Comparison of Non-Gated vs. ECG-gated CT Angiography of Fontan Circulation in Patients with Implanted Stents in Pulmonary Branches

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ABSTRACT

Background: Motion artifacts may degrade CT examination of Fontan pathway and hinder accurate diagnosis of in-stent restenosis. Purpose: We retrospectively compared ECG-gated multi-detector computed tomography (CT) with non-ECG-gated CT in order to demonstrate whether or not one of the methods should be preferred. Method: The study included 13 patients with surgically reconstructed Fontan pathway. A total of 16 CT examinations were performed between February 2010 and November 2015.The incidence of motion artifacts in Fontan pathway and pulmonary branches were analysed subjectively by two readers. The effective dose for each examination was calculated. Results: Just in one non-gated CT examination was evidence of motion artifact in distal part of left pulmonary artery. The mean normalized effective radiation dose was 2.33 mSv (±0.62) for the non-ECG-gated scans and 4.55 mSv (±0.85) for the ECG-gated scans ($p \le 0.05$). Conclusion: Non-gated CT angiography with single phase reconstruction significantly reduces radiation dose without loss of image quality compared with ECG-gated CT angiography.

KEYWORDS

CT angiography; Fontan circulation; stents

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INTRODUCTION

The patients who have undergone the Fontan procedure (a palliative surgical procedure used in children with univentricular hearts, is usually performed at 2 or 3 years of age and it means creation of tunnel between superior vena cava, inferior vena cava and pulmonary branches) suffer from many complications (extracardiac or intracardiac). Complications following surgical intervention in these patients may have serious consequences (1–3). Pulmonary branch stenosis is one of the most frequent complications in Fontans. The transcatheter interventions (balloon angioplasty or stent placement) are the most effective methods in the treatment of stenoses (4).

An accurate, accessible imaging technique is required for the detection of pathology, which may further facilitate fast, appropriate treatment. The traditional imaging technique for the pre- and post-operative evaluation of patients with congenital heart disease (CHD) is echocardiography. The diagnostic quality of echocardiography is highly dependent on the operator and the presence of an adequate acoustic window. Digital subtraction angiography due to its invasive character has limited use in follow-up of these patients. MRI is an excellent diagnostic tool particularly for evaluation of young children with CHD who will require several follow-up examinations in their lifetime (5, 6). Moreover, the diagnostic capabilities of MRI are limited in the presence of surgical devices and implanted stents due to the signal dropout in the region of the stent (7). These patients are better followed by CT for these reasons. Evaluation of in-stent restenosis by CT is optimal. Visualization of stent in these patients is due to Fontan physiology challenging (8). It is very important to achieve homogenous enhancement in all parts of Fontan circulation because mixing of enhanced and unenhanced blood may make impossible evaluation of thrombus or in-stent restenosis. However, CT with retrospective ECG-gating facilitates non-invasive imaging of the Fontan circulation without detrimental motion artifacts. The technique incurs a relatively higher radiation dose to the often very young patients and has aroused growing concern in radiological communities.

Attempting to avoid high radiation dose, we decided to perform non-gated CT angiography in Fontans.

The aim of this study was to investigate:

a) Occurence of motion artifacts in non ECG gated CT vs. gated CT.
b) Dose reduction with non-ECG gated CT vs. ECG gated CT.

MATERIAL AND METHODS

PATIENT POPULATION

The study population included 13 patients after Fontan procedure and with implanted stent in pulmonary branch or fenestration. A total of 16 CT examinations were performed between February 2010 and November 2015 (non-gated CT angiography in 8 examinations, ECG-gated in 8 examinations). Informed consent was obtained for each patient prior to CT angiography. Indications for initial Fontan-surgery included various types of CHD described in patient characteristics Table 1. All patients underwent a modified Fontan operation. Total cavo-pulmonary connections were performed in all patients. The clinical indications for CT study were assessment of in-stent restenosis and in some patients also visualization of Fontan fenestration with implanted stent. Data were analyzed in a retrospective manner.

Tab. 1: Demographic data of patients.

No of patients	13
Gender	
Male	12
Female	1
Age	
Mean	10.1 y
Range	3–17 y
Diagnosis	
HLHs	6
HRHs	3
PA	3
EA	1
Implanted stent	
Pulmonary branch	10
Fenestration	3

EA – Ebstein anomaly, HLHs – hypoplastic left heart syndrome, HRHs – hypoplasitc right heart syndrome, PA – pulmonary atresia

IMAGE ACQUISITION

Computed tomographic examinations were performed using a CT scanner (AquilionONE; Toshiba Medical Systems, Nasu, Japan). Scan parameters for non-ECG-gated examinations and retrospectively ECG-gated examinations are summarized in Table 2. This CT scanner uses Adaptive Iterative Dose Reduction 3D (AIDR 3D) which reduces image noise.

We use a noniodine contrast medium (Ultravist 370; Shering, Berlin, Germany) of 1–1.5 ml/kg into right antecubital vein, through 20–22-guage needle. Injection rates were as fast as practical given the needle and patient size. We use 1-minute delay scan for assessment of stents implanted in pulmonary branches or in fenestration. In patients without stent in fenestration arterial phase is

Tab. 2: Scan parameters.

Detector collimation	0.5 mm
Gantry rotation time	0.5 s
Pitch factor	0.828
Tube voltage	80 kV for patients 40 kg or less 120 kV for patient more than 40 kg
Effective tube current time	100–250 mA
Slice thickness	0.5 mm
Reconstruction interval	0.5 mm
Scan range	from the lung apex to the liver

needed for visualization of this fenestration. Then the bolus tracking method is preferred with a region of interest placed in superior vena cava or in the place of connection of superior vena cava with pulmonary branches, and threshold attenuation of 150 HU is set.

To reduce artifacts from undiluted contrast material and to reduce the total amount of contrast material, a saline bolus chasing technique was applied. Realised CT scans were performed as helical acquisition in 64-CT mode. CT scanning was realised from the lung apex to the liver for detection of other pathologies.

IMAGE INTERPRETATION

For subjective analysis, two radiologists evaluated the CT images in consensus. They observed the presence or absence of motion artifacts in both pulmonary arteries (proximal and distal parts) and the Fontan tract (Fig. 1) using a four point ordinal scale, with integers ranging from 1 to 4, to rate image quality (Tab. 3). Readers were blinded to patient identity, clinical information and acquisition parameters. Motion artifacts of the Fontan pathway were defined as the doubling of anatomic structures or step artifacts (Fig. 2).

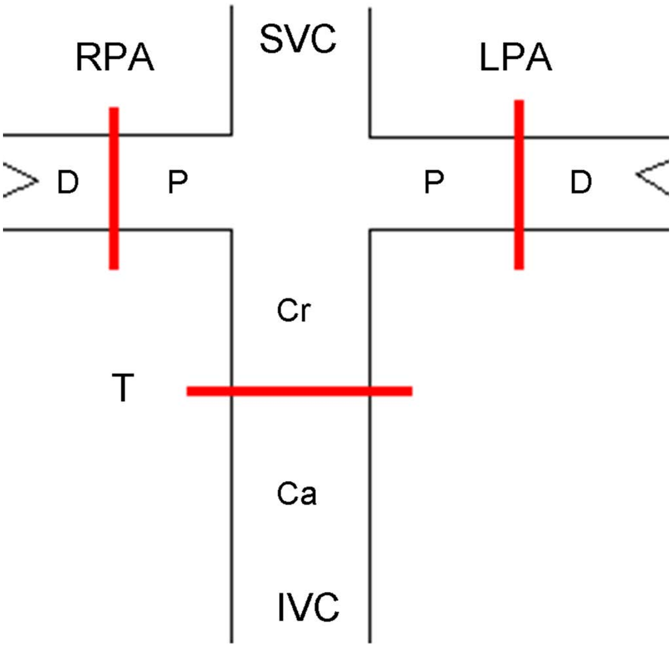

Fig. 1: Scheme of evaluation of motion artifacts. IVC – inferior vena cava, LPA – left pulmonary artery, RPA – right pulmonary artery, SVC – superior vena cava, T – tunnel, Ca – caudal, Cr – cranial, P – proximal, D – distal.

Tab. 3: Rating of motion artefacts of the Fontan circulation.

Rating	Criteria
1	No motion artifacts
2	Minimal motion artifacts – slight blurring and/or slight structural discontinuity
3	Moderate motion artifacts – moderate blurring and/or distinct structural discontinuity
4	Severe motion artifacts, not diagnostic – pronounced blurring and/or severe structural discontinuity

Fig. 2: Sagital view. a) CT scan demostrates presence of no motion artefacts in LPA; b) CT scan demonstrates presence of motion artifact in distal part of left pulmonary artery (doubling of contour).

RADIATION DOSE

The dose reports for all examinations were retrieved from the picture archiving and communication system. Dose-length product was recorded in each case. Estimated effective radiation dosages (mSv) were calculated for each scan using the following equation: DLP × 0.026 (infants > 1 year to 5 years old) or × 0.018 (children > 5 years to 10 years) or × 0.014 (adults). The figures displayed in the CT console were multiplied by a factor of 2 for children and of 3 for infants in order to give a realistic estimate of the patient's dose because conversion coefficients have been obtained for a 16 cm CT dose phantom, whereas the CT console indicator will provide DLP assuming the use of the 32-cm diameter body phantom.

STATISTICAL ANALYSIS

Statistical analysis included the calculation of means and standard deviations. Mann-Whitney U test was used to compare occurrence of motion artifacts in non-ECG gated CT vs. gated CT.

For statistical analysis was used program JMP version 4.0.2. (SAS Institute, USA).

RESULTS

Just in one non-gated CT examination was evidence of motion artifact in left pulmonary artery (Tab. 4).

The mean normalized effective dose was 2.33 mSv (±0.62) for the non-gated scans and 4.55 mSv (±0.85) for the ECG-gated scans. The increase in radiation dose by the use of ECG gating was evident ($p \leq 0.05$).

Tab. 4: Distribution of motion artifact ratings in non-gated and ECG-gated scans.

		1	2	3	4
RPA P	ECG gated	8			
	Non-gated	8			
RPA D	ECG gated	8			
	Non-gated	8			
LPA P	ECG gated	8			
	Non-gated	7	1		

LPA D	ECG gated	8			
	Non-gated	7	1		
T Cr	ECG gated	8			
	Non-gated	8			
T Ca	ECG gated	8			
	Non-gated	8			

DISCUSSION

Visualization of implanted stents in pulmonary branches or Fontan fenestration is very complicated (Fig. 3). ECHO with its poor acoustic window and high interobserver reliability as well as digital subtraction angiography due to its invasive character have limited use. MRI represents an excellent diagnostic tool for evaluation of young children with congenital heart diseases who will require several follow-up examinations in their lifetime. Moreover, the diagnostic capabilities of MRI are limited in the presence of surgical devices and implanted stents due to signal drop-out in the region of the stent (9, 10).

Fig. 3: Curved planar reconstruction shows perfect delineation of each part of Fontan circuit. Right pulmonary artery is not visualized in this figure. Stent placed in LPA. IVC – inferior vena cava, LPA – left pulmonary artery, SVC – superior vena cava, T – tunnel.

So for the visualization of Fontan circulation with implanted stent CT angiography is the preferable method because provide the best opportunity to visualize in-stent restenosis in comparison to MRI. For the detection of in-stent restenosis homogenous enhancement of Fontan circuit is necessary because mixing of enhanced and unenhanced blood may make impossible evaluation of thrombus or in-stent restenosis. Many techniques achieving homogenous enhancement were published. Greenberg used a dual injection technique to perform CT angiography in six patients with extracardiac or lateral tunnel palliations. We think that using of this technique is very traumatizing for children. Park et al. tried this injection technique in some patients but arrival of the contrast media in the superior vena cava and the Fontan tract at the same time was difficult to achieve because of the different resistances of the route, different degrees of the collateral pathway formation, and the different flow velocities of each pathway. His study demonstrates that a 3-minute-delay scan is the most optimal protocol in Fontan patients for the detection of thrombus regardless of intravenous route or surgical technique used. (11, 12, 13) We think that visualization of in-stents restenosis using the one-minute delayed scan is optimal. The similar studies comparing dose reduction in ECG-gated and non-gated CT scan in Fontans with implanted stents haven't been published yet.

We assumed the dose reduction, but the presence of motion artifacts was the question. Realised non-gated CT examinations confirmed the significant dose reduction without loss of image quality.

Non-gated CT angiography in Fontan patients can be preferable method for the visualization of implanted stents in Fontan circuit without loss of image quality and with the significant dose reduction.

STUDY LIMITATION

It is not a randomized study and has a low sample size.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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