Original Investigation

Advanced Modeled Iterative Reconstruction (ADMIRE) Facilitates Radiation Dose Reduction in Abdominal CT

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Rationale and Objectives: This study aimed to determine the potential degree of radiation dose reduction achievable using Advanced Modeled Iterative Reconstruction (ADMIRE) in abdominal computed tomography (CT) while maintaining image quality. Moreover, this study compared differences in image noise reduction of this iterative algorithm with radiation dose reduction.

Methods: Eleven consecutive patients scheduled for abdominal CT were scanned according to our institute's standard protocol (100 kV, 289 reference mAs). Using a proprietary reconstruction software, CT images of these patients were reconstructed as either full-dose weighted filtered back projections or with simulated radiation dose reductions down to 10% of the full-dose level and ADMIRE at either strength 3 or strength 5. Images were marked with arrows pointing on anatomic structures of the abdomen, differing in their contrast to the surrounding tissue. Structures were grouped into high-, medium-, and low-contrast subgroups. In addition, the intrinsic noise of these structures was measured. That followed, image pairs were presented to observers, with five readers assessing image quality using two-alternative-forced-choice comparisons. In total, 3000 comparisons were performed that way.

Results: Both ADMIRE 3 and 5 decreased noise of the anatomic structures significantly compared to the filtered back projection, with an additional significant difference between ADMIRE 3 and 5. Radiation dose reduction potential for ADMIRE ranged from 29.0% to 53.5%, with no significant differences between ADMIRE 3 and 5 within the contrast subgroups.The potential levels of radiation dose reduction for ADMIRE 3 differed significantly between high-, medium-, and low-contrast structures, whereas for ADMIRE 5, there was only a significant difference between the high- and the medium-contrast subgroups.

Conclusion: Although ADMIRE 5 permits significantly higher noise reduction potential than ADMIRE 3, it does not facilitate higher levels of radiation dose reduction. ADMIRE nonetheless holds remarkable potential for radiation dose reduction, which features a certain dependency on the contrast of the structure of interest. Applying ADMIRE with a strength of 3 in abdominal CT may permit radiation dose reduction of about 30%.

Key Words: Radiation dose reduction; CT; iterative reconstruction; ADMIRE.

BACKGROUND

Computed tomography (CT) of the abdomen is an indispensable tool for clinical diagnosis.Nonetheless, radiation dose exposure raises several widely known concerns. Hence, according to the as-low-as-reasonably-achievable principle, radiation dose should be reduced while preserving diagnostic image quality.

As radiation dose reduction in CT examinations leads to increased image noise (given all other parameters constant) and thus impaired diagnostic image quality, one very promising technique for radiation dose reduction is the implementation of iterative reconstruction (IR) algorithms for noise reduction. In contrast to traditional weighted filtered back projection (FBP), IR algorithms can be considered as feedback mechanisms, with a simulator of the CT physics in the feedback loop. The feed forward loop updates the reconstruction image, based on deviations between the measured and the simulated scans (1). One of the most recent commercially available IR algorithms is the Advanced Modeled Iterative Reconstruction (ADMIRE; Siemens Healthineers, Forchheim, Germany), which uses IR from the raw data domain in combination with noise reduction in the image space in a hybrid manner. It applies statistical modeling in the raw data domain, followed by back projection, application of statistical model in the image domain (regularization), and

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forward projection. The resulting pseudo raw data are compared to the measured data and iteratively reinserted into the loop afterward (2). Compared to its predecessor SAFIRE (Sinogram-affirmed Iterative Reconstruction), the analysis incorporates not only nearest neighbor data but also a larger neighborhood at an anatomically reasonable length scale with respect to clinical applications (2). The ADMIRE strength setting primarily controls the level of noise reduction the algorithm aims at and therefore an increase in ADMIRE strength should allow higher radiation dose reduction potential.

Nonetheless, the question remains to what extent ADMIRE allows reducing radiation dose while maintaining image quality. This study therefore aimed to determine the level of radiation dose reduction, at which images of abdominal structures at reduced radiation dose levels, but iteratively reconstructed, exhibited similar quality to full-dose FBP images. For this purpose, two-alternative-forced-choice comparisons of simulated radiation dose reductions of abdominal CTs with full-dose images were applied.

METHODS

Patient Examination

This single-center study was approved by the institutional review board and complies with the Declaration of Helsinki. Eleven consecutive patients (7 male, 4 female, mean age 64.1 ± 11.4 years) scheduled for thoracoabdominal CT were prospectively included in this study. Written informed consent was obtained from all patients.

All examinations were performed on a 128-section CT system (Definition AS+; Siemens Healthineers), with a collimation of 128 × 0.6 mm and a pitch factor of 0.9. Attenuation-based tube current modulation (CAREdose 4D) and tube voltage selection (CAREkV) were used. The image quality level was set to a reference tube current of 289 mAs and a tube voltage of 120 kV, with the CAREkV algorithm selecting a tube voltage of 100 kV in all patients. Furthermore, 100 mL of contrast agent (Iomeron 350; Bracco, Konstanz, Germany) was injected using a power injector at a flow rate of 3 mL/s, followed by a 40 mL saline flush at the same flow rate. Scan started with a delay of 70 seconds. kV, mAs, CT dose index volume (in mGy), and dose-length-product (in mGy·cm) were saved within the patient protocol.

Image Reconstruction

For image reconstruction purposes of this study, we relied on the proprietary reconstruction workstation ReconCT (Siemens Healthineers). This software tool allows one to read CT raw data and perform reconstructions identical to the FBP and ADMIRE reconstructions at the acquisition workstation, but in addition, it offers the possibility of adding noise to the image material. The addition of noise simulates an examination with reduced tube current and thus reduced radiation dose. Special efforts have been taken to calibrate the amount and structure of noise added to the images to simulate defined levels of radiation dose reduction, and ReconCT has been proven to sufficiently manage this task (3).

CT raw data were loaded into the ReconCT workstation and reconstructed with standard FBP and a soft-tissue reconstruction kernel (B31f). ADMIRE reconstructions were performed with the corresponding soft-tissue kernel (I31f) at a full-dose level, and additionally with simulated dose reduction down to 10% of the original dose in steps of 10%. Reconstructed datasets were transferred to a workstation (Horos; http://www.horosproject.org/) and viewed in MPR mode (5-mm axial slice thickness, window center 40 HU [Hounsfield unit], window width 350 HU). Arrows were added to the axial slices, pointing on different anatomic structures: adrenal glands (AGs), common hepatic artery (CHA), extrahepatic part of the common hepatic duct (CHD), falciform ligament (FL), intrapancreatic part of the common bile duct (CBD), and the duodenal wall (DW).

Every structure was marked by S.E. with an arrow in 5 of the 11 patients' images arbitrarily, and marked images were exported in DICOM format. In addition, regions of interest (ROIs) were drawn within the structures and their attenuation was noted along with the attenuation of the surrounding tissue. The difference between these two attenuation values was used as a measure for the intrinsic contrast of the given anatomic structure. The structures above were grouped into high-contrast (AG, CHA), medium-contrast (CHD, FL), and low-contrast (CBD, DW) subgroups according to their attenuation differences. The standard deviation within the ROIs, measured in HU, was used as a surrogate parameter for the noise of these structures (3).

For image evaluation, a dedicated monitor system (EIZO RadiForce RX650, Eizo, Hakusan, Japan) was used, with a home-built software tool presenting two images side by side. One of these two images (randomly assigned to either the monitor's left or right side) always constituted the full-dose FBP of a given anatomic structure, and the image on the monitor's other side was always a dose-reduced iteratively reconstructed image of the identical structure of the same patient. The user was asked to click on the image displaying the marked structure in superior manner (two-alternative-forced-choice). There was no specific definition of "superior" given, but the observers were to decide which image they would prefer for diagnostic issues. After clicking on the image of choice, the given answer was saved and the next random image pair was presented. Because of the random presentation and random assignment of the dose-reduced image to either the monitor's left or right side the observers could be considered blinded. In total, five observers (four board-certified radiologists, one radiology resident with 4 years of experience) were trained with datasets not part of the study and subsequently rated 3000 image pairs. The observers performed the rating procedure at different time points without any communication between them.

Statistical Analysis

The differences between the anatomic structures' attenuation and the surrounding tissue as a measure for the structures'