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Radiation dose reduction in cardiovascular CT angiography with iterative reconstruction (AIDR 3D) in a swine model: a model of paediatric cardiac imaging

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AIM: To investigate the potential dose reduction in cardiovascular computed tomography angiography (CTA) in a swine model using 320-detector volume CT with adaptive iterative dose reduction in three dimensions (AIDR 3D) reconstruction to maintain a comparable image quality (IQ) to that reconstructed by a conventional filtered back projection (FBP) algorithm.

METHODS AND MATERIALS: Twenty-four mini-pigs underwent cardiovascular CTA four times at 80 KVp and different tube currents. An automatic exposure control (AEC) system was used and the noise index (NI) was predetermined at a standard deviation (SD) of 20 (Method A, routine dose), and 25, 30, 35 (Methods B–D) to reduce the dose gradually. Method A was reconstructed with FBP. Methods B–D were reconstructed using AIDR 3D (strong). Two radiologists graded IQ by reviewing both cardiac and vascular structures using a five-point scale. Quantitative IQ parameters of image noise, signal-to-noise ratio (SNR), and contrast-to-noise ratio (CNR) were measured and compared. A receiver-operating characteristic (ROC) analysis was performed to select a radiation reduction threshold and maintain comparable IQ (score $\geq$4).

RESULTS: Method B and C had significantly lower image noise ($p<0.0001$), higher CNR and SNR than Method A ($p<0.0001$). Compared with Method A (noise: 52.7±8.3; SNR: 11.7±2.8; and CNR: 9.9±2.7), Method C had comparable subjective IQ and higher objective IQ (noise: 38.9±6.1; SNR: 16.3±3.5; and CNR: 13.5±3.3). The results of the ROC curve showed that Method C (SD30) was the optimal dose threshold to maintain a comparable subjective IQ (AUC: 0.85, 95% confidence interval [CI]: 0.80–0.90). The effective dose (ED) of Method C was reduced by 49%, compared to that of Method A (0.33±0.08 mSv versus 0.65±0.15 mSv).

CONCLUSION: AIDR 3D at a strong level combined with an AEC system can potentially reduce the ED by 49% and maintain an IQ comparable to that achieved using a routine-dose and FBP reconstruction in mini-pig cardiovascular CTA.

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Introduction

Multisection computed tomography (CT) has been widely used in paediatric congenital heart disease (CHD) with constant improvements in temporal and spatial resolution.[1,2] Infants are at least four-times more sensitive to X-rays than adults.[3] In addition, children have a higher risk of radiation-induced cancer due to their longer life expectancy with longer post-exposure latent periods than adults[3]; thus, the radiation dose due to MSCT in infants is a concern. To date, the radiation dose in paediatric cardiovascular CT angiography (CTA) has been reduced to 0.4–2.8 mSv,[2,4,5] in combination with various low-dose techniques. The dose is individualized depending on body weight (or body size) and imaging parameters are adapted,[4] such as a reduction in tube current and voltage,[4,6] automatic exposure control (AEC),[7,8] and the use of the prospective electrocardiogram (ECG)-gating technique[5,9]; however, conventional filtered back projection (FBP) algorithm reconstruction usually causes an increase in image noise when the tube potential or current is reduced, which affects image quality (IQ) significantly.[9]

Iterative reconstruction (IR) algorithms have been used in CT reconstruction in recent years. It has been demonstrated that IR can significantly reduce noise in adult cardiovascular disease imaging. Even when the dose was reduced by 62.5%, the diagnostic IQ was maintained.[10] There are, however, few reports on the application of IR techniques in the field of paediatric cardiovascular CT. Han *et al.*[11] and Miéville *et al.*[12] studied the influence of SAFIRE (Sinogram Affirmed Iterative Reconstruction) and ASIR (Adaptive Statistical Iterative Reconstruction) on cardiovascular IQ in infants. They found that IR improved the subjective and objective quality indices (signal-to-noise ratio [SNR], and contrast-to-noise ratio [CNR]) of images.[11,12] AIDR 3D (Adaptive Iterative Dose Reduction in three dimensions), which is an algorithm that reduces streak artefacts and image noise in the projection domain and the image domain, has not been fully evaluated.[13]

It is necessary to apply the ALARA (as low as reasonably achievable) principle to paediatric cardiovascular CTA.[14] Therefore, in the present study, normal mini-pigs were selected to simulate 0–3-year-old infants to investigate the potential reduction dose during cardiovascular CTA using low-dose prospective ECG-gating, 320-detector CT with AIDR 3D reconstruction to maintain a comparable IQ to that using conventional FBP reconstruction.

Materials and methods

Animal preparation

Twenty-four Chinese mini-pigs were selected and categorized into three groups according to their weight (range: 0–5, 5.1–9, and 9.1–15 kg), with eight in each. The animals were injected intraperitoneally with 0.4 ml/ kg xylazine hydrochloride (1.5 ml: 30 mg; Jilin Huamu Animal Health Product Company, Changchun, China) to induce anaesthesia. They were then fixed in the supine position and an intravenous catheter (24 G, 0.75″) was placed in the vein at the ear edge. The ECG-gating device was connected. If any of the swine awakened during the experiment, additional anaesthesia was administered. The study was approved by the local Animal Ethics Committee.

CTA protocol

Cardiovascular CTA was performed on a 320-detector CT system (Aquilion One, Toshiba Medical Systems, Tochigi-ken, Japan). Following anaesthetization, the scan length was set at 160 mm and covered the area from the thorax to the lower edge of the costal arch. The Toshiba CT systems uses the AEC technique (SureExposure^{3D}, Toshiba Medical Systems), which adjusts the tube current to maintain a user-specified noise index (NI) in the image data. The tube current is applied to a patient-equivalent water phantom to achieve the selected standard deviation (SD).[15] Both reconstructions (FBP and AIDR 3D) were used at four different NI levels (SD: 20, 25, 30, and 35). The routine-dose scan (80 kVp, SD20) was performed first and defined as Method A. The tube voltage was unchanged (80 kVp) and the tube current was reduced by gradually increasing the NI (SD 25, 30 and 35). These low-dose scans were defined as Methods B, C, and D, respectively. The scans were performed over 2 days. Methods A and B were conducted on the first day with an interval of 0.5 hours. Methods C and D were conducted the following day using the same intervals. The reference standard setting of NI was decided according to the initial clinical experiences and vendor recommendation. Intravenous contrast medium (iohexol, 300 mg iodine/ml; GE Healthcare, Shanghai, China) was administered using a dual-tube high-pressure syringe (REF XD 2051, Ulrich Medical, Belgium, Germany) with a flow of 1–1.25 ml/ kg and a flow rate of 0.8–1 ml/s, and then 10 ml of saline was injected at the same speed. The automatic tracking triggering technique was employed, the region of interest (ROI) of 1–2 cm^2 was set in the descending aorta at the level of the pulmonary artery bifurcation, and the triggering threshold was 80 HU. Scanning started when the CT value reached the threshold.

The imaging parameters were as follows: prospective ECG-triggering scan mode, triggering time was 40–50% of the R–R interval, gantry rotation time was 0.35 seconds, collimator was 0.5 mm, section thickness was 1 mm, interval was 1 mm and field-of-view was 200mm. The end systolic window (a prospective exposure window of 40–50% of the R–R interval) was chosen due to the high heart rates of the pigs. A single-beat half-segment acquisition was also used.

CT data reconstruction and image analysis

Method A (the routine-dose) underwent FBP reconstruction and Methods B, C, and D (low-dose) underwent AIDR 3D reconstruction with a strong reduction in noise level. Images of the mediastinal and lung windows were reconstructed using the FC43 and FC52 convolution kernels,