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Original Article

Radiation dose reports and determinants of image quality during ECG-triggered Cardiac Computed Tomography Angiography in children

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Abstract

Aim: This study aimed to evaluate the radiation doses and determinants of image quality during prospective and retrospective ECG-triggered cardiac computed tomography angiography.

Materials and Methods: Patients included study who underwent ECG-triggered and low radiation dose dual-source cardiac computed tomography angiography scans. Dose length product values were obtained from the computed tomography scanning protocol. Effective dose (mSv) was estimated using the dose length product method with a conversion factor (mSv/mGy × cm). All images were evaluated and scored by two pediatric radiologists.

Results: 37 patients have ECG-triggered cardiac computed tomography. The ages of the patients were between 3 days to 17 years (mean 73.78 ±79.95 months). The average heart rate of the patients was 101.11±27.12 bpm. The mean DLP was 93.05 ±64.4 mGy/cm. The mean effective dose was calculated as 1.74 ±1.03 mSv. We found good agreement between observers while analyzing determinants of image quality (kappa values 0.71-0.80).

Conclusion: High-quality images with a low dose can be obtained with an ECG-triggered cardiac computed tomography angiography method. Because of the high sensitivity of radiation in children, dose reduction techniques should be used effectively. Cardiac computed tomography examinations can be performed at diagnostic quality limits with prospective ECG-triggered technique in patients with high pitch, low kV, and dual source techniques.

Keywords: Cardiac computed tomography angiography; children; radiation dose

INTRODUCTION

Congenital heart diseases (CHD) are diagnosed by different imaging methods. Transthoracic echocardiography (TTE) is an available and practical method; it is generally the first choice in these methods. However, aortic arch, coronary arteries, pulmonary artery branches, pulmonary veins, and other structures cannot be fully visualized in TTE. Since the importance of detailed anatomy is crucial for surgical planning, magnetic resonance imaging (MRI) and cardiac computed tomography angiography (CCTA) are being more widely used for diagnosis and preoperative planning. Although MRI has several disadvantages, long scanning time and anesthesia requirements are problematic for especially in critically ill neonates with CHD.

Among these imaging methods, CCTA is superior because of its availability, improved spatial and temporal resolution, and short scan times. The foremost disadvantage of CCTA is the exposure of the patient to ionizing radiation. Especially children are more sensitive to ionizing radiation than adults. Therefore, low mAs and kVp values are used to reduce radiation dose in pediatric protocols based on the ALARA principle (As Low As Reasonably Achievable). Besides this, to reduce radiation exposure while still maintaining an image of diagnostic quality, many techniques have been developed (1-3).

This study aimed to evaluate the radiation doses and determinants of image quality during prospective and retrospective ECG-triggered CCTA.

MATERIALS and METHODS

Patient population

This study approved by our institutional review board. This is a retrospective study so informed consent and approval requirement waived. 37 patients included study (14 were girl and 23 were boy, age ranged 0-17 years old) who underwent ECG triggered and low radiation dose dual-

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source cardiac computed tomography scans between Feb 2016 and Aug 2018 was performed using Siemens Somatom force (Siemens Healthcare GmbH, Erlangen, Germany). 11 patients with tetralogy of Fallot, six patients with pulmonary artery dilatation, three patients with arcus aorta abnormalities, and remaining patients with various pathologies.

CT Imaging and Dose

Dose Length Product (DLP) values were obtained from the CT scanning protocol. Effective dose (ED) (mSv) was estimated using the DLP method with a conversion factor (mSv/mGy × cm). The radiation dose was determined based on DLP in CT scanning protocol using a 32-cm phantom. The conversion factor of chest was 0.039 for 0-1-year-old, 0.026 for 2-4 years old, 0.018 for 5-9 years old, and 0.013 for 10-17 years old (4). CT parameters were as follows: 2×192×0.6-mm slice collimation using a z-axis flying focal spot technique; 0.25 s gantry rotation time; temporal resolution of 66 ms and an isotropic resolution of 0.3 mm. Automated tube voltage was used according to the patient's size. High-pitch technique (pitch value range 1 to 3.2) was used as much as the patient-related factors (low heart rate and breath cooperation) permitted. Images were acquired from the thoracic inlet to the base of the heart. A dose of 1.5-2.0 mL/kg of iodinated contrast medium (iohexol, iodine content 350 mg/mL; Omnipaque TM, GE Healthcare) was intravenously administered via the peripheral vein. After contrast medium injection, a saline solution of 1 mL/kg was injected. The flow rate of contrast and saline was 0.5-3 mL/s. A "manual" bolus-tracking technique was used, where the monitoring section was set at the four chambers of the heart, and the region of interest (ROI) was placed in the air outside the thorax. In cases where CCTA was performed for suspected coronary artery anomalies, the ROI was placed in the left atrium. CCTA examinations were successfully performed on all patients without complications. Image reconstruction was made using iterative reconstruction technique (Advanced Modeled Iterative Reconstruction (ADMIRE), Siemens Healthcare, Erlangen, Germany) which minimizing artifacts and needs low dose by evaluating data from both detectors - surrounding elements and applying noise cancellation technique based on the original raw data. Images were evaluated at the workstation (Syngo. via Multimodality Workplace, Siemens Healthcare). Reconstructed images were obtained with maximum intensity projection (MIP), multiplanar reconstruction (MPR), and 3D volume rendering techniques (VRT).

Image Evaluation

All images were evaluated and scored by two pediatric radiologists (7 and 10 years of experience). Six parameters were evaluated for determinants of image quality; quality of right coronary artery (RCA), left anterior descending coronary artery (LAD), left circumflex coronary artery (LCx), pulmonary artery (PA), ascending aorta, and interventricular septum. The image quality was evaluated point 1 through point 5 according to a 5-point scale under the following criteria: score 5: excellent; 4: good; 3: fair; 2: poor; 1: nondiagnostic. Observers were blinded to clinical findings and other observer scores during evaluating the images.

Statistical Analysis

Statistical analysis was performed using SPSS version 22.0. Patient's age, gender, indication for the exam, exam protocol, total exam doses analyzed retrospectively. DLP and ED values were compared between age groups. The normal distribution of the data was evaluated by the Kolmogorov-Smirnov test. When the data were not parametric, the means were compared using Mann-Whitney U test and Kruskal-Wallis test. The image quality assessment data were expressed as mean ± SD. The inter-observer agreement for the image quality scoring assessment was tested using Cohen's kappa (k) value. K score of 0.01 to 0.20 means slight agreement; 0.21 to 0.4 means fair agreement; 0.41 to 0.60 means moderate agreement; 0.61 to 0.8 means good agreement; and 0.81 to 1.00 means excellent agreement. $P < 0.05$ was considered to be of statistical significance.

RESULTS

The ages of the patients were between 3 days to 17 years (mean 73.78±79.95 months). 37 patients have ECG-triggered cardiac CT. The average heart rate of the patients was 101.11±27.12 bpm. The mean DLP was 93.05±64.4 mGy/cm. The mean ED was calculated as 1.74 ±1.03 mSv. Data by age group for DLP and ED are summarized in Table 1.

Table 1. Demographic findings, scan parameters and radiation dose reports of patients according to the age groups. (bpm: beats per minute)

Age Group	n	Heart rate (bpm)	DLP (mGy/cm)	Effective dose (mSv)
0-1	17	123 ± 15.87 (101-165)	38 ±19.75 (18-85)	1.32 ±0.75 (0.57-2.76)
2-4	4	104.5 ±11.38 (88-114)	77.25 ±49.13 (17-130)	2 ±1.22 (0.44-3.38)
5-9	2	107 ±5.65 (103-111)	96 ±106.07 (21-171)	1.73 ±1.90 (0.38-3.08)
10-17	14	70.61 ±10.59 (54-90)	163.79 ±42.38 (61-235)	2.17 ±0.55 (0.8-3.05)
Total	37	101.11±27.12 (54-165)	93.05 ±64.4 (17-235)	1.74 ± 1.03 (0.38-3.38)

Two techniques we used for CCTA: retrospective and prospective. We used a prospective technique for nine patients. This patients' radiation doses statically lower from retrospective technique ($p<0.05$) (Table 2).

The greater group of indication for the exam was preoperative coronary anatomy evaluation of tetralogy of fallot patients. The diagnosis of nine patients was tetralogy of fallot disease. The operation method can be changed due to abnormal or variational coronary anatomy.

At Figure 1 a tetralogy of fallot patient CCTA findings and dose report summarized.

Table 2. Minimum, maximum and median values of prospective and retrospective technique ECG triggered cardiac CT groups (*Mann-Whitney U test, p <0.05

Technique	Prospective	Retrospective	Total	p Value
n	9	28	37	
Heart rate (bpm) min-max (mean)	63 -111 (94.00)	54-165 (103.39)	54-165 (101.11)	0.272
DLP (mGy/cm) min-max (mean)	18-179 (23.80)	17-235 (84.11)	17-235 (71.54)	0.028*
Effective Dose (mSv) min-max (mean)	0.38-3.09 (0.66)	0.44-4.0 (1.84)	0.38-4.0 (1.60)	0.01*

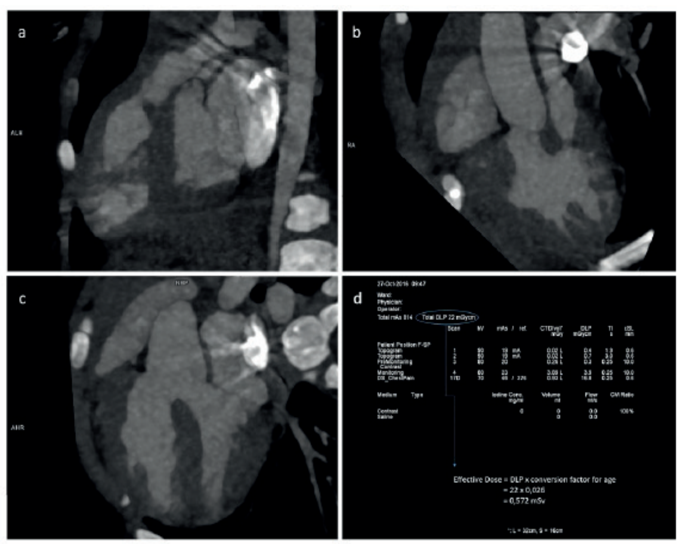

Figure 1. Findings and dose report of a Tetralogy of Fallot disease. a) oblique sagittal MIP image of pulmonary artery b) oblique coronal MIP image of pulmonary artery c) image of the overriding aorta associated with both of ventricles d) dose report and calculating of effective radiation dose

Table 3 .Mean image quality and interobserver agreement according to parameters

Parameters	Mean image quality	Kappa value
RCA	3.73	0.71
LAD	3.71	0.75
LCx	3.21	0.77
Pulmonary artery	4.51	0.73
Ascending aorta	4.58	0.80
Interventricular septum	4.5	0.79

We found good agreement between observers while analyzing image quality of RCA, LAD, LCx, PA, ascending aorta (AA) and interventricular septum (IVS) (kappa values 0,71-0,80) (Table 3). RCA and LAD image quality were found statically higher than LCx.

DISCUSSION

To obtain high-quality images in children, especially with complex cardiac anomalies is crucial for correct diagnosis and planning surgical therapy. High-quality images with a low dose can be obtained with an ECG-triggered CCTA method. Especially if the patient's heart rate is normal, prospective ECG-triggered CCTA reduces the dose of ionizing radiation more than retrospective. High-pitch technique, low tube potential (low kVp), and dual-source CT scans are among the factors contributing to reducing the radiation dose.

When retrospective technique includes all phases, the prospective technique only allows the exposure to apply at a certain predefined period of cardiac cycle. Therefore, a prospective technique can lower the radiation dose while ensuring the diagnostic images. With high heart rate, we prefer retrospective technique because the best exposure period for prospective technique may not be detected. We used the retrospective technique more frequently because the average heart rate of our patients was high. In patients with lower heart rate, high-pitch technique, dual-source, and prospective ECG-triggered techniques were used, and the mean radiation doses of these patients were significantly lower than retrospective technique ECG-triggered CCTA. Technically, the dose is significantly reduced with predicting the best systolic phase with ECG monitorization and short phase exposure when compared to whole phases of cardiac cycle exposure in retrospective technique. The retrospective technique should be preferred in patients requiring cardiac anatomic evaluation as well as function and cardiac hemodynamics evaluation. This was one of the reasons why we used a large number of retrospective techniques.

In a study, Barrera at al evaluated the image quality of coronary arteries interobserver. They reviewed prospectively ECG-triggered high-pitch dual-source CCTA scans of 45 children (5). Children ages were ranged 0-17 years old. They observed the average effective radiation dose of patients was 1.82 mSv. The image quality of coronary segments (proximal and middle segments of the RCA, left main coronary artery (LMCA), proximal LAD, and proximal LCx) were evaluated. They found proximal RCA, LMCA and proximal LCx showed the best mean image quality scores. Proximal RCA showed the best interobserver agreement while the LMCA showed the lowest. Unlike this study, we also evaluated pulmonary artery, ascending aorta, and interventricular septum. We evaluated coronary arteries and the others separately because the coronary arteries are smaller in diameter. The image quality of the pulmonary artery, ascending aorta and interventricular septum was naturally higher. Previous studies were found that the image quality of LAD and LCx higher than RCA (5-8). We found the image quality of RCA and LAD was statically higher than LCx unlikely previous studies. This is likely because of our retrospectively ECG-triggered technique studies are larger than prospectively. So, we can evaluate end-diastolic phase of the cardiac cycle and RCA could be seen better than systolic phase. All parameters we evaluated were had a good interobserver agreement (kappa values 0,71-0,80)

Preoperative coronary artery evaluation can be lifesaving in some patients. If a major coronary artery branch crosses the infundibulum, conventional transventricular repair of right ventricular outflow tract obstruction may cause coronary injury. The surgeon wants to see coronary anatomy before operation (9-11).

The retrospective design, limited patients population, and asymmetric distribution of patients' age groups and study techniques are the main limitations of this study.

CONCLUSION

Because of the high sensitivity of radiation in children, dose reduction techniques should be used effectively. Cardiac CT examinations can be performed at diagnostic quality limits with quite lower effective doses using prospective ECG-triggered technique in children with high pitch, low kVp, and dual source techniques.

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