Mechanisms of coronary complications after the arterial switch for transposition of the great arteries

Phalla Ou, MD, PhD,[a,b] Diala Khraiche, MD,[c] David S. Celermajer, PhD, FRACP, DSc, FAA,[d] Gabriella Agnoletti, MD, PhD,[c] Kim-Hanh Le Quan Sang, MD,[e] Jean Christophe Thalabard, MD, PhD,[b] Mathieu Quintin, MS,[f] Olivier Raisky, MD, PhD,[c] Pascal Vouhe, MD, PhD,[c] Daniel Sidi, MD, PhD,[c] and Damien Bonnet, MD, PhD[c]

Background: The arterial switch operation (ASO) for transposition of the great arteries requires transfer of the coronary arteries from the aorta to the proximal pulmonary artery (neoaorta). This is complicated by variable coronary anatomy before transfer. In 8% to 10% of cases, there is evidence of late coronary stenosis and/or occlusion, often with catastrophic clinical consequences. The mechanism of such complications has not been well studied.

Methods and Results: We analyzed 190 consecutive high-resolution computed tomographic scans from the ASO procedure (patients aged 5-16 years) and found 17 patients with significant (>30% up to occlusion) coronary lesions (8.9%); all were later confirmed by conventional angiography. The left main coronary artery was abnormal in 9 patients (ostium in all), the left anterior descending artery in 3, the circumflex in 2, and the right coronary artery in 3 patients. Using multiplanar and 3-dimensional reconstructions of the coronary arteries, aorta, and pulmonary artery, we identified the commonest mechanisms of coronary abnormalities. For the left main and left anterior descending artery, anterior positioning of the transferred left coronary artery (between 12 and 1 o'clock on the neoaorta) appeared to predispose to a tangential course of the proximal left coronary artery promoting stenosis. All circumflex lesions occurred in Yacoub type D coronaries where a long initially retroaortic artery was stretched by its new positioning behind an enlarged neoaorta. Right coronary artery lesions occurred only in cases in which the reimplantation site was very high above the right coronary sinus with potential compression from the main pulmonary artery bifurcation immediately above.

Conclusions: Thus detailed multiplanar computed tomographic scanning can elucidate the mechanisms of late coronary complications after the ASO. Understanding these aspects could help to improve surgical technique to minimize the risk of late coronary obstructions. (J Thorac Cardiovasc Surg 2013;145:1263-9)

JTCS VIDEO CLIP Video clip is available online.

The arterial switch operation (ASO) is the treatment of choice for transposition of the great arteries.[1] The technique requires transfer of the coronary arteries from the aorta to the proximal pulmonary artery (neoaorta). This is complicated by the variable coronary anatomy before transfer.[2] In 8% to 10% of cases, there is evidence of late coronary stenosis and/or occlusion, often with serious clinical consequences.[3-6]

Such coronary lesions are somewhat predictable in certain situations, for example, with the intramural course or with Yacoub type B coronary arteries.[2] However, the mechanism of the complications has not been well explained in the vast majority of cases in which the preoperative coronary pattern is apparently favorable (Yacoub A or D). In these patients, peculiar relationships between the reimplanted coronary arteries and the adjacent great arteries are suspected.[6] Postoperative modifications and/or spatial rearrangements of the great arteries as children grow may cause complications such as compression, kinking, or stretching that usually involve the ostial and proximal segments.[3]

Multislice computed tomography (CT) has been demonstrated to be a suitable alternative noninvasive method for the detection of coronary complications after ASO.[7-9] It also provides invaluable data about the 3-dimensional relationships between the coronaries and adjacent great arteries. The aim of our study was to assess the postoperative relationship of the reimplanted coronaries and great arteries with multiplanar and 3-dimensional reconstructions of the

From Hôpital Necker-Enfants Malades,[a] AP-HP, University Paris-Descartes, Paris, France; Laboratoire MAP5 – UMR 8145,[b] University Paris-Descartes, Paris, France; Centre de Référence des Malformations Cardiaques Congénitales Complexes-M3C,[c] Hôpital Necker-Enfants Malades, AP-HP, University Paris-Descartes, Paris, France; Department of Medicine,[d] Royal Prince Alfred Hospital, University of Sydney, Sydney, Australia; Hôpital Necker-Enfants Malades,[e] Clinical Pharmacology, Department of Genetics, AP-HP, University Paris-Descartes, Paris, France; and DRCD,[f] AP-HP, Paris, France.

Disclosures: Authors have nothing to disclose with regard to commercial support.

Received for publication March 15, 2011; revisions received May 11, 2012; accepted for publication June 8, 2012; available ahead of print July 16, 2012.

Address for reprints: Phalla Ou, MD, PhD, Hôpital Necker-Enfants Malades, 149 rue de Sèvres, 75743 Paris Cedex 15, France (E-mail: phalla.ou@nck.aphp.fr).

0022-5223/$36.00

http://dx.doi.org/10.1016/j.jtcvs.2012.06.009

Abbreviations and Acronyms

ASO	= arterial switch operation
CT	= computed tomography
LAD	= left anterior descending artery
LMCA	= left main coronary artery
MRI	= magnetic resonance imaging
RCA	= right coronary artery

vessels to better understand the commonest mechanisms of coronary lesions after ASO.

PATIENTS AND METHODS

At our institution, children surviving the ASO for transposition of the great arteries undergo routine multislice CT for clinical purposes at the age of approximately 5 years. In cases in which CT suggests a coronary abnormality, conventional coronary angiography is performed for confirmation and for assessment of collaterals.

We analyzed 190 consecutive high-resolution CT scans performed from 2005 to 2010 from the ASO procedure. Patients were aged 5 years to 16 years. Exclusion criteria were preoperative intramural course of the coronary arteries.

CT Angiography

All examinations were performed with a 64-slice CT machine (LightSpeed VCT; GE Medical Systems, Milwaukee, Wis). All patients were in sinus rhythm and, if not contraindicated, received oral beta-blocker medication (propranolol 1-2 mg/kg) 1 hour before CT examination with the aim of lowering resting heart rate to less than 80 beats/min.

CT scanning was performed with intravenous contrast enhancement, as previously described.[8] In brief, iodine contrast agent was injected (iohexol 300 mg/mL, 1.5 to 2 mL/kg, at a rate of 2-3 mL/s) with a power injector, followed by a chaser bolus of 10 to 15 mL saline into a peripheral vein. The standard CT angiography acquisition was made in a craniocaudal direction, extended from the pulmonary trunk to just below the base of the heart. Retrospective electrocardiogram-gated acquisitions protocol included a 350-ms speed rotation and a collimation of 64×0.625 mm. The CT parameters were adapted to the patient's weight and a fully automated real-time, anatomy-based, dose-regulation algorithm modulated the effective tube current.

A first set of images was reconstructed systematically at 75% of the R-R interval, with a smooth kernel and mediastinal windows. The entire cardiac cycle was systematically reconstructed from 10% to 90% of the R-R interval, with an increment of 10%.

Conventional Coronary Angiography

Conventional coronary angiography was performed with oral sedation (hydroxyzine, 1 mg/kg 1 hour before the examination, maximum 100 mg) and local anesthesia using 4F catheters, as previously described.[3]

Analysis of CT Data

Great arteries and coronary arteries were analyzed using axial slices and with the aid of postprocessing tools including multiplanar reconstruction, maximum-intensity thin-slab projection, and 3-dimensional reconstruction. Coronary analysis was limited to the ostial and proximal segments. Coronary lesions were stated as significant if greater than 30% obstruction.

Spatial relationships between the coronaries and the adjacent great arteries (aorta and pulmonary artery) were quantitatively characterized with the use of 2 measurements, called the "coronary angle" and the "coronary–pulmonary bifurcation distance."

The coronary angle was determined as follows (Figure 1): On an axial image with maximum intensity projection showing both the coronaries and the great arteries, we determined the center line that passes through the centers of both the pulmonary artery and the aorta. Then, we drew the reference line (0°) that passes through the center of the aorta and that is perpendicular to the aortopulmonary centerline. The coronary angle (expressed in degrees) was given by the measure of the angle between the reference line and the coronary ostia.

The coronary–pulmonary bifurcation distance was determined as follows. The coronary ostia and the center of the pulmonary bifurcation were visualized at the joint native axial images (slice thickness, 0.625 mm). The distance (d, mm) separating the 2 levels was calculated as d = (level of the center of the pulmonary bifurcation − level of the coronary ostium) × 0.625.

Statistical Analysis

Data were stored and anlayzed using the JMP software version 5.0.1a (SAS Institute, Inc, Cary, NC). Values are expressed as mean ± standard deviation, range, or median. Differences between the coronary angles and coronary–pulmonary bifurcation were tested by unpaired t tests at the 95% confidence level (2-tailed).

RESULTS

We found 17 (8.9%) patients with significant (>30% stenosis up to complete occlusion) coronary lesions; all were later confirmed by conventional angiography. The left main coronary artery (LMCA) was abnormal in 9 patients (ostium in all): the left anterior descending artery (LAD) in 3, the circumflex in 2, and the right coronary artery (RCA) in 3 patients.

As compared with patients without any coronary abnormality, the 12 patients with lesions involving the LMCA and the LAD had a more anterior reimplantation of the left coronary arteries. The site of reimplantation of the transferred coronaries was between 12 and 1 o'clock on the neoaorta, corresponding to a mean left coronary angle of 87° ± 5° versus 75° ± 8° ($P = .02$) (Figure 2). In addition to the anterior positioning, the LAD was also reimplanted too high above the left aortic sinus. The coronary–pulmonary artery bifurcation distance was shorter in the 3 patients with a lesion of the LAD as compared with those without any lesion (4.5 ± 1 mm vs 7.9 ± 2 mm; $P = .015$) (Figure 3).

All circumflex lesions occurred in Yacoub type D coronaries where a long initially retroaortic artery was stretched by its new positioning behind the neoaorta. The coronary–pulmonary artery bifurcation distance is longer in the 2 patients with a lesion of the circumflex as compared with those without any lesion (26 ± 5.2 mm vs 16.7 ± 7 mm; $P = .01$) (Figure 4).

All RCA lesions occurred in cases in which the reimplantation site was far above the right coronary sinus. The coronary–pulmonary artery bifurcation distance was shorter in the 3 patients with a lesion of the RCA as compared with those without any lesion (5 ± 1.5 mm vs 8.8 ± 1.7 mm; $P = .03$) (Figure 5).

Outcome of Patients With Coronary Obstruction

One patient with a focal and tight stenosis of left coronary artery ostium underwent successful balloon dilatation. He

CHD