



Cardiac CT angiography after coronary artery surgery in children using 64-slice CT scan

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Abstract

Objective: The purpose of this study was to compare the diagnostic accuracy of 64-slice CT with that of invasive angiography in the detection of graft and/or coronary angioplasty stenosis in children who had undergone coronary artery surgery.

Population and methods: Fifteen consecutive children (8 male and 7 female; age 9.2 ± 6.1 years) underwent 64-slice CT because of chest pain or ECG changes mean 4.8 ± 3.7 years after surgical coronary artery surgery; 10 patients had coronary angioplasty using a patch from the saphenous vein, four had mammary artery bypass, and one had saphenous vein bypass. Six main segments of the coronary arteries and all the bypass graft considered as a single segment were analyzed and compared with invasive angiography used as the reference standard.

Results: CT correctly identified the four children with coronary angioplasty and mammary graft lesions that were confirmed by conventional angiography: one patient had a significant stenosis ($>50\%$ stenosis) at the mammary bypass graft anastomosis site; three other had non-significant stenosis ($<50\%$ stenosis) including a mild lesion of the saphenous vein patch in two patients and a mild lesion at the anastomosis site of the mammary bypass in one. All segments identified as normal by CT in the other 11 children were also found to be normal by conventional angiography.

Conclusion: In centers expert in this technique, 64-slice CT scanning is a promising, rapid, and useful diagnostic technique for evaluating both coronary angioplasty and bypass graft lesions in children who had undergone coronary artery surgery.

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1. Introduction

Coronary artery obstructive lesions are rare events in children. Differing from adults, in whom coronary artery obstructive lesions are caused by atherosclerotic coronary artery disease. Whilst coronary obstructive lesions in children may be congenital when coronary arteries have an anomalous origin, or they may occur as complications of progressive supravulvular aortic stenosis, Kawasaki disease, surgical procedures such as the arterial switch operation for transposition of great arteries or other iatrogenic lesions [1]. Conventional percutaneous transluminal

angioplasty may still be proposed in selected cases, however, therapeutic solutions are generally surgical and they consist in coronary angioplasty by using a venous patch or in bypass graft by using the internal mammary arteries or the saphenous veins [2].

Coronary artery patency assessment is an important issue during the follow-up of children who had undergone coronary artery surgery. Although invasive, catheter angiography is the modality of reference. The new generation 64-slice CT scan is a promising tool for assessing graft patency in adult patients [3]. Its accuracy and clinical value in pediatric patients need to be determined, in this setting [4].

The purpose of this study was to investigate the accuracy of 64-slice CT scan in the evaluation of coronary angioplasty and bypass graft patency after surgical coronary revascularization in pediatric patients.

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Table 1
Clinical characteristics of patients

Patients	Original diagnosis	Original surgical technique	AGE at first surgery	Complication	Age at revascularization surgery	Technique of revascularization surgery
1	TGA, abnormal origin of LCA. Intramural LCA	Two trap-door	Neonatal	Peri-operative stenosis of LMA	Neonatal	Left coronary bypass graft
2	TGA, abnormal origin of LCA. Intramural LCA	Two trap-door	Neonatal	Peri-operative stenosis of LMA	Neonatal	Left coronary bypass graft
3	TGA, Type C, intramural LCA	Two trap-door	Neonatal	Peri-operative stenosis of LMA	Neonatal	Left coronary bypass graft
4	TGA, type A	Single trap-door	Neonatal	Stenosis of LMA	3 years	Left coronary bypass graft
5	TGA, type A	Two trap-door	Neonatal	Stenosis of LAD	5 months	Left coronary bypass graft
6	TGA, type A	Single trap-door	Neonatal	Stenosis of RCA	10 years	Right coronary bypass with saphenous vein
7	TGA, type A	Single trap-door	Neonatal	Stenosis of LMA	6 years	Coronary angioplasty of LMA with saphenous vein
8	TGA, VSD, coarctation, type A	Two trap-door	Neonatal	Stenosis of left coronary ostium	6 months	Coronary angioplasty of LMA with saphenous vein
9	TGA, type A	Two trap-door	Neonatal	Stenosis of LMA	7 years	Coronary angioplasty of LMA with saphenous vein
10	TGA, type E	Two trap-door	Neonatal	Stenosis of LMA	8 years	Coronary angioplasty of LMA with saphenous vein
11	TGA, Type C, intramural LMA	Two trap-door	Neonatal	Stenosis of LMA	4 years	Coronary angioplasty of LMA with saphenous vein
12	TGA, VSD, PS, type A	Two trap-door	3 months	Stenosis of LMA	5 months	Coronary angioplasty of LMA with saphenous vein
13	TGA, type A	Two trap-door	Neonatal	Stenosis of LMA	12 years	Coronary angioplasty of LMA with saphenous vein
14	Anomalous LCA with intramural course	Reimplantation of the LCA in the left sinus	11 years	Stenosis of left coronary ostium	11 years	Coronary angioplasty of LMA with saphenous vein
15	Supraortic stenosis	–	2 years	Stenosis of left coronary ostium	2 years	Coronary angioplasty of LMA with saphenous vein

LAD: left anterior descending coronary artery; LCA: left coronary artery; LMA: left main artery; PS: pulmonary stenosis; RCA: right coronary artery; Type A, B, C, D, E: coronary pattern according to Yacoub's classification; TGA: transposition of great arteries; VSD: ventricular septal defect.

2. Subjects and methods

2.1. Patients

Between July 2005 and December 2007, 17 children (10 male and 7 female; mean age 10.5 ± 5.8 years; median = 10 years) with status post-surgical coronary revascularization, were prospectively referred for conventional invasive coronary angiography because of chest pain or ECG changes mean 4.8 ± 3.7 years after coronary artery surgery. Only 15 (8 male and 7 female; mean age 9.2 ± 6.1 years) were included in the study and underwent 64-slice CT in the 24 h before or after their conventional coronary study: Ten patients had undergone coronary artery angioplasty using a patch from the saphenous vein; four patients had undergone an arterial bypass graft on the left anterior descending coronary artery with using the left internal mammary artery; and one patient had undergone a vein bypass with using the saphenous vein. The two patients who refused CT examination were excluded from the study. Exclusion criteria were renal dysfunction (creatinine clearance <80 ml/min), known allergy to iodine contrast agent, cardiac insufficiency, or an unstable clinical condition. The clinical patients' characteristics and their

indication for surgical coronary revascularization are summarized in Table 1. Parents of all children were informed of the cumulative radiation exposure. They gave written, informed consent, and the protocol had institutional review board approval.

2.2. CT examination technique

All patients were in sinus rhythm and received oral beta-blocker medication (propranolol 2 mg/kg) at least 1 h before CT examination to obtain a resting heart rate <80 beats/min. No sedation was required. All children were trained by a technician 30 min before the CT examination to hold their breath for at least 7 s.

CT examinations were performed with 64-slice CT scanner (LightSpeed VCT, General Electrics, Milwaukee, USA) with a beam collimation 64×0.625 mm thickness, a pitch of 0.16–0.22 depending of the heart rate, and a gantry rotation time of 0.35 s. Tube output was 80–100 kV. The effective tube current was modulated by an implemented fully automated real-time anatomy-based dose regulation algorithm (range from 250 to 450 mA), giving the following DLP = 474.8 ± 32 mGy cm. The mean effective dose 6.88 ± 1.2 mSv was derived from the DLP

and conversion coefficients for chest taking account patient age, as proposed by Shrimpton and Wall [5].

Scanning direction was craniocaudal during a single inspiratory breath-hold, and the ECG signal was recorded simultaneously. An automated injector was used for administration of a bolus of contrast agent (iohexol 300 mg I/ml) in a peripheral vein (volume 1.5–2 ml/kg, flow rate 2–3.5 ml/s depending on the size of the patient, followed by a 5–10 ml of saline solution). A bolus-tracking technique was used with the region of interest placed in the ascending aorta; the acquisitions started at a threshold of 300 UH. The scanning range covered from the pulmonary trunk to just below the base of the heart. It was started at the level of the clavicles in children with left internal mammary artery graft.

2.3. CT image reconstruction and analysis

A first set of images was obtained systematically at 75% of the R–R interval (corresponding to late diastole). Further image reconstructions are performed at every 10% of the R–R interval. Images were transferred to a dedicated offline computer workstation (Advantage Windows 4.2, GE Medical System) and reconstructed with multiplanar reformation, maximum intensity projection, and volume rendering reformation.

2.4. Conventional coronary angiography

Coronary angiography was performed according to standard technique, using 4–5F catheters. Two to four projections were performed (anteroposterior, left and right anterior oblique 20°, left anterior oblique 90°) to visualize the coronary arteries and grafts after injection of an iodine contrast agent (iohexol 300 mg I/ml).

The mean effective dose 3.5 ± 1.9 mSv was calculated with using a PC-based X-ray Monte Carlo program (Radiation and Nuclear Safety Agency, Helsinki, Finland) [6].

2.5. Data analysis

All invasive angiograms were analyzed by an experienced interventional pediatric cardiologist. CT images were analyzed

by two other independent physicians (one cardiologist and one radiologist) with experience in congenital heart diseases, blind to the invasive angiography findings. Inter-observer variability for detecting proximal coronary lesions and bypass graft lesions on CT was determined by κ -statistics.

With regards to the specific mechanisms of the coronary lesions (fibrosis scar involving the ostial and/or proximal coronary segments) after surgical revascularization, we only focused the analyzes on only six main segments of coronary arteries: the left main coronary artery, the proximal and the middle segments of the left descending coronary artery, the proximal segment of the circumflex artery, the proximal and the middle segments of the right coronary artery. Bypass graft was analyzed as a single segment at the site of anastomosis as well as along the entire course of the graft.

Each narrowing of more than 50% of the vessel diameter was determined to be significant stenosis in native segments as well as in the bypass graft. Irregular segments with narrowing less than 50% of the normal vessel diameter were considered as non-significantly stenosed. The status of each coronary segment for each patient as assessed by multislice CT scan was compared with findings by invasive angiography used as the reference standard.

3. Results

The mean heart rate at rest was 86 ± 19 beats/min (range 74–110 beats/min). Effective β -blockade (mean 72 ± 9 beats/min, range 58–77 beats/min) and breath holding during the acquisition resulted in interpretable images in all patients. CT was performed without complications in all patients. The duration of CT acquisition did not exceed 7 s.

Of the 15 patients, CT identified four children presenting with coronary lesions: one child with significant stenosis ($>50\%$ stenosis) and three children with non-significant stenosis ($<50\%$ stenosis). Interobserver variability was $\kappa = 0.87$.

The patient with significant stenosis presented a significant lesion at the anastomosis site between the left internal mammary artery and the left descending artery (Fig. 1). This finding was confirmed by conventional angiography and it leads to new successfully revascularization surgery. Coronary lesions



Fig. 1. Bypass graft stenosis. Sagittal oblique and axial oblique views on CT (left and middle panels) show a significant stenosis at the anastomosis site between the left internal mammary artery and the left anterior descending artery (arrow). Confirmation of the lesion on selective catheter angiography (right panel).



Fig. 2. Patency of the proximal saphenous vein bypass. Patent proximal saphenous vein bypass 8 years postoperatively in a 10-year-old child who had presented with a long occlusion of the right coronary artery 2 years after an arterial switch operation. Please note the patency of the anastomosis site between the vein graft and the native coronary artery (arrow). Right anterior oblique view of the right coronary artery on CT (left panel) and on selective coronary artery angiography (right panel).

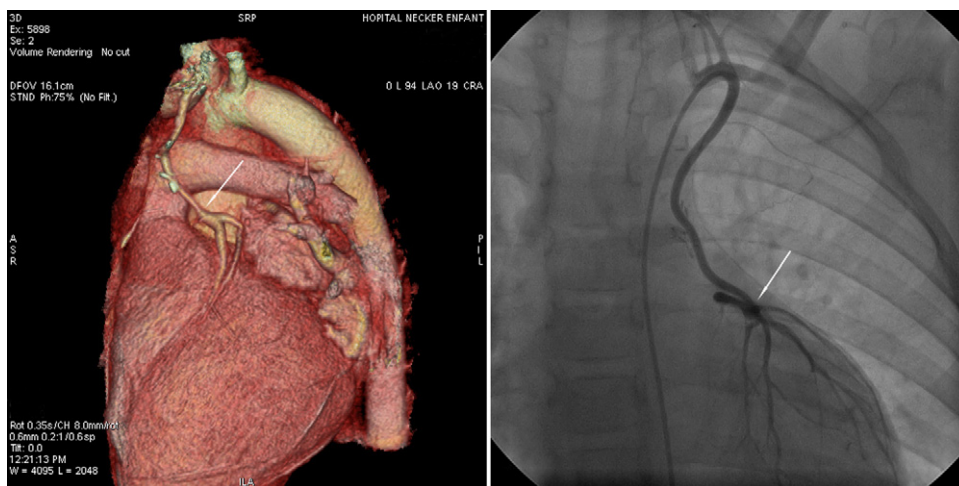


Fig. 3. Patency of the mammary bypass graft. Volume-rendered 64-slice CT (left panel) shows patency of the left internal mammary bypass graft. Selective catheter angiography (right panel) confirms the patency of both the graft and the anastomosis site (arrow) with the left anterior descending artery.

corresponding to non-significant stenosis involving three segments of three different patients were follows: (1) proximal circumflex angioplasty with saphenous patch; (2) proximal left main coronary artery angioplasty with saphenous patch; (3) anastomosis site between the left anterior descending artery and the mammary graft. These three non-significant stenosed segments were confirmed by conventional angiography. In the 11 patients with normal CT, no stenosis was found by conventional angiography (Figs. 2 and 3). The sensitivity and specificity of CT are 100% as compared to catheter angiography.

4. Discussion

Our study demonstrates that 64-slice CT angiography and X-ray angiography are equivalent for coronary artery patency assessment in children who had undergone previous coronary artery surgery. CT coronary angiography has the advantage to be faster and readily available technique and is less invasive than

catheter angiography. It should now be preferred as the noninvasive alternate method for examining the coronary circulation in children in this setting. However, the indication should always be clearly explained to patients and/or guardian because of ionizing radiation with a higher radiation dose.

Surgical coronary revascularization may be necessary even in early childhood to treat coronary artery obstruction as in cases of anomalous origin and/or intramural course, Kawasaki disease [7,8], congenital supra-aortic stenosis [9], surgical procedure such as the arterial switch operation for transposition of great arteries [2,10,11] or other iatrogenic lesions [1]. After revascularization surgery, coronary and bypass graft evaluation may be required several times from childhood to old age. The standard of reference for direct assessment of coronaries and bypass grafts is the selective angiography. However, catheter coronary angiography is an invasive and expensive procedure which inevitably involves some degree of procedure-related risks. Moreover it may require hospitalization after arterial puncture.

In this context, a reliable and noninvasive method of detection may be of clinical interest. Exercise-ECG, stress-echocardiography, and nuclear imaging are useful for detection of myocardial ischemia, but they are unable to exactly determine the site and extent of obstructive disease. Magnetic resonance imaging (MRI) is a totally noninvasive alternative for assessing coronary diseases and ischemic signs, avoiding ionizing radiation. However, this exciting technique is still hampered by a low spatial resolution and a lengthy scanning time. Furthermore evaluation of the anastomotic sites on MRI is not yet reliable, especially because of the importance of motion artifacts [12]. MRI is an evolving technique that should become invaluable in the next few years in this setting, as recently highlighted by Taylor et al., who has reported promising results for imaging the proximal coronary arteries with cardiovascular MR in children, who had undergone arterial switch operation for transposition of the great arteries [13].

Sixty-four slice CT scan is a readily imaging technique for assessment of coronary artery graft bypass in adults [4]. Recent studies are concordant in finding relevant sensitivity and negative predictive value for coronary and graft obstructive lesions [14,15]. Only a few experiences are reported in literature in children in this setting [3]. Our study demonstrates the clinical usefulness of multislice CT as a reliable imaging modality in the evaluation of coronary angioplasty and bypass graft in children having undergone coronary revascularization surgery. These pediatric patients may benefit from this technique, especially children who present with unconvincing chest pain and/or non specific ECG changes. CT may serve as a filter avoiding normal invasive angiography, but expense of a higher radiation exposure.

CT coronary angiography is particularly accurate for assessing the ostial and proximal segments of the coronary arteries. In centers expert in this technique, CT is routinely used for screening lesions involving the ostial and proximal segments of the reimplanted coronary arteries in children having undergone arterial switch operation [14]. In clinical practice, the abnormalities of importance after the coronary angioplasty and bypass graft operation also occur in the proximal segments, and thus justify the use of CT, in this setting. Certain technical aspects are of importance for the success of the examination in children. Attentive cooperation of children is crucial, as acquisitions depend on breath holding for approximately 5–7 s to minimize respiratory motion artifact. In our experience, such condition is feasible by reassurance, sympathetic explanation and training with breath holding maneuvers before the examination. Oral beta-blockade is another important point, and must be taken at least 1 h (for propranolol) before the examination in order to decrease the heart rate less than 80 bpm [16]. So our current policy is to use 64-slice CT scan, in complement to myocardial scintigraphy, as non invasive diagnostic and screening tools for detecting coronary angioplasty and bypass graft complications in the follow-up of children who had undergone coronary revascularization. This attitude is only applied after a clear explanation to the patients and/or guardian as regards to the ionizing radiation.

Radiation exposure with CT is the major disadvantage as the mean effective dose was nearly two times higher than catheter

angiography. Thus, it is certainly not reasonable to perform serial follow-up CT scans. However, a single and high-quality CT would be useful to exclude noninvasively dramatic coronary complications. In case of negative result, CT examination would provide reassurance, avoiding a normal invasive angiography. In our practice, we paid attention to limit radiation exposure as low as reasonably achievable. The ALARA (“as low as reasonably achievable”) principal is applied in daily practice: CT acquisitions are performed at low kilovoltage (80–100 kV) and mA are modulated and adapted to children weight [17].

Limitations of the study include the small number of patients. However, recruiting these selected pediatric patients is not easy in practice because the prevalence of this setting is low. In addition, it was ethically difficult to expose a larger cohort of children to both CT and invasive angiography, leading to a cumulative radiation dose. Since invasive angiography is the reference standard, physicians would not consider CT as an alternative modality unless such comparative study had been made. Such comparison is thus necessary to demonstrate the clinical usefulness of CT in this setting.

5. Conclusion

In centers expert in this technique, 64-slice CT scanning is a promising, rapid, and useful diagnostic technique for evaluating both coronary angioplasty and bypass graft lesions in children who had undergone coronary artery surgery.

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