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Structure and function of the ascending aorta in palliated transposition of the great arteries

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ABSTRACT

Background: In transposition of the great arteries (TGA), the right ventricle (RV) is subaortic and abnormal aortic structure or function could adversely affect the capacity of the RV to supply the systemic circulation. Our aim was to assess aortic dimensions and distensibility and RV function in patients with palliated TGA using cardiovascular magnetic resonance imaging (CMR).

Methods: We studied 29 patients (22 males; age 29 ± 4 years) with simple TGA, who underwent an atrial switch procedure, and 29 age and sex matched controls. All subjects had cine and phase contrast CMR to evaluate aortic function and global RV function.

Results: TGA patients had significant dilatation of the aortic annulus (21.0 ± 3.6 mm vs. 17.6 ± 4.1 mm, $p = 0.002$) and the sinus of Valsalva (30.0 ± 4 mm vs. 26.8 ± 4.2 mm, $p = 0.005$,) compared to controls. These findings were associated with reduced distensibility of the ascending aorta in patients with TGA (3.5 ± 1.6 vs. 5.3 ± 2.4 $mmHg^{-1}.10^{-3}$, $p = 0.0009$). We could not show a significant correlation between aortic stiffness indices and RV size, function, mass or presence of fibrosis.

Conclusion: The aortic root dilates and the ascending aorta stiffens in TGA, during young adult life. Although these proximal aortic changes did not show adverse effects on the RV in our young TGA sample, they might have important long-term physiopathological consequences in these patients.

1. Introduction

Due to the past advances in the management of children with congenital heart disease (CHD), the number of adults (over the age of 16 years) with CHD is increasing unceasingly, becoming higher than children with CHD [1]. Consequently, adult cardiologists are dealing with more cases of CHD of a more complex nature. Transposition of the great arteries (TGA) is one of the most common forms of complex CHD, affecting approximately 1 out of 3500–5000 live births [2]. In this severe CHD, impairment of ventriculo-arterial coupling is caused by abnormal rotation of the outflow tract during embryogenesis. In animals, the extracellular matrix has been shown to be involved in the control of conotruncal development [3] and in humans, one study has reported abnormal carotid artery elasticity in patients with TGA [4]. Following these studies, we sought to examine ascending aorta biomechanics in patients with TGA palliated by an atrial switch as the aorta has not been surgically modified in this condition compared to study evaluating aortic function after arterial switch or coarctation repair.

Magnetic resonance imaging (MRI) along with pressure measurements can provide a comprehensive non invasive analysis of aortic function. Therefore, in the present study, such data were used to analyze changes in proximal aortic biomechanics in TGA patients. We further studied the possible influence of aortic arch geometry on aortic biomechanics in this setting since we had previously found a relationship between aortic arch angulation and ascending aortic stiffness in repaired coarctation of the aorta [5,6].

Increased aortic stiffness, if present, could adversely impact the systemic right ventricle (RV), because arterial stiffness increases central aortic pressure and thus ventricular afterload. After atrial switch surgery in TGA, the morphologic anatomic right ventricle (RV) is left to sustain the systemic circulation, resulting frequently in RV dysfunction. Accordingly, the aims of the present study were: 1) to assess aortic dimensions, geometry and elasticity in TGA patients after atrial switch surgery, and 2) assess the relationship between aortic function and systemic RV performance in these patients.

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2. Materials and methods

2.1. Patient population

We retrospectively studied 29 (22 males, mean age: 29 ± 4 years, range: 18 to 38 years) consecutive patients with simple TGA who underwent an atrial switch procedure (22 Senning and 7 Mustard procedures). TGA patients with concomitant aortic coarctation, atrial fibrillation, hypertension or diabetes mellitus were excluded. The atrial switch operation had been performed between the age of 4 months and 3 years resulting in an averaged time since repair of 27 ± 3 years. Among the TGA patients, 14 received medication by either beta-blockers (n = 10), angiotensin receptor blockers (n = 1), angiotensin converting enzyme inhibitors (n = 7) and/or diuretics (n = 4). For data comparison, the TGA patients were matched for age and sex with 29 volunteers free of overt cardiovascular disease, who had no personal history and symptoms of cardiac disease as well as normal physical, electrocardiographic and echocardiographic examinations.

2.2. MRI acquisitions

CMR was performed with a 1.5-T MRI scanner (Signa HDx, GE Healthcare, Waukesha, WI, USA) using electrocardiogram (ECG) gating with fiber-optic leads and an 8-channel cardiac phased array surface coil. ECG gated steady-state free-precession cine (SSFP) images were obtained during breathholding in axial, long axis (2-, 3-, and 4 chamber views) and then 10 to 16 short axis views, with 8 mm thickness and 1-mm inter-slice gap, covering the RV from the atrio-ventricular ring to the apex. To visualize every segment of the thoracic aorta, three axial and oblique transverse views were acquired using cine segmented ECG-gated SSFP sequence.

For local ascending aortic distensibility measurements, an axial acquisition was prescribed perpendicular to the mid-ascending and -descending aorta at the level of the bifurcation of the pulmonary trunk (Fig. 1) using the cine SSFP sequence with the following average scan parameters: field-of-view = 370 mm × 370 mm, repetition time = 3.2 ms, echo time = 1.4 ms, flip angle = 50°, slice thickness = 8 mm, pixel size = 1.65 mm × 1.92 mm, and inter phase duration = 33 ms. To estimate pulse wave velocity, the breathhold gradient echo phase contrast pulse sequence was applied at the same location using the following average imaging parameters: repetition time = 7.5 ms, echo time = 3.5 ms, views per segment = 2, rectangular field-of-view = 50%, flip angle = 20°, inter phase duration = 15 ms, pixel size = 1.58 mm × 1.58 mm, slice thickness = 8 mm, and maximal velocity encoding = 200 cm/s. To assess the presence of late myocardial gadolinium enhancement (LGE), 12 to 16 contiguous 6 mm-thick slices were acquired per breath-hold with a 3D segmented inversion-recovery (IR) sequence at 6 to 11 min in 3-chamber view and twice in short axis view. 3D LGE imaging was followed by the acquisition of 8 short axis slices using the 2D IR sequence 10 to 16 min after intravenous injection of 0.2 mmol/kg gadolinium dimeglubine (Dotarem, Roissy, France). For each individual patient, the inversion time was optimized to null viable myocardium.

In all subjects, systolic and diastolic blood pressures were measured three times, within the magnet, before and after each acquisition of the aortic data by using an automated brachial artery sphygmomanometer cuff placed around the right arm (Vital Sign Monitor 300, Welch Allyn). The blood pressure calculated as the average of the three measurements was used for the following physiological calculations.

2.3. RV function measurements

RV images were analyzed using a commercial software package (MASS; Medis, Leiden, The Netherland). RV ejection fraction, mass and volumes were measured by drawing RV endocardial and epicardial contours at end-diastole and end-systole in all short axis slices.

2.4. Aortic function and geometry measurements

Trans sectional aortic root dimensions were measured from the oblique views, on images perpendicular to the aorta at the levels of the aortic annulus, the sinus of Valsalva, the sinotubular junction, and the ascending and the descending aorta at the level of the bifurcation of the pulmonary trunk (Fig. 1).

A new validated custom software (ARTFUN, INSERM U678) [7–9] was used for the measurement of aortic functional and geometrical parameters. This software enables an automated segmentation of both ascending and descending aortic contours on all the phases of the cardiac cycle. In the present study, this software was used for aortic contours segmentation from phase contrast modulus images for flow analysis and from SSFP cine images for aortic area measurements. The estimation of the ascending aortic area was repeated by two independent operators to assess inter-observer variability.

For each subject, the aortic areas were used to calculate the ascending and descending aorta distensibility. Distensibility was defined as the ratio between the relative change in aortic area (aortic strain = ΔA/Amin) and the brachial pulse pressure (ΔP) [10]: distensibility = ΔA/(Amin × ΔP). ΔA was the difference between the maximal systolic (Amax) and the minimal diastolic (Amin) aortic lumen areas estimated from SSFP images.

Aortic arch PWV was calculated, as previously described [9,11], by dividing the distance separating the ascending and the descending aorta by the transit time needed for the flow wave to cover this distance. The distance traveled by the flow wave was measured as the centerline of the aorta. Twelve to 18 markers were manually placed on the center of the aortic lumen on axial oblique and saggital oblique SSFP views of the aortic arch, resulting in a three-dimensional curve along the center of the vessel. The first and last marker corresponded, respectively, to the center of the ascending and descending aorta defined on the plane used for velocity acquisition.

Finally, the relationship between the regional aortic arch PWV and the local PWV, which was calculated from the ascending aorta distensibility using the Bramwell–Hill equation [11,12], was studied.

As previously described [6], we quantitatively characterized the shape of the aortic arch by measuring its height (H) and width (W) and calculating H/W ratio (Fig. 2)

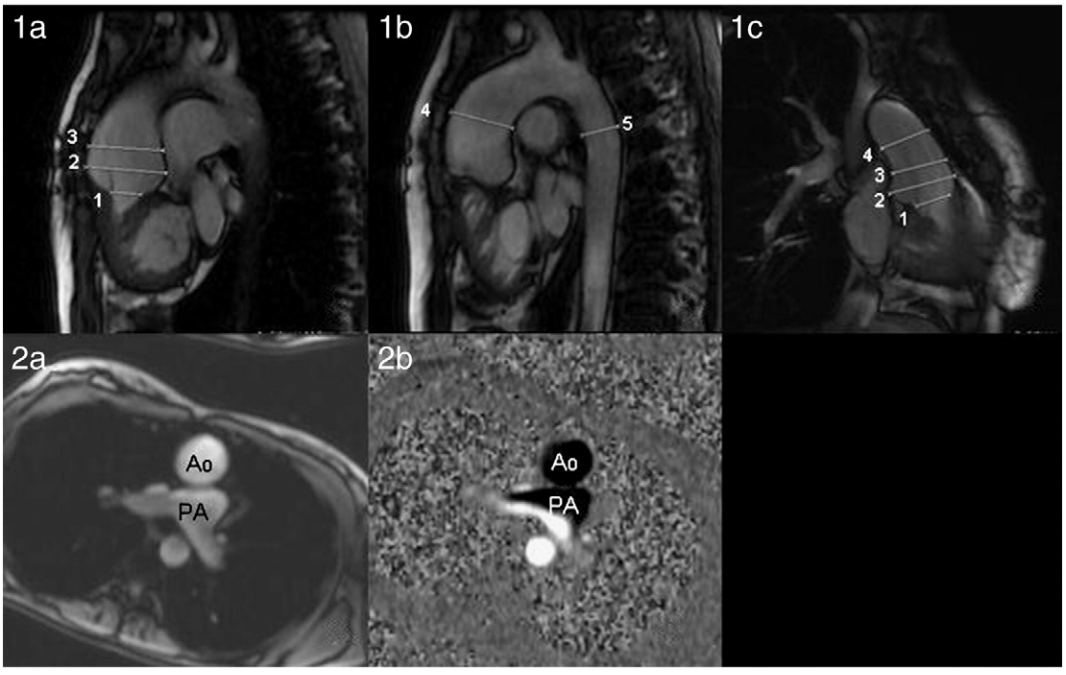

Fig. 1. Aortic diameters measured on two consecutive saggital oblique views (1a and 1b) and on a coronal oblique view (1c), perpendicular to aorta, at the level of the aortic annulus (level 1: 14 mm), the sinus of Valsalva (level 2: 41 mm), the sinotubular junction (level 3: 35 mm), the ascending aorta (level 4: 32 mm) and the descending aorta (level 5: 18 mm). In this example, the aortic root was dilated. 2a and 2b are axial acquisitions at the level of the bifurcation of the pulmonary trunk. Aortic segmentation was performed on SSFP cine images (2a) for aortic area measurements and on phase contrast modulus images (2b) for flow analysis.