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Technical report

Gated cardiac CT in infants: What can we expect from deep learning image reconstruction algorithm?

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ABSTRACT

Background: ECG-gated cardiac CT is now widely used in infants with congenital heart disease (CHD). Deep Learning Image Reconstruction (DLIR) could improve image quality while minimizing the radiation dose.
Objectives: To define the potential dose reduction using DLIR with an anthropomorphic phantom.
Method: An anthropomorphic pediatric phantom was scanned with an ECG-gated cardiac CT at four dose levels. Images were reconstructed with an iterative and a deep-learning reconstruction algorithm (ASIR-V and DLIR). Detectability of high-contrast vessels were computed using a mathematical observer. Discrimination between two vessels was assessed by measuring the CT spatial resolution. The potential dose reduction while keeping a similar level of image quality was assessed.
Results: DLIR-H enhances detectability by 2.4% and discrimination performances by 20.9% in comparison with ASIR-V 50. To maintain a similar level of detection, the dose could be reduced by 64% using high-strength DLIR in comparison with ASIR-V50.
Conclusion: DLIR offers the potential for a substantial dose reduction while preserving image quality compared to ASIR-V.

1. Introduction

Millions of babies are born with a congenital heart disease (CHD) every year.[1] An accurate diagnosis of CHD before surgical correction is crucial. ECG-gated cardiac CT remains the standard imaging method due to its high spatial and temporal resolution.[2] CT provides good image quality in a short acquisition time, reducing the need for sedation. Furthermore, the three-dimensional volumetric datasets available with CT are useful for pre-operative evaluation of anatomical structures.[3]

Recently, reconstruction algorithms based on artificial intelligence, such as deep learning image reconstruction (DLIR), have been introduced to routine clinical practice. DLIR is the first Food and Drug Administration cleared technology to utilize a deep neural network-based reconstruction engine to improve image quality on CT.[4] Noise is suppressed without impacting anatomical and pathological structures. Dose reduction has been reported by several authors for adult cardiac CTs.[5–7] However, to our knowledge no study was focused on pediatric cardiac CT. To objectively assess a potential dose reduction in CT with a new algorithm, phantom study is often used as a standard since an experimental process conducted directly on patients to decrease dose and assess image quality is not feasible.[8]

The objective of this study was to optimize CT radiation exposure while maintaining an equivalent image quality for the diagnosis of CHD using a DLIR reconstruction.

Abbreviations: ASIR-V, Adaptive Statistical Iterative Reconstruction-V; CHD, Congenital Heart Disease; CTDI, Volume CT dose index; DLIR, Deep Learning Image Reconstruction; ECG, Electrocardiography; HU, Hounsfield Unit; NPS, Noise Power Spectrum; NPWE, Non-Prewhitening With Eye filter; TTF, Target Transfer Function.

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2. Materials and methods

2.1. Materials

A pediatric chest anthropomorphic phantom was used to assess image quality and the potential dose reduction using DLIR. The phantom mimics the attenuation of a 6-months old child and contains two separate parts: a soft-tissue background to assess the noise and a 2 cm-diameter contrast rod (400 HU at 80 kVp) to assess the CT spatial resolution. A platform connected to the CT could simulate a heart beating at 130 bpm without moving the phantom.

2.2. Image acquisition

Phantom was scanned on a 256-detectors Revolution ™ CT (GE Healthcare), using the clinical protocol for CHD in axial mode with a 160 mm collimation for four dose levels: 0.7, 1.3, 2 and the mean clinical dose, 2.6 mGy. The gantry rotation time was 0.28s, the tube voltage was 80 kVp and automatic tube current modulation was used to perform the acquisitions. Acquisitions were repeated 20 times to statistically obtain precise image quality results.

Contiguous images were reconstructed using a slice thickness of 0.625 mm with various iterative reconstruction algorithms, ASIR-V0, ASIR-V50, ASIR-V80 and DLIR-H. The CTDI was extracted from the dose report of each exam.

2.3. Quantitative analysis

The quantitative analysis was performed by a medical physicist (A.V., with five years of experience). The noise magnitude and texture were assessed using 600 regions of interest of 200 × 200 pixels in the homogeneous phantom part, following the methodology described by Boone et al.[9]

Then, the CT spatial resolution was computed using the edge of the high contrast rod, following the methodology described by Samei et al.[10] 500 squared regions of interest of 200 × 200 pixels were used to calculate the target transfer function (TTF), which measures how spatial frequencies pass through the CT.[5] The minimal distance between two high contrast vessels to correctly distinguish them was then extracted from the TTF. The value of the TTF at 5% was used, which commonly represents the spatial resolution limit to distinguish two structures.[11]

By integrating the noise properties and the CT spatial resolution (TTF), the detectability of two simulated 1 mm in diameter enhanced vessels at 250 and 400 HU was assessed using a mathematical model observer described by Ott et al.[12] This model has demonstrated a good agreement with human observers' performances.[13] The contrast values of the two vessels were chosen based on the minimal enhancement accepted clinically for the ascending aorta and pulmonary trunk. The area under the receiver operating characteristic curve (AUC) was used as a figure of merit to describe the detectability and fitted as a function of the dose level. Potential dose reduction (while maintaining similar AUC values) was computed by comparing DLIR-H and ASIR-V 50, the actual clinical standard.

2.4. Statistical analysis

All analyses were performed using the Scipy (v1,9,0) package for Python (v3.8). Continuous data were presented as mean ± standard deviation. Due to the high number of acquisitions for each condition necessary to precisely compute the various metrics, no standard deviation can be calculated for the mathematical model observer.

3. Results

Fig. 1 shows the detectability of two vessels with a contrast of 250 HU and 400 HU as a function of the dose level for the different types of image reconstruction (ASIR-V0, ASIR-V50, ASIR-V80 and DLIR H).

As expected, the detectability increased with higher doses for both contrast values. Comparing various strengths of iterative algorithms, the detectability is higher for ASIR-V80 than for ASIR-V0. The use of the high-strength DLIR algorithm increased detectability in comparison with ASIR-V50. AUC values for DLIR-H and ASIRV-50 were 1 and 0.977, respectively for the mean clinical dose 2.6 mGy. DLIR improved image quality by reducing noise as shown in Fig. 2. To maintain a similar level of detection, the dose could be reduced by 64% using high-strength DLIR in comparison with ASIR-V50.

The minimal distance needed between the wall of two vessels to distinguish them perfectly (1 mm in diameter, 400 HU of contrast) was defined based on the CT spatial resolution (Table 1). The various strength of IR algorithm ASIR-V didn't improve the minimal distance to distinguish two vessels. At various dose levels, high-strength DLIR improved the ability to distinguish two vessels by 20.9% in comparison with ASIRV-50. The minimum distance to distinguish two vessels was 1.96 mm.

Table 1 Minimal distance in mm to distinguish two 1 mm in diameter vessels with a contrast of 400 HU.

4. Discussion

As proposed by several authors for adult cardiac CT, the introduction of DLIR in clinical practice could reduce patient exposure.[5–7] To assess a potential dose reduction for pediatric cardiac CT, an anthropomorphic phantom mimicking the attenuation of newborns was used. Our phantom analysis showed a potential dose reduction with high-strength DLIR of 64% with similar detectability level, even providing a better spatial resolution. The potential of discrimination between two vessels while covering the whole cardiovascular system was 20% higher. Similarly, Benz et al.,[14] showed a reduction in radiation dose for adult cardiac CT with DLIR by 43% without significant impact on image noise. As already demonstrated by Euler et al.,[15] the various strengths of IR algorithm

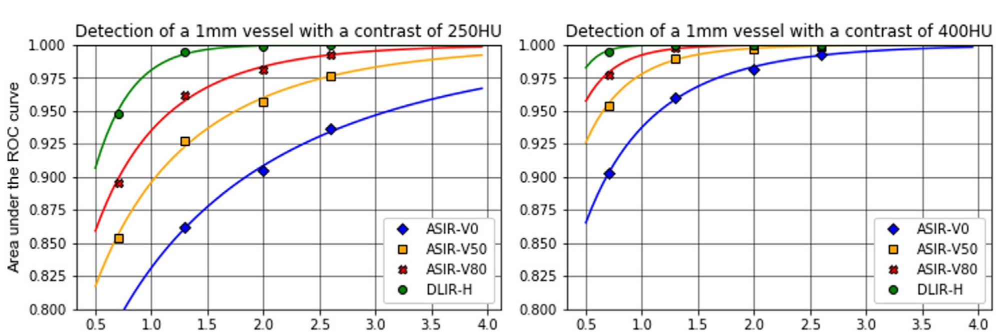

Fig. 1. Detection of a 1 mm vessel with a contrast of respectively 250 HU and 400 HU for the four dose levels (colour dots at 0.7, 1.3, 2, 2.6) and four various algorithms (represented by diamonds, squarres, crosses and circles lines).

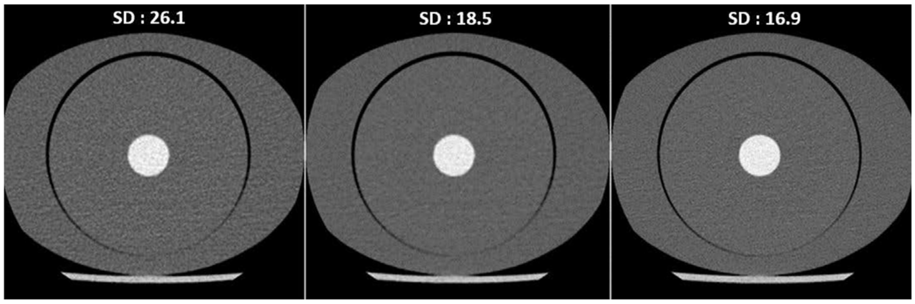

Fig. 2. Pediatric phantom containing the high-contrast rod for the target transfer function computation reconstructed with various IR algorithms: (left) ASIR-V 0%, middle (ASIR-V 50%), right (DLIR-H). Noise is expressed as the standard-deviation (SD).

Table 1
Minimal distance in mm to distinguish two 1 mm vessels with a contrast of 400 HU.

CTDIvol (mGy)/Reconstruction Algorithm	0.7	1.3	2	2.6
DLIR-H	1.96	1.96	1.95	1.96
ASIR-V0	2.53	2.52	2.51	2.51
ASIR-V50	2.51	2.49	2.48	2.44
ASIR-V80	2.5	2.56	2.57	2.57

ASIR-V have only an impact on the noise level and not on CT spatial resolution. This explains why ASIRV-0, ASIRV-50, and ASIRV-80 exhibit similar minimum distances to distinguish two high-contrast vessels.

Further limitations of this study include the use of a single CT manufacturer, which restricts external validation. Furthermore, despite the use of a platform connected to the CT simulating heart beating, the anthropomorphic phantom was not moving during the CT acquisition. Temporal resolution should also be assessed and could decrease the detectability performances on phantoms. However, with its higher spatial resolution, DLIR could also decrease motion blurring.[16] Finally, even if phantom studies are the first step to assess maximal dose reduction that could be achieved, this should now be confirmed in clinical conditions with subjective and quantitative analysis on patients, as proposed by Benz et al.[6]

5. Conclusion

In conclusion, in pediatric cardiac CT, DLIR-H offers a potential dose reduction of 64% while maintaining a similar level of detection and a better spatial resolution in comparison with ASIR-V50.

Declaration of competing interest

The authors have no conflicts of interest to disclose. All co-authors have seen and agree with the contents of the manuscript and there is no financial interest to report. We certify that the submission is original work and is not under review at any other publication. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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