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Free-breathing 320-row computed tomographic angiography with low-tube voltage and hybrid iterative reconstruction in infants with complex congenital heart disease

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ABSTRACT

We explored the clinical value of low-tube voltage prospective second-generation ECG-triggered 320-row CT angiography in infants with complex CHD (37 male, 23 female, aged 0–2 years). The diagnostic accuracy of 320-row CT in complex CHD was 99.4% for intracardiac cardiovascular malformations, 99.8% for extracardiac cardiovascular malformations, and 100% for other malformations. The average subjective overall image quality score for cardiac structures was 3.7 ± 0.5 points. Second-generation 320-row CT angiography with low-tube voltage and prospective ECG-triggered volume target scanning allows accurate diagnosis of cardiovascular anomalies in infants with complex CHD.

1. Introduction

Conventional cardiac angiography (CCA) is a recognized gold standard method for evaluating complex congenital heart disease (CHD) in infants. However, catheterization of an infant or young child, especially one with complex CHD, is rather difficult because of the patient's small size and inability to cooperate. Moreover, CCA is an invasive procedure with an approximately 1% intraoperative mortality rate [1], and there is also the potential for high exposure to radiation [2].

Because of these risks, non-invasive examination methods have replaced invasive angiography for the detection of complex CHD in infants. Transthoracic echocardiography is often used to diagnose CHD, but the limits of the acoustic window, poor spatial resolution, and the subjectivity of the operator's judgments are major drawbacks to this procedure [3]. Moreover, transthoracic assessment of the inner structures of the body that are far from the chest wall, such as the pulmonary vein, aortic arch, and descending aorta, is sometimes problematic.

In recent years, cardiac magnetic resonance imaging (MRI) has developed rapidly as a diagnostic tool, and can be used for evaluation of both cardiac anatomy and function. However, this type of examination requires specialized hardware and experience, which is not universally available [4]. Further, neonatal cardiac MRI involves relatively long imaging times, usually requires general anesthesia with intubation for suspended respiration, and decreased signal-to-noise ratios and high baseline heart rates pose technical challenges in the smallest patients. MRI with anesthesia has been shown to be generally safe, but the highest risks of adverse anesthetic events with MRI are in hospitalized patients and in patients younger than 1 year of age. The relative risk of an adverse event during a cardiac MRI if performed with anesthesia is 3.9 [5–7]. In addition, repeated or prolonged use of general anesthetics or sedative drugs during early childhood may be associated with negative effects on the developing brain [8–11]. These effects include an increased risk of developing learning difficulties such as impaired language and communication skills [10] as well as behavioral or developmental problems [11].

Recently, the spatial and temporal resolution of multi-slice computed tomography (CT) has been greatly improved, and this method has been increasingly used in the diagnosis of CHD in infants and young children. The faster scan time, and the better image quality can be

Abbreviations: CCA, conventional cardiac angiography; CHD, congenital heart disease; CT, computed tomography; ECG, electrocardiogram; MRI, magnetic resonance imaging

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useful for infants who cannot hold their breath. A slice obtained by second-generation 320-row CT prospective electrocardiogram (ECG)-gating takes only 0.275 s to acquire because of its more rapid gantry rotation and 16 cm z-axis coverage in almost all cases of complex CHD. The temporal resolution of this latest CT technique has a volume scanning mode, which can reach 137.5 ms and can achieve 180°/360° without moving. This provides the data of all organs and avoids the migration data error caused by the placement movement of patients from spiral scanning, the time interval difference of image composition, and the unnecessary scan dose caused by repetitive scanning [12]. In clinical practice, a shorter scan time is needed for sedated children who cannot hold their breath. This imaging method is preferred for cardiac CT angiography in patients with a high heart rate, especially infants and children, and may be the best way of evaluating infants with complex CHD. Further, the combination of low-tube voltage and hybrid iterative reconstruction can lower the radiation dose exposure without impairing image quality [13]. However, there are few reports on the use of 320-row CT and there is very little information on its use for diagnostic purposes in infants with complex CHD [12]. To our knowledge, there have been no studies demonstrating the clinical utility of prospective ECG-triggered second-generation 320-row CT angiography, with the combination of low-tube voltage and hybrid iterative reconstruction in infants. Further, there have been no studies of the effect of body size (which can vary widely in the course of days in infants) on the visibility of cardiac structures in this age group.

The aim of this study was to explore the clinical value and detectability of low-dose prospective ECG-triggered 320-row CT angiography based on age and body size in infants with complex CHD.

2. Methods

The study protocol was approved by the institutional review boards of the participating institutions. The need for written informed consent was waived in view of the retrospective nature of the research.

The study included 60 consecutive infants with complex CHD (37 male, 23 female, aged 0–2 years) who underwent examination by 320-row CT angiography with low-dose prospective ECG-triggered volume target scanning between August 2015 and January 2017. At our institution, CT angiography is part of the cardiovascular evaluation in patients with complex CHD and is performed as clinically indicated. Complex CHD is defined as CHD with more than one distinct cardiovascular anomaly, and all anomalies were confirmed by surgical and/or CCA findings.

2.1. 320-Row CT scan protocol

The examinations were performed using a second-generation 320-detector row CT scanner (Aquilion ONE Vision; Toshiba Medical Systems, Nasu, Japan), which has a detector width of 160 mm and 320 detector rows. The CT gantry has a minimum rotation time of 275 ms. All tests using 320-row CT angiography with prospective ECG-triggered mode were performed while the children were breathing freely. A chloral hydrate enema was used for sedation during scanning and the dose was calculated based on each child's body weight and clinical need. Iodinated contrast medium (Iopamiron, 300 mg I/mL, Bayer, Tokyo, Japan) was injected via a peripheral vein using a double-head power injector (Nemoto Kyorindo Co. Ltd., Tokyo, Japan) with a volume of 2.0 mL/kg body weight followed by a saline chaser of 0.67 mL/kg body weight. The injection rate was calculated as the total injected volume divided by 80 s, and the data acquisition was performed at 80 s. For example, a 6-kg baby would be injected with 12 mL of contrast medium and 4 mL of saline at a flow rate of 0.2 mL per second. The scan volume was set to the whole chest, extending from the supraclavicular level superiorly to just below the diaphragm inferiorly. In cases of suspected heterotaxy or anomalous inferior vena cava drainage, the scan volume was extended to the infrarenal region. The patients were imaged using a prospective triggered target CT angiographic volume scan with a rotation time of 0.275 s and a tube voltage of 80 kVp. The center for the data acquisition phase window in this study was set to 45% of the R–R interval. The scan range depended on the patient's size and heart rate as well as the area to be evaluated, which varied from 10 cm to 16 cm, and the tube current was set by automatic exposure control (noise level, standard deviation 20; thickness, 0.5 mm). The effective dose was derived from the dose-length product and conversion coefficients for the chest, taking into account the patient's age [14,15].

2.2. Image post-processing and analysis

Full volumes were reconstructed in 0.5 mm-thickness slices. In addition to the CT axial images, multiplanar reconstruction, volume rendering reconstruction, and maximum intensity projection images can also be used to display heart malformations.

The CT images were interpreted without knowledge of the results of surgery, CCA, or transthoracic echocardiography. CT angiographic images were presented in random order. Using surgical and/or CCA findings as the reference standard, the diagnostic accuracy was evaluated based on patient age. The overall image quality was evaluated semi-quantitatively by two board-certified radiologists (SK and KS) with over 5 years of diagnostic experience in cardiac radiology. If a reviewer was the original primary reader for the case, they would only be able to evaluate it again after > 3 months from the initial clinical reading. The evaluation criteria were based on a five-point rubric (5, excellent anatomical clarity and image quality; 4, good anatomical clarity, all structures are clearly interpretable; 3, fair anatomical clarity, the anatomical relationships can be defined with relative confidence; 2, poor image quality or anatomical detail, incomplete demonstration of anatomical structures; 1, no useful information obtained) [15].

In the event of disagreement in scoring between the two observers, the mean of the two results was used for the score. Examinations graded over 3 were considered sufficient for complete diagnosis.

2.3. Evaluation of radiation dose

The radiation exposure parameters, comprising imaging range, dose-length product, and volume CT dose index [16], were recorded for each infant who underwent CT angiographic examination. The cardiac CT angiographic effective dose was calculated from the dose-length product multiplied by the conversion factor [17]. The size of the CT dose index phantom was 16 cm. The specific dose-length product conversion coefficients for infants vary according to age as follows: younger than 4 months, 0.039 mSv/[mGy·cm]; age 4 months to 1 year, 0.026 mSv/[mGy·cm]; and age 1 year to 6 years, mSv/[mGy·cm] [14,15].

2.4. Statistical analysis

The measurement data are expressed as the means ± standard deviation. The results of surgery or CCA were regarded as the reference standard when calculating the diagnostic accuracy of 320-row CT. The diagnostic consistency of the two readers for subjective image quality scoring was processed using the kappa statistic as follows: 0, no agreement; 0.01–0.20, poor agreement; 0.21–0.400, fair agreement; 0.41–0.600, moderate agreement; 0.61–0.80, substantial agreement; and 0.81–0.99, almost perfect agreement. A P-value < 0.05 was considered to be statistically significant.

3. Results

Patient characteristics are shown according to age in Table 1. There were 105 intracardiac cardiovascular malformations, 76 extracardiac