus Stk, were included. Our search identified 66 patients and these were included in the study. For these patients we recorded patient demographics, such as the age, gender, and the body mass index (BMI). The Stk technique is currently used for diagnosis routinely at our institution.

Scanning Technique

CT examinations of the abdomen and pelvis were performed using a commercial 64-detector CT scanner (Light Speed VCT, GE Healthcare, Milwaukee, WI) after administration of 80–120 mL of an intravenous contrast medium (Omnipaque 300, GE Healthcare, Cork, Ireland).

The images were acquired in the portal venous phase of contrast enhancement with a range of 150 to 350 mA and optimized for the patient's size using automated tube current modulation with a fixed noise index of 16. The maximum volume CT dose index (CTD_{ivol} is a standardized measure of radiation dose and is calculated by dividing $CTDI_w$ by the pitch factor) for the 40 cm display field of view (DFOV) and smaller group was 36 mGy and for the 42 cm DFOV and larger group was 48 mGy. All patients were scanned from the dome of the liver to the level of the ischial tuberosities. The scanning parameters were 64 × 0.625-mm detector configuration, 40 mm/sec table speed per gantry rotation, 0.8-second gantry rotation time, and 0.984:1 beam pitch. The images were reconstructed from the raw CT raw data at a 2.5-mm slice thickness at 2.5-mm intervals. The mean DFOV was 38.87 cm ± 3.84 cm (min 32 cm and max 50 cm).

Three different reconstruction techniques were used to create three sets of images for review which were applied to the filtered back projection (FBP): i.e. the StK +ASIR 30% (ASIR 30%), the StK technique, and the SK technique. The strength of ASIR at 30% was chosen based on information gained from other imaging centers regarding the acceptability of the image quality. For our retrospective study, all three reconstructions reviewed by three blinded abdominal radiologists with 6, 10, and 19 years of experience, respectively.

Qualitative Assessment

The images were viewed on a standard FDA-approved Phillip's iSite diagnostic picture archiving and communication system monitor (PACS). The standard screen was used for evaluation of the images. The reader radiologists were blinded to the reconstruction settings, and the images were displayed in a random order. The randomization was done by a presenting radiologist and the randomized images were sent to the PACS and stored under the respective patient data. The images were stripped off the DICOM headers so that only the presenting radiologist was aware of the reconstruction was used. StK, SK, and ASIR 30% images were reviewed side-by-side (placing the images next to each other on the monitor) in a blinded fashion in the axial plane. The radiologists underwent a training session to optimally assess the image quality prior to evaluation of the three different set of images.

The images were qualitatively assessed according to the European Guidelines on Quality criteria for CT[9]. Three radiologists reviewed the images after the training sessions and scored them on a scale of 1 to 5 (1 = worst and 5 = best) for image quality (sharpness, contrast, noise, artifacts, and diagnostic acceptability).

Visualization/Conspicuity: The radiologists assessed conspicuity of the following structures: the diaphragm; the liver and spleen; and retroperitoneal structures such as the kidneys, and any herniation of the viscera. The radiologists used the following grades: 1 = cannot identify, 2 = suboptimal, 3 = acceptable, 4 = better than acceptable, 5 = excellently visualized.

Critical Reproduction: Critical reproduction of small structures such as intrahepatic and portal vein, hepatic veins, liver hilum structures, CBD, CBD in the pancreatic parenchyma, gallbladder wall, extra hepatic portal vein, splenic artery and splenic vein, superior mesenteric vein, aorta and inferior vena cava, celiac trunk, and superior mesenteric artery were evaluated and were also assessed using the following scale: 1 = blurry, 2 = suboptimal, 3 = acceptable, 4 = better than acceptable, and 5 = sharpest.

Visualization of large vessels (aorta and iliac arteries), liver, spleen, diaphragm, and retroperitoneal organs was assessed using the following scale: 1 = cannot identify, 2 = suboptimal, 3 = acceptable, 4 = better than acceptable and 5 = excellently visualized.

Image contrast, Image noise and Artifacts

Image contrast was ranked and assessed by using a five-point scale (5 = excellent image contrast, 4 = above average contrast, 3 = acceptable image contrast, 2 = suboptimal image contrast, and 1 = very poor contrast).

Subjective image noise was assessed by using a five-point scale (1 = minimal image noise, 2 = less than average noise, 3 = average image noise, 4 = above average noise, and 5 = unacceptable image noise).

The following artifacts were assessed: helical or windmill artifacts; streak artifacts owing to metal and leads; beam-hardening artifacts owing to the patients having their arms by their side; truncation

artifact owing to large body size or off-centering; and blotchy or pixilated appearance of the CT image.

Artifacts anywhere seen on the CT scans were graded using a four-point scale: 1 = artifacts affecting diagnostic information, 2 = major artifacts affecting visualization of major structures but diagnosis still possible, 3 = minor artifacts not interfering with diagnostic decision-making, and 4 = No artifacts.

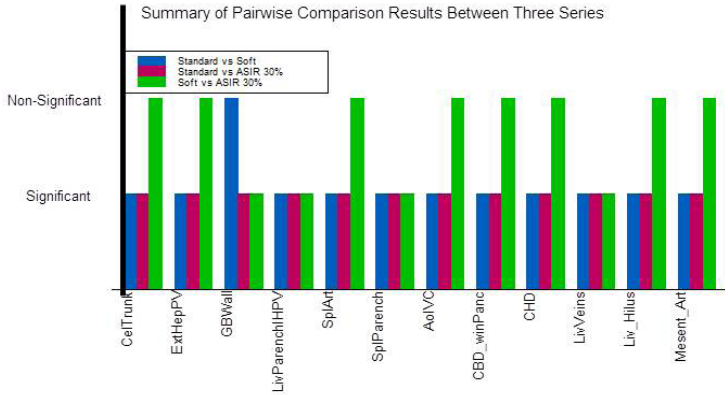

Figure 1 Pairwise comparison of the critical reproduction of abdominal structures taken during the portal venous phase of contrast enhancement and reconstructed with (ASIR) 30%, SK, or StK alone. These were considered statistically significant if $p<0.05$. The categories are items assessed qualitatively, e.g., critical reproduction of celiac trunk, gallbladder wall, etc.: Those comparisons that were not significant had taller bars. For example, for critical reproduction of the celiac trunk, SK *vs* ASIR 30% (green bar) was insignificant. The trend of graph of quality measures suggests that there was little difference between SK and ASIR 30% (the majority of the green bars indicate insignificant differences). In contrast, there was often significant difference (indicated by short bars) between StK and SK (blue bars) and also between StK and ASIR 30% (red bars).

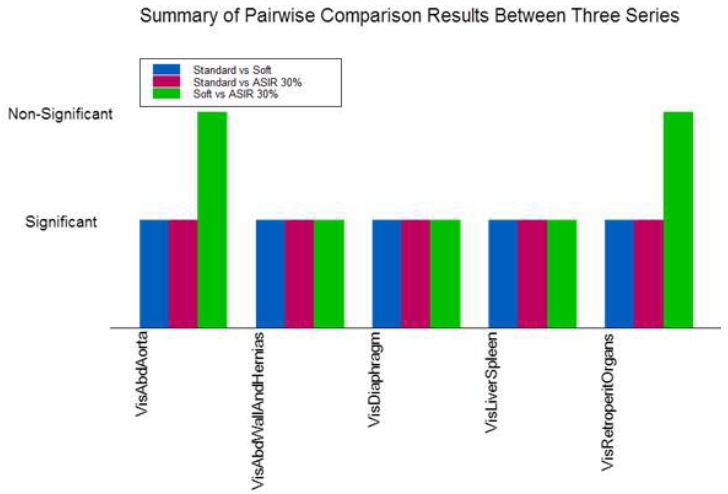

Figure 2 Pairwise comparisons of the qualitative visualization/ conspicuity (Vis) of various abdomen structures taken during the portal venous phase of contrast enhancement and reconstructed with adaptive statistical iterative reconstruction (ASIR) 30%, SK, or StK alone. These were considered statistically significant if $p<0.05$. The categories are items assessed qualitatively, e.g., quality of visualization of celiac trunk, gallbladder wall, etc. Those comparisons that were not significant had taller bars. For example, for visualization of the celiac trunk, SK *vs* ASIR 30% (green bar) was insignificant. The trend of graph of quality measures suggests that there was little difference between SK and ASIR 30% (the majority of the green bars indicate insignificant differences). In contrast, there was often significant difference (indicated by short bars) between StK kernel and SK (blue bars) and also between StK and ASIR 30% (red bars).

Quantitative Assessment

The contrast-to-noise ratio (CNR) and the signal-to-noise ratio (SNR) of the scans for each of the three reconstruction techniques were evaluated. For calculation of the CNR and SNR, the Hounsfield unit values of the liver were measured using circular regions of interest (ROIs) over an area of 20 mm^2. The placement of ROIs was standardized. The ROI and standard deviation (SD) for the anterior subcutaneous fat of the patient was measured at L4 vertebral body level. The ROIs were drawn on the aorta below the level of the diaphragm and on the liver posterior to the right portal vein. These ROIs were drawn on each of the three series at the same level. The CNR was calculated as the absolute value of (ROI value in the normal liver tissue minus ROI of fat) divided by (SD of fat). The SNR value for the liver images, for example, was calculated as the value of the ROI in the liver divided by the SD of the ROI in the liver.

Percent reduction in SD is equal to noise reduction. SD of the Liver ROI reconstructed with SK and ASIR 30% techniques were compared with the image reconstructed with the StK technique. Noise reduction was calculated as [(Mean SD of liver ROI on StK-mean SD of liver ROI on ASIR 30 %) / mean SD of liver ROI on StK ×100].

Statistical Analysis

For each scoring category, a multivariate ordinal regression model using the generalized estimating equation method was used to assess the effect of series on relative rank, adjusting for reader, age, sex, and display field of view (DFOV). The relative ranks were obtained by comparing three series within the same patient and same reader: the highest score was assigned a relative rank of 1, and the lowest score was assigned a relative rank of 3. Ties were assigned the same relative ranks. Therefore, an ordinal regression model was considered to be the most appropriate analytic model. The generalized estimating equation method takes into account the correlations among measurements from the same patient.

Summary of pair-wise comparisons among series with respect to the CNR and SNR were performed. Estimates and standard error were based on a linear mixed model. P values were adjusted using the Tukey-Kramer method to control overall type I error rate. *P*-value was considered statistically significant at < 0.05.

RESULTS

Our cohort included the CT scans from 31 men and 35 women. The patients' mean age was 59 years (range, 19-88 years). The average DFOV was 39 cm (range, 32-50 cm). The BMI of the patients was 25.8 + SD 7.25.

Qualitative Assessment

On the basis of model estimates, CT images reconstructed with the ASIR 30% and SK techniques were significantly better compared to the StK technique for assessment of abdominal structures (Figure 1), for the visualization/conspicuity of various abdominal structures (Figure 2) and for image contrast (Figure 3).

The SK and StK techniques produced significantly fewer minor artifacts (blotchy /pixilated) than did the ASIR 30% (P =.0001) (Fig 3). These minor artifacts from ASIR 30% did not degrade diagnostic quality of the CT image interpretation and all the images were interpretable.

There was no significant difference in the quality of the images with regard to patient weight or DFOV (Table 1).

It was noted that readers differed among themselves significantly (P <0.01) in terms of all scoring categories, indicating low agreement

among readers with regard to relative ranking. The ASIR 30% technique was ranked the best for image noise reduction and for contrast in 92% and 89% of the cases, respectively by all readers (Figure 4).

Quantitative Assessment

SNRs did not significantly differ among series on the basis of linear mixed model estimates ($P = 0.86$) by likelihood ratio test.

The ASIR 30% and SK had significantly higher CNRs than did the StK alone ($P < 0.002$ and.009, respectively) (Table 2).

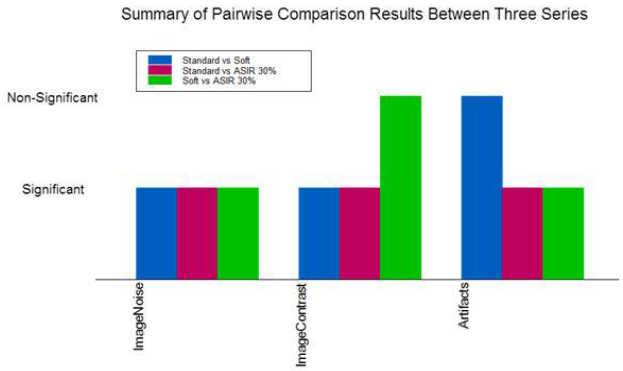

Figure 3 Pairwise comparison of the qualitative assessment of image noise, contrast and artifacts of images of various abdomen structures taken during the portal venous phase of contrast enhancement and reconstructed with adaptive statistical iterative reconstruction (ASIR) 30%, SK, or StK alone. These were considered statistically significant if $p<0.05$. For example, for visualization of image noise on the three different reconstructions all the bars are equal suggesting that the noise was different between the three reconstructed images. The image contrast was not statistically significant between the SK and the ASIR30% (green bar) and the artifacts were not statistically significant between StK and SK (blue bar).

The ASIR 30% and the SK techniques had similar CNRs ($P = 0.79$). ASIR 30% yielded a 22% higher CNR than StK. The SD of the liver ROI (minimum and maximum) was 12.80-26.3, 12.60-27.8, and 14.60-37, for the ASIR 30%, the SK, and the StK techniques, respectively.

The ASIR 30% technique based on SD, reduced image noise in the liver images by 20.6% compared with the StK alone. The SK technique reduced liver image noise by 18.2 % compared with the StK technique alone. DFOV did not have a statistically significant effect on CNR or on image noise difference.

DISCUSSION

Owing to the concerns about increased radiation exposure in patients undergoing CT examination, several techniques have been developed to minimize radiation dose without compromising image quality.

Table 1 Qualitative comparison of ASIR 30% vs. SK and StK based on patients DFOV.

Category	ASIR *vs* Soft and Standard	*P* values
Image Noise	DFOV	0.2579
Image Contrast	DFOV	0.7715
Artifacts	DFOV	0.3095

Table 2 Quantitative Assessment of Liver Contrast-to-Noise Ratio (CNR), with Summary of Pair-wise Comparisons among Series with Respect to CNR.

Quantitative Assessment of Liver CNR			
Comparisons	**Estimated mean CNR**	**Standard Error**	****Adjusted *P* value**
*ASIR 30% vs. Soft Kernel	0.009	0.029	0.95
ASIR 30% vs. Standard Kernel	0.14	0.03	< 0.0001
Soft Kernel vs. Standard Kernel	0.13	0.03	0.0002

*ASIR 30% plus StK; **adjusted using the Tukey-Kramer method to control overall type I error rate.

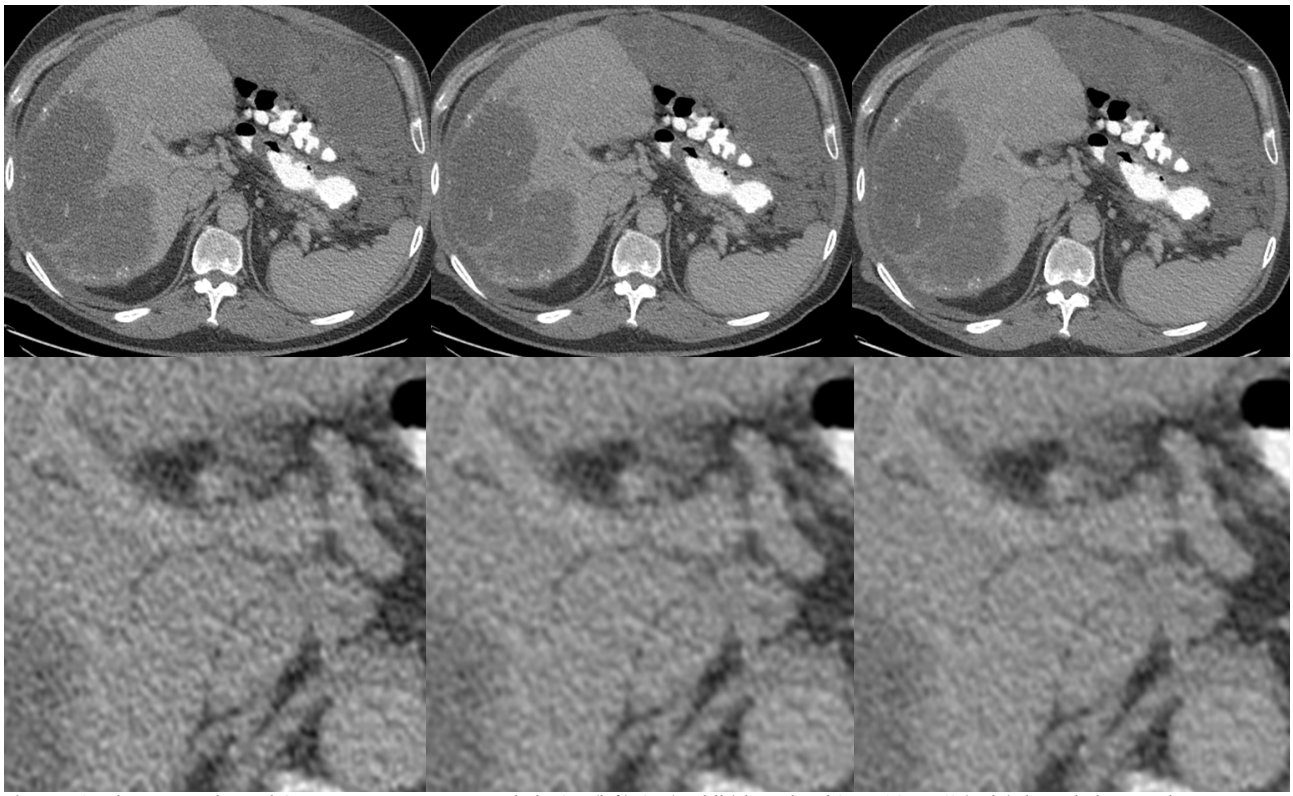

Figure 4 Axial contrast enhanced CT scans reconstructions with the StK (left), SK (middle) kernel and StK +ASIR30% (right) through the porta hepatis region.

Several newer CT scanners can apply techniques such as statistical and pure iterative reconstruction to reduce image noise on CT scans. However, such techniques are not ubiquitous and are typically not available retroactively for older models of CT scanners. ASIR is an add-on feature and must be purchased for existing scanners that do not have this software already built in. To control equipment costs while allowing radiation exposure to be minimized, it can be useful to re-examine various parameters for CT image creation, such as the SK, for the purpose of image noise reduction and image quality improvement.

As this was our first experience with using the SK and ASIR30% techniques, we were not aware of what artifacts or limitations we might encounter. Because no additional radiation dose was involved in making additional image sets, we made the additional sets to avoid the circumstances of unanticipated artifacts limiting interpretation. In the images reconstructed with the SK or the ASIR 30% techniques, we found significantly less image noise than in images reconstructed with the StK technique alone, which is consistent with the improved image noise described by Singh and others[8,10-17]. ASIR 30% and the SK technique performed similarly with respect to image noise reduction (20.6% *vs* 18.2%) compared with the StK technique alone. In our study the soft and the ASIR 30% reduced noise compared to the StK technique alone. Suggesting that these techniques will produce a sharper image since, as the noise levels increases, the resulting images are grainier.

Our study suggests that the image quality of ASIR 30% plus StK and the SK techniques is superior to the StK technique based on higher CNR of the liver and noise reduction on these series. Similar results were obtained with ASIR by Matsuda *et al*[18], who evaluated the value of ASIR in CT porto-venography; they found that ASIR helped reduce the noise and improve the CNR of the liver images and the liver vasculature images. Although the ASIR technique has been shown to enable reduce radiation dose without compromising image quality[19], to our knowledge, no previous studies have evaluated images to assess the effect of the SK technique compared with the ASIR30% and StK techniques. In our study, the SK technique produced better image quality, quantitatively and qualitatively than the StK technique and similar image quality compared to ASIR30%.

In our experience with General Electric CT scanner, we found that the various models that we have, from a 16-detector row through a 64-detector row, have a SK capability. We suspect that for other vendors, a similar reconstruction variable is likely available and that it would be worthwhile to evaluate the capabilities of such a variable on older generations of equipment still in use to improve image quality and to facilitate a program of radiation dose reduction.

Another issue that we encountered was that of image artifacts. In our experience, the ASIR 30% plus StK reconstructions showed an increased incidence of blotchy and pixelated images, similar to those described by Prakash *et al*[8] using ASIR40%.However, it was minimal and did not compromise the image quality. Interestingly, Singh et al using 30%, 50% and 70% ASIR[10] published a more recent study stating that they did not see such artifacts on their images conceivably due to interval software improvements.

This study has several limitations. First it was retrospective study. Secondly we did not use a low-dose CT technique, as might be used in the general community, to evaluate the reconstructions techniques; rather, we used a routine CT dose as we were evaluating patients in an oncologic setting, which is used to assess subtle disease. Thirdly, we evaluated the quality of the images, only in the abdomen and only on the portal venous phase of contrast enhancement. Fourthly, we did not evaluate ASIR levels other than 30%. Higher levels of ASIR would have further decreased image noise but may perhaps also have been associated with more image artifacts. Despite these limitations we found that the SK and ASIR 30% performed similar to one another at a routine dose CT to reduce the image noise and improve image quality, when compared to the StK.

CT image noise is improved quantitatively and qualitatively when images are reconstructed using either the ASIR 30% or the SK techniques compared with the StK technique. Although newer, more powerful reconstruction technologies exist, such as model-based iterative reconstruction on the newest scanners, application of a SK compared favorably with ASIR 30% and offers a method for noise reduction, improved image quality and potentially for radiation dose reduction that may be applicable on the fleets of existing older CT scanning platforms.

CONFLICT OF INTEREST

There are no conflicts of interest with regard to the present study.

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