Right Coronary Artery May Grow Even Better than Normal After Arterial Switch Operation for Complete Transposition of the Great Arteries

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Research article

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(1) Title page

Title; Right coronary artery may grow even better than normal after arterial switch operation for complete transposition of the great arteries

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(2) Abstract

Background: It is unclear if coronary arteries properly grow in patients who underwent arterial switch operation for complete transposition of the great arteries. The purpose of this study was to clarify the mode of coronary growth and size in these patients.

Methods: Eighteen patients who underwent arterial switch operation for complete transposition of the great arteries from 2000 to 2012 in our institution, and in whom coronary angiography was performed in late operative phase, were enrolled in this study. Growth of coronary arteries was evaluated by cubage of coronary arteries based on analyses with coronary angiography. Coronary arteries were divided into small segments and each segment was approximated by a truncated right circular cone. The sum of the cubage of each truncated cone in one coronary artery was approximated as total cubage of the coronary. the coronary cubage index was then calculated by dividing total cubage of a coronary artery by the patient's body surface area. The coronary cubage indexes of the enrolled patients were compared with that of control patients with healed Kawasaki disease.

Results: The left coronary cubage indexes of the complete transposition of the great arteries group and the control group were 1.05 ± 0.34 and 0.94 ± 0.34 (p=0.598), respectively, and no significant deference was found between groups. On the contrary, the right cubage index of the complete transposition of great arteries group was significantly larger than the control group (1.08 ± 0.44 and 0.54 ± 0.37, respectively; p=0.007), and total coronary cubage index (left coronary index + right coronary index) of the complete transposition of the great arteries group was also larger than the control group as well (2.13 ± 0.7 and 1.47 ± 0.6, respectively; p=0.026).

Conclusion: The left coronary arteries after arterial switch operation for complete transposition of great arteries grow as large as normal; however, the right coronary arteries possibly grow even larger.

311words

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(3) Main text

Introduction

Complete transposition of the great arteries (d-TGA) can be safely corrected in neonates by the arterial switch operation (ASO) and long-term survival is satisfyingly good [1,2]. On the contrary, concerns regarding coronary arteries after ASO still last; Turner reported that myocardial flow reserve may be impaired in patients with anatomic left anterior descending artery (LAD) abnormalities [3], and Mavroudis reported that one-third of patients who underwent ASO required reoperations for lesions related with coronary arteries [4]. Particularly, the size of left coronary artery has often been studied and discussed [1,5,6] because it potentially might cause failing ventricle, however the clinical question if coronary arteries properly grow in patients who underwent ASO is still unclear. The purpose of this study was to clarify the mode of coronary growth and size in these patients.

Patients and Methods

Study design and patient population

This was a retrospective cohort study performed at a single Japanese center in human subjects. We identified 18 patients who underwent ASO for d-TGA from 2000 to 2012 in our institution, and in whom coronary angiography (CAG) was performed in late operative phase; in 4-7 years after ASO to evaluate coronary growth and pathology. Mean age and body surface area (BSA) aged 11-191 days (median;18 days) at the ASO. Eleven of them had d-TGA with intact ventricular septum (d-TGA/IVS) and seven had d-TGA with ventricular septal defect (d-TGA/VSD). Eight patients with Kawasaki disease, who were confirmed to have no coronary pathological lesions by CAG, were selected and also enrolled in this study as age-, and BSA-adjusted control subjects. This study was reviewed and approved by the institutional review board at Yokohama City University. Informed consent was obtained from all patients' parents or legal guardians.

Angiographic analyses

Growth of coronary arteries was evaluated by cubage of coronary arteries based on analyses with CAG. Coronary arteries were divided into small segments on CAG and each segment was approximated by a truncated right circular cone. A cubage (mm^3; C) of each truncated cone can be calculated with proximal and distal radiuses (mm; r, R) and length ($mm;$ L) of each segment using the following mathematical formula.

$$C = \frac{\pi}{3} \times L \times (r^2 + rR + R^2)\ mm^3$$

The sum of the cubage of each truncated cone in one coronary artery could be acceptable approximation of total cubage of the coronary (T). (Fig 1)

$$T = \sum (C_1 + C_2 + C_3 + \cdots + C_n)$$

Left main trunk and right coronary artery were analyzed on frontal view, and left anterior descending artery, first diagonal branch and circumflex system were analyzed on lateral view. Figure 2 shows a sample of CAG analysis (Fig 2). Coronary cubage index was calculated by dividing total cubage of a coronary artery by the patient's BSA. BSA (m^2) was calculated by multiplying 0.007184 by $Weight(kg)^{0.425}$ and $Height(cm)^{0.725}$ according to the DuBois and DuBois formula [7].

Radiuses and lengths were measured on CAG with OsiriX DICOM viewer version 4.1.2 (Pixmeo SARL. Bernex, Switzerland). Data collection and cubage calculations were performed with Excel software (Microsoft Corporation, Remond, WA, USA).

Statistical analysis

All statistical analyses were performed with IBM SPSS statics 20. Continuous variables were expressed as mean ± standard deviation and were compared using the student's t test. Categorical variables are expressed as absolute numbers or percentages and were compared using chi-square testing. The level of statistical significance was set at $p < 0.05$.

Results

Patients demographics

The list of all 18 patients with d-TGA is given in Table 1. Briefly, 10 out of 18 patients were boys, the median age and BSA at the time of coronary angiography was 6.2 years and 0.75 m^2, respectively (Table 1). The median age at the time of ASO was 18 days (range; 11-48 days), excluding a case who underwent Aubert-Imai operation as a two-stage surgery at the age of 191 days. d-TGA/IVS was diagnosed in 11 patients and d-TGA/VSD was in 7 patients. Coronary anatomies were classified by Shaher's classification [8]; Shaher type 1 was confirmed in 11 patients, type 2A in 3, and type 5A in 3. The median age and BSA of control (Kawasaki) group was 6.0 years and 0.77 m^2, respectively, that were almost same as those of TGA group. No stenosis nor occlusion of coronary artery was detected by CAG in both groups.

Coronary cubage indexes (cubage(mm^3) / BSA(m^2))

The left coronary cubage indexes of d-TGA group and control group were 1.05 ± 0.34 and 0.94 ± 0.34 ($p=0.598$), respectively, and no significant difference was found between groups. On the contrary, the right cubage index of d-TGA group was significantly larger than control group (1.08 ± 0.44 and 0.54 ± 0.37, respectively; $p=0.007$), and total coronary cubage index (left coronary index + right coronary index) of d-TGA group was larger than control group as well (2.13 ± 0.7 and 1.47 ± 0.6, respectively; $p=0.026$). (Table 2)

Discussion

ASO is a standard surgical strategy for d-TGA described by Jatene and Lecompte [9,10] which is technically demanding especially in translocation of coronary arteries. Previous studies reported that there possibly could be abnormal myocardial perfusion in children after ASO [3]; however, the mode of coronary arteries growth and function after ASO are still unclear. Yatsunami showed the left coronary arteries were smaller than normal after ASO and that the dominant, large right coronary artery does not fully compensate [5]. On the contrary, Turner advocated that anatomic coronary growth is normal in almost 90% coronary arteries after ASO [3]. Our results of this present study differ from these previous reports; the left coronary arteries after ASO grew as large as normal (Kawasaki), and the right coronary arteries grew even larger.

From the embryologic point of view, the development of the coronary vasculature starts from the appearance of round blood islands on epicardium, and then these islands preferentially develop in the sulci of the heart surface and form a rudimentary plexus [11,12]. This coronary plexus grows and climbs superiorly, and then develops the coronary network. The coronary stems are formed from the coronary network and attaches to the aortic root. Based on the embryologic and anatomical differences of relationship of great arteries and ventricles between the normal and the d-TGA fetus, the reasons underlying our results should be discussed in taking the logical fetal circulation into account. The oxygen saturation of the blood distributed in the ascending aorta is 65%, mixture of the blood from foramen ovale with an oxygen saturation of about 85% and that from pulmonary veins with an oxygen saturation of about 60% in the normal fetus [13]. On the contrary, the blood ejected by the right ventricle to the ascending aorta have an oxygen saturation of about as low as 45%; mixture of blood from placenta with an oxygen saturation of about 85% and that from systemic circulation with an oxygen saturation of about 35%, that is similar to that of the pulmonary artery in the normal fetus

[13]. Therefore, the oxygen saturation of the blood distributed in the coronary artery of the d-TGA fetus would be lower than that of the normal fetus [13]. Based on this logic, total coronary blood flow of the d-TGA fetus should consequently be 1.5 times higher than that of the normal fetus to provide the proper oxygen delivery. One can then hypotheses that coronary arteries of d-TGA possibly grow the same as or even better than the normal due to the higher coronary flow.

Previous studies documented that the right coronary arteries are larger than the left, which consists with our results. It is questioned why this phenomenon happens. The right coronary artery flow has been documented to increase with a positive correlation to systolic right ventricular pressure in children with congenital heart defect [14]. The right ventricles corresponding to systemic circulation in d-TGA should have higher systolic pressure than normal. The right coronary artery flow then consequently increase, therefore, we could hypothesize that it leads to enlarged right coronary arteries. Moreover, the fact that the distance between the right coronary stems and the aortic root which is located anterior to the main pulmonary artery in TGA fetus is shorter than normal might increase the right coronary flow.

Hemodynamically and anatomically different circumstances of the coronary artery development is considered to play major roles for the results of the present study as described above. Although these factors mainly affect within embryos and neonates before correction, we believe that they can substantially impact to the coronary artery growth even years after ASO.

Study limitations.

This study included single center data and the numbers of the subjects are small. Regardless of the type of coronary artery anatomy in d-TGA, the coronary cubage was comprehensively evaluated. But impacts of coronary artery anatomy to the coronary growth could not be evaluated because of small samples. Observational period was as short as 5-7 years in this study. Longer observation of larger cohorts of patients is then necessary to evaluate the coronary artery growth more properly. Also, the impact of embryonic circulation on coronary artery growth even after the corrective surgery has to be studied from the point of gene expression.

Conclusion

The left coronary arteries after ASO for d-TGA grow as large as normal; however, the right coronary arteries possibly grow even larger. Further evaluation with long observation of larger cohorts is mandatory for verifying these results.

Abbreviations

d-TGA: Complete transposition of the great arteries, ASO: arterial switch operation, LAD: left descending artery, CAG: coronary angiography, BSA: body surface area, VSD: ventricular septal defect, IVS: intact ventricular septum

Declarations

Ethical Approval and Consent to participate

This study was approved by the institutional review board at Yokohama City University. Informed consent was obtained from all patients' parents or legal guardians.

Consent for publication

Consent for publication was obtained from all patients' parents or legal guardians.

Availability of supporting data

All data are available.

Competing interests

All authors declare that they have no competing interests.

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Authors' contributions

DM and YI designed the study. DM and MoG wrote and submitted the manuscript. DM, YI, MaG, NT, SK, KK, TM, SY, TC collected and analyzed data together. SS and MM supervised this study. All authors read the final version of this article and approved for publication.

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References

[1] Williams WG, McCrindle BW, Ashburn DA, Jonas RA, Mavroudis C, Blackstone EH, the members of the Congenital heart Surgeon's Society. Outcome of 829 neonates with complete transposition of the great arteries 12-17 years after repair. Eur J Cardiothorac Surg 2003;24:1-10

[2] Masuda M, Kado H,Nakajima K , Onizuka T, Kurisu K, Morita S, Shiokawa Y, Imoto Y, Tominaga R, Yasui H. Early and Late Results of Total Correction of Congenital Cardiac Anomalies in Infancy. Jpn J Thorac Cardiovasc Surg. 2001 Aug;49(8):497-503

[3] Turner DR, Muzik O, Forbs TJ, Sullivan NM, Singh TP. Coronary diameter and vasodilator function in children following arterial switch operation for complete

transposition of the great arteries. Am j Cardiol 2010;106:421-425

[4] Mavroudis C, Stewart RD, Backer CL, Rudra H, Vargo P, Jacobs ML. Reoperative techniques for complications after arterial switch. Ann Thirac Surg 2011;92:1747-1755

[5] Yatsunami K, Nakazawa M, Kondo C, Teshima H, Momma K, Takanashi Y, Imai Y. Small left coronary arteries after arterial switch operation for complete transposition. Ann Thorac surg 1997;64:746-751

[6] Amin Z, McElhinney DB, Moore P, Reddy VM, Hanley FM. Coronary arterial size late after the atrial intervention procedure for transposition of the great arteries: implications for the arterial switch operation. J Thorac Cardiovasc Surg. 2000;120:1047-1052

[7] DuBois D, DuBois EF. A formula to estimate the approximate surface area if height and weight be known. Arch Intern Med 1916;17:863-871

[8] Shaher RM, Puddu GC. Coronary arterial anatomy in complete transposition of the great vessels. Am J Cardiol 1966;17:355-361

[9] Jatene AD, Fonted VF, Paulista PP, Souza LC, Neger F, Galantier M, Sousa JE. Anatomic correction of transposition of the great vessels. J Thorac Cardiovasc Surg. 1976;72:364-370

[10] Lecompte Y, Zannini L, Hanzan E, Jarreau MM, Bex JP, Tu TV, Neveux JY. Anatomic

correction of transposition of the great arteries. J Thorac Cardiovasc Surg 1981;82:629-631.

[11] Hutching GM, Kessler-Hanna A, Moore GW. Development of the coronary arteries in the embryonic human heart. Circulation 1988;77:1250-1257

[12] Goda M, Arakawa K, Yano H, Himeno H, Yamazaki I, Suzuki S, Masuda M. Congenital aortopulmonary fistulas combined with bilateral coronary artery fistulas. Ann Thorac Surg 2011;92:1524-1526

[13] Rudolph AM. Aortopulmonary transposition, Congenital Diseases of the Heart. 3rd ed. San Francisco: Wiley-Blackwell, 2009. p.465-505

[14] Watanabe N, Awa S, Akagi M, Ando Y, Oki N, Watagai T, et al. Effect of heart rate and right ventricular pressure on right coronary arterial flow and its systolic versus diastolic distribution in a variety of congenital heart diseases in children. Pediatr Int. 2000;42:476-482.

Figures

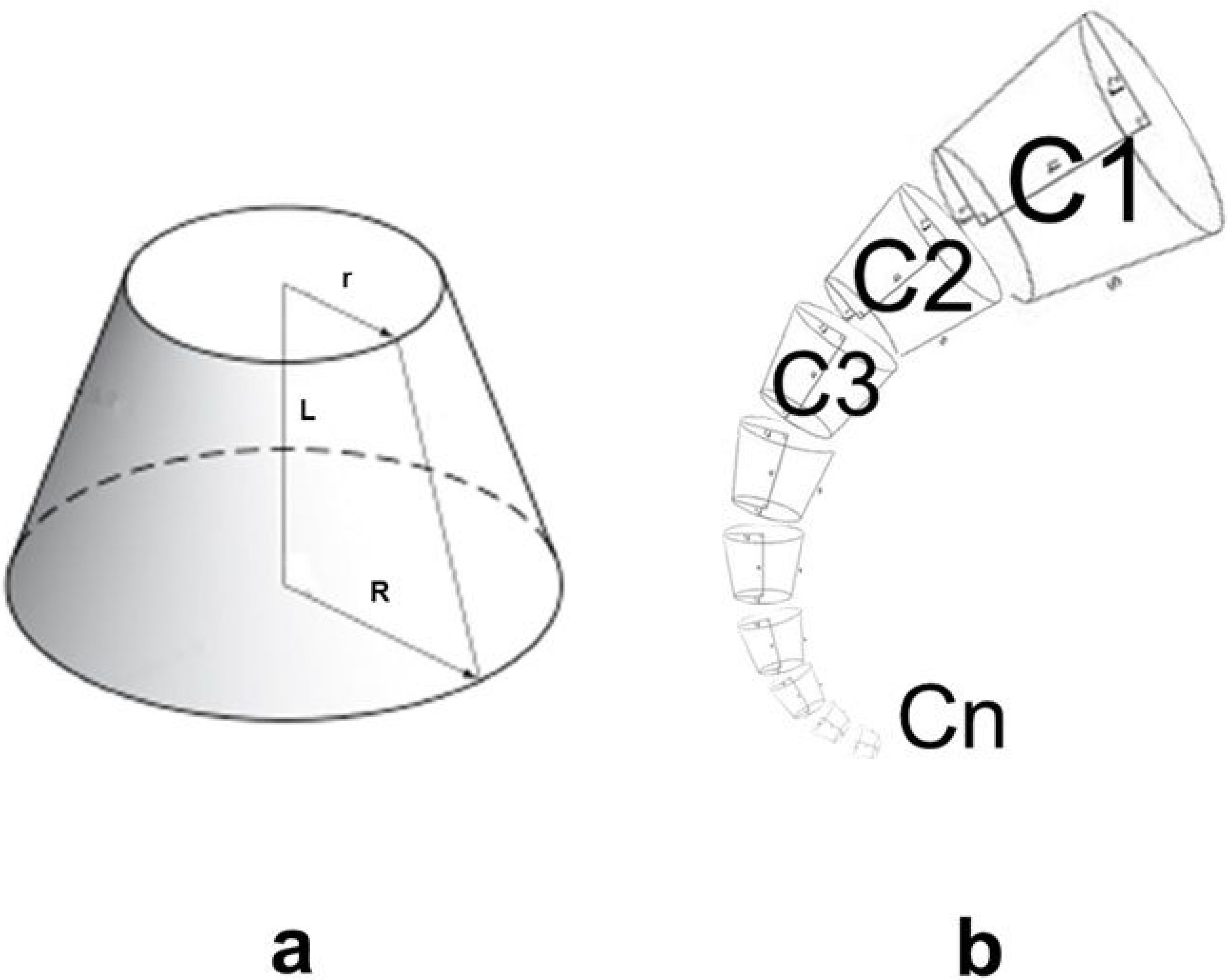

Figure 1

Approximation of coronary arteries by multiple circular truncated cones a. A cubage (C) of each truncated cone can be calculated with proximal and distal radiuses (r, R) and length (L) of each segment using the following mathematical formula. $C = \pi/3 \times L \times (r^2 + rR + R^2)$ mm^3 b. The sum of the cubage of each truncated cone in one coronary artery could be acceptable approximation of total cubage of the coronary (T). $T = \sum (C_1 + C_2 + C_3 + \dots + C_n)$

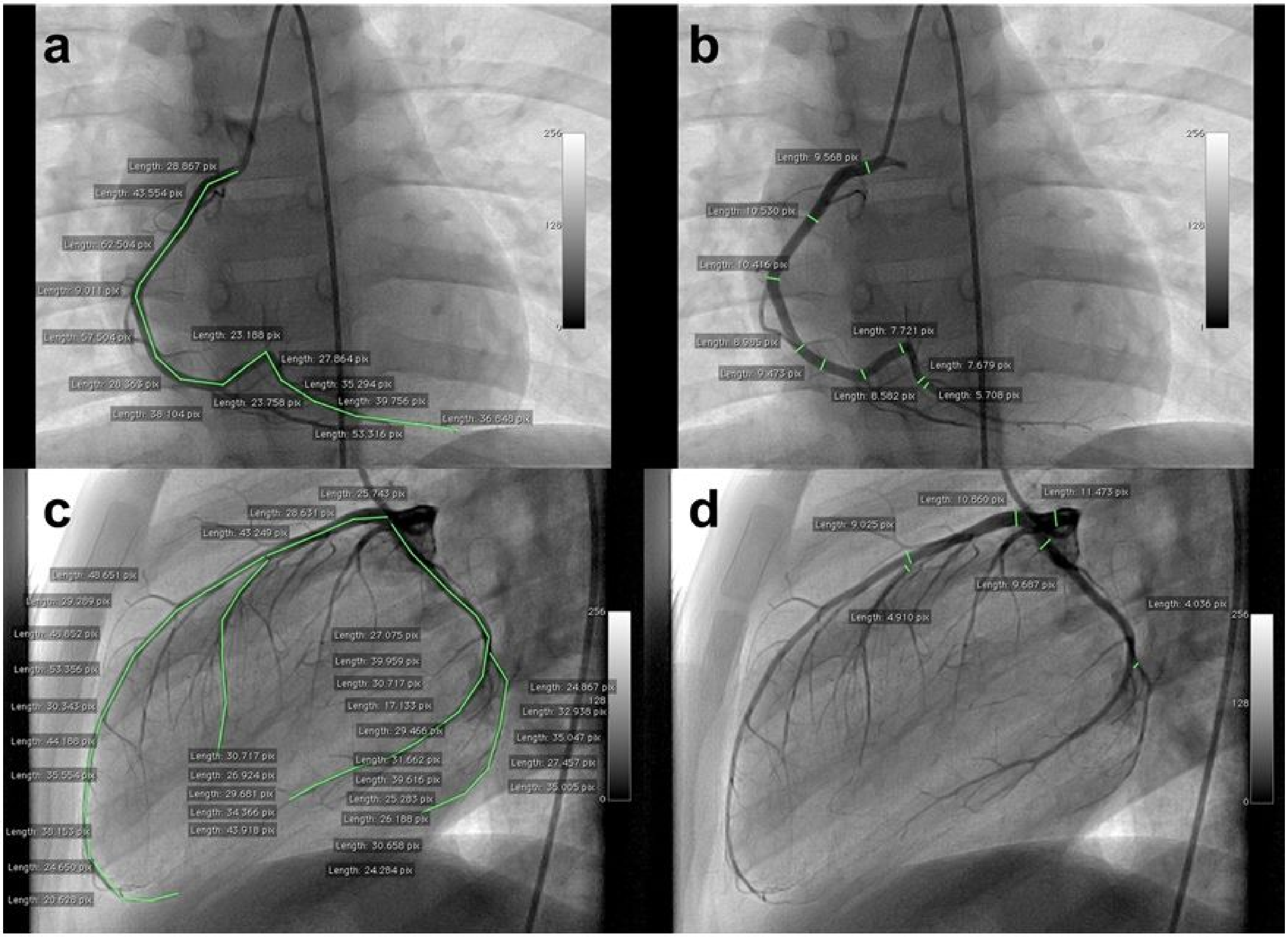

Figure 2

Angiographical analysis Radiuses and lengths of each segments of coronary arteries were measured on CAG with OsiriX DICOM viewer version 4.1.2. a, b; Right coronary artery and left main trunk were analyzed on frontal view. c, d; Left anterior descending artery, first diagonal branch and circumflex system were analyzed on lateral view.

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