anatomy
http://dergipark.org.tr/en/pub/anatomy
An International Journal of Experimental and Clinical Anatomy

Original Article

http://dergipark.org.tr/en/pub/anatomy
Received: April 28, 2022; Accepted: December 12, 2022
doi:10.2399/ana.22.3282183

Transposition of the great arteries: single center experiences

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Abstract

Objectives: Transposition of great arteries is the most common cyanotic congenital heart disease. It is characterized by ventriculoarterial discordance and atrioventricular concordance. The aim of the present study was to review the anatomical and embryological basis of this anomaly and to discuss the surgical outcomes of arterial switch operations.

Methods: The study included a total of 61 patients who underwent arterial switch operation. Demographic, anatomical, operative data, duration of stay in intensive care unit, need of postoperative extra corporeal membrane oxigenator, need of delayed sternal closure and mortality rate were retrieved from the institutional databases and medical records.

Results: The median age of the patients was 22.9±61.26 (1–455) days, and their weights ranged between 3391.97±686.6 (1900–5500) grams. Transposition of great arteries accompanied intact ventricular septum in 39 patients (63.9%) and ventricular septal defect in 22 patients (36.1%). Coronary arteries were abnormal in 11 patients (18%). Mortality was observed in 7 patients (11.5%) and was seen 5.71±2.98 (1–10) days after surgery. The incidence of coronary anomaly in patients with mortality was 28.6%. The most common coronary anomaly in patients with coronary anomaly with mortality is the anomaly in which the circumflex artery originates from the right coronary artery.

Conclusion: Arterial switch operations provide anatomical and complete correction in transposition of great arteries. It can be performed with appropriate timing, good preoperative, peroperative and postoperative management with low mortality. Coronary artery anomaly is not a contraindication for arterial switch operations, and with the detailed and careful evaluation of the appropriate coronary artery anatomy, transpositions with coronary anomalies are often uneventful.

Keywords: arterial switch operation; Jatene operation; Lecompte maneuver; transposition of great arteries

Anatomy 2022;16(3):172–178

Introduction

Transposition of great arteries (TGA) is the most common cyanotic congenital heart disease. It constitutes 5% of all congenital heart diseases.[1] In this disease, the heart is characterized by ventriculoarterial discordance, atrioventricular concordence. The pulmonary artery (PA) arises from the left ventricle (LV), while the aorta arises from the right ventricle (RV).[2] If there is no other accompanying cardiac lesion, this disease is called TGA with intact ventricular septum (TGA-IVS). TGA is called as complex TGA in the presence of accompanying cardiac anomalies. These lesions are ventricular septal defect (VSD) (45%), left ventricular outflow tract (LVOT) stenosis (25%), and aortic coarctation (5%). In general, there is no familial transmission in TGA. It has not been found to be associated with syndromes and chromosomal anomalies. It is seen two times more in males than in females.[3,4]

In TGA, the atria and ventricles have typical structural features and the conduction system is normally distributed. There is a fibrous continuity between the mitral and pulmonary valves. Coronary arteries usually arise from the aortic sinus, which faces the pulmonary trunk. Most commonly, the left anterior descending coronary artery (LAD) and circumflex artery (Cx) arise as a single root, while the right coronary artery (RCA)

arises as a separate root. In some patients, LAD, Cx and RCA emerge as a single root. There is also a variation in which LAD and Cx emerge as two separate ostiums on a single root. Apart from this, there is rarely a variation where the left main coronary artery (LMCA) or LAD is intramural between the pulmonary and aortic root.[5–12]

Embryological theories in the formation of TGA can be summarized as below:[5–7]

- Flat truncoconal septation hypothesis, which blames abnormal septation of the aorta and PA,
- The hypothesis of an abnormal fibrous skeletal continuum in which the pulmonary-mitral fibrous continuum occurs instead of the normal aortic-mitral fibrous continuum.
- The hypothesis of abnormal embryonic hemodynamics due to obstructive and different flow patterns,
- Reverse truncal ridge hypothesis, which points to the reverse development of regions under the semilunar valves.

Due to this anomaly, the mixing is insufficient and this parallel circulation creates deep hypoxia. This results in hypoxia, acidosis, and death. In selected centers, short-term survival is above 95% with fast-acting preoperative management, timely surgery, and close postoperative monitoring.[2–4]

Arterial switch operation (ASO) was first described by Adib Jatene in 1976.[13] ASO is performed in the neonatal period and is the first-choice surgery in case of anatomical suitability. Atrial switch or two-stage ASO can be performed at later ages. Despite the medical and surgical advances in the diagnosis of TGA and low mortality rates, these patients should be followed up preoperatively, intraoperatively and postoperatively in a multidisciplinary manner, especially from the antenatal period. The aim of the present study was to review the anatomical and embryological basis of this anomaly and to discuss the surgical outcomes of arterial switch operations.

Materials and Methods

This retrospective study was conducted at a paediatric heart center between February 2019-March 2022. The study included a total of 61 patients who underwent ASO.

Data including age, sex, type of TGA, surgical technique, presence of coronary anomaly, duration of cardiopulmonary bypass (CPB) and cross-clamp (CC) time, duration of stay in the pediatric cardiovascular surgery (CVS) intensive care unit (ICU), duration of stay in the neonatal ICU, need of postoperative extra corporeal membrane oxigenator (ECMO) and duration of ECMO support, need of periton dialysis, need of continuous renal replacement therapy (CRRT), need of delayed sternal closure and duration of sternal closure and mortality rate were all retrieved from the institutional databases and medical records.

All TGA patients who underwent ASO by the same surgical team were included in the study. Aortabicaval cannulation was performed in all patients. The patients were cooled to 28°C and after the patients were taken to CPB, the patent ductus arteriosus (PDA) was ligated and divided after transfixation sutures. DelNido cardioplegia and topical cooling were used for myocardial protection after CC was placed, and antegrade cardioplegia was repeated every 60 minutes. Coronary arteries were moved to the neoaorta by direct anastomosis or Trap-door technique. Which technique to use was decided after intraoperative evaluation of the aortic and pulmonary annulus. After translocation of the coronary arteries to the neoaorta, the Lecompte maneuver was performed and the neoaortic anastomosis was completed. Neopulmonary anastomosis was completed using fresh pericardium.

Interquartile range (IQR) was used to express continuous data, whereas frequency and percentages were used to represent categorical variables. A p-value of less than 0.05 was considered statistically significant for all statistical analyses, which were carried out using the SPSS for Windows version 25.0 program (SPSS Inc., Chicago, IL, USA).

Results

The median age of the patients was 22.9±61.26 (1–455) days, and their weights ranged between 3391.97±686.6 (1900–5500) grams. 56 patients (91.8%) were in the neonatal period. The diagnosis was TGA-IVS in 39 patients (63.9%), and TGA with VSD (TGA-VSD) in 22 patients (36.1%). Diagnosis was made by transthoracic echocardiography (ECHO) in all cases. 22 patients (36.1%) had fetal ECHO during the antenatal period. Balloon atrial septostomy (BAS) was performed in the catheter laboratory in 42 patients (68.9%) with restrictive atrial septal defect (ASD). ASO was applied to all patients. Coronary artery anatomy was normal in 50 cases (82%). Coronary arteries were abnormal in 11 patients (18%). Cx was originating from the RCA in 4 cases (36.4%), and a single coronary root was present in 4 cases (36.4%). In 2 cases, LAD was dislocated from the RCA and Cx was dislocated from its normal position (18.2%) and in 1 patient, the coronary arteries were double looping (9.1%).

All patients were operated under CPB. Mean CPB time was 135.44±29 (78–247) minutes, CC time was 87.95±18.8 (52–136) minutes. Inotropic support was started in all patients after CPB. Depending on the hemodynamic status of the patients, the sternum was closed or left open, and they were followed up in the pediatric CVS ICU. Delayed sternal closure was performed to 40 patients. (65.6%) In these patients, the sternum was closed at the bedside in ICU on the appropriate day according to the hemodynamic status of the patient. Mean sternal closure time was 3.58±3.22 (1–16) days. Patients who continued to have hemodynamic instability and could not wean from CPB or needed CPB again after leaving were transferred to ICU under ECMO support. In patients who could leave ECMO according to hemodynamic status, weaning was performed at the bedside in ICU. The patients who needed ECMO were 7 (11.5%), 3 (4.9%) patients who could leave ECMO, mean time to leave ECMO was 9±5 (4–14) days. Peritoneal dialysis was performed in 7 patients (11.5%) and CRRT in 2 patients (3.3%).

Mortality was observed in 7 patients (11.5%). Mortality was seen 5.71±2.98 (1–10) days after surgery. The incidence of coronary anomaly in patients with mortality was 28.6%. The most common coronary anomaly in patients with coronary anomaly with mortality was the anomaly in which the Cx originates from the RCA.

The patients were followed up in the pediatric CVS ICU after ASO. The patients were taken to the neonatal ICU after the need for inotropes was over. The extubation and enteral feeding processes of the patients were performed in the neonatal ICU. The hospitalization period in the pediatric CVS ICU was 7.92±8.73 (1–62) days, and the hospitalization period in the neonatal ICU was 24.62±20.8 (0–90) days.

Discussion

TGA was first described by Mathew Bailie in 1797 in the second edition of the book "The Morbid Anatomy of some of the Most important Parts of the Body", but the term transposition was first used by Farre in 1814.[8] In this congenital cardiac malformation, there is atrioventricular concordance and ventriculoarterial discordance, that is, the morphological right atrium (RA) connects to the morphological RV, but this ventricle connects to the aorta instead of the PA, unlike the usual situation. Likewise, the morphological left atrium (LA) connects to the morphological LV, while the morphological LV connects to the PA.

TGA is the most common cyanotic congenital heart disease. It constitutes 5% of all congenital heart diseases.[1] TGA occurs in 20–30 of 100,000 live births.[9] It is seen two times more in male than in female.[3,4] This disease is accompanied by non-cardiac anomalies in 10% of cases.[10]

In 50% of cases, only ventriculoarterial discordance, atrioventricular concordance is found. This situation is called Simple TGA. In case of VSD, LVOT stenosis, arch anomalies or systemic venous return anomalies, it is called Complex TGA. VSD is relatively common, but its location and size are variable. There may be varying degrees of malalignment between the outlet and the trabecular septum. Anterior and right deviation of the outlet septum can cause pulmonary overriding and subaortic stenosis. Aortic hypoplasia, coarctation, or aortic interruption may be seen in these cases. If the outlet septum shows posterior and left malalignment, this results in subpulmonary stenosis.[11] LVOT stenosis occurs in approximately 25% of cases and is more common in VSD-TGA patients. In our series, the number of patients with TGA-IVS was 39 (63.9%), while the number of patients with TGA-VSD was 22 (36.1%). The incidence of coronary anomaly in transposition of the great arteries is not to be underestimated. While the incidence of coronary anomalies in our series was 18%, the most common coronary anomalies were Cx originating from RCA and coronary arteries originating as a single coronary root.

Contrary to what it should be, the systemic and pulmonary circulation in these patients progress in parallel, not in series. While oxygenated blood circulates between the left chambers of the lung and heart, systemic blood circulation is provided by another closed circulation starting from the right chambers of the heart and ending in the right chambers of the heart. In this case, life becomes possible only with a connection between these two circulations.[12]

Central cyanosis and deep hypoxia are seen due to parallel circulation in this pathology. The degree of hypoxia determines the amount of mixture between circulation. In cases where the ventricular septum is intact and the ASD is restrictive, hypoxia and cyanosis begin from the first hours of life. Hypoxia is exacerbated in the presence of accompanying LVOT stenosis or pulmonary stenosis. Conversely, if adequate mixing is achieved in the presence of a large VSD, cyanosis may be overlooked, and even heart failure due to increased ventricular load may occur.[13]

The exact etiology of this disease is unknown. Gestational diabetes, maternal exposure to rodenticides

and herbicides and maternal antiepileptic use are blamed in the etiology.[14] Although different mutations are prominent in this pathology, no clearly related gene has been detected. Although chest radiography and electrocardiography are helpful in diagnosis, they do not have specific findings. In TGA, the superior mediastinum is narrowed on chest radiography and there is a characteristic egg-shaped heart. Increased pulmonary vascularity with cardiomegaly can be seen in VSD-TGA. In the current era, TGA is diagnosed with transthoracic ECHO with ventriculoarterial discordance. Parasternal long axis and also the subcostal-parasternal apical chamber views of two-dimensional (2D) ECHO demonstrates PA originating from the LV coursing posteriorly and the aorta from RV in the same plane coursing anteriorly. Aorta is identified as the great vessel from which the coronary arteries are seen originating, PA is identified as the great vessel that bifurcates. Right anterior aorta and central position of pulmonary valve are seen. Important anatomical and presurgical details should be determined with ECHO including VSD, LVOT obstruction, morphology and the size of semilunar valves, the origins of coronary arteries and their branching.

Coronary anomalies are so common in TGA. According to Leiden cenvention and Yacoub and Radley-Smith classification, Type A (normal) coronary distribution is most common. Type B, single coronary ostium from a posterior facing sinus; type C, separate close origins of the left and right coronary arteries from a posterior facing sinuses (often with intramural course); type D, Cx from RCA; type E, Cx from right posterior sinus and LAD and RCA from the left posterior facing sinus are the other defined types. In our series the most common coronary anomalies are Cx arising from RCA and single coronary ostium with total 72.8%.

Prenatal diagnosis of TGA with fetal ECHO is increasing nowadays and leads counseling families of the diseases, delivery planning and to provide appropriate postpartum management. Fetal four-chamber view is normal but typical features include the aorta anterior to the PA and parallel outflow tracts at the outflow tract position. Restriction of ductus arteriosus and foramen ovale are two important point which may be predictive of severe hypoxemia after delivery.[15] In our series 37.7% of patients had antenatal diagnosis of TGA.

The main goal in this pathology is to provide an adequate mixture in the affected newborn. An adequate ASD or VSD can provide adequate mixing in the neonate and saves the patient time until corrective surgery. Patients who do not have a sufficiently large ASD or VSD need different interventions before surgical correction. Intravenous infusion of prostaglandin E1 (PGE1) is necessary to maintain patency of the ductus arteriosus. In this way, pulmonary blood flow increases and pulmonary venous return and left atrial pressure increase. This creates a left-right shunt at the atrial level. Side effects of PGE1 are apnea, bradycardia, systemic hypotension, fluid-electrolyte imbalances, fever and flushing in the acute period. Its late side effects are dose-independent cortical hyperosteosis.[16]

Although PGE1 increases mixing between circulations, it is often not sufficient and additional interference is needed. BAS also known as the Raskind procedure, has an important place in the presurgical follow-up of these patients. The purpose of this procedure is to increase interatrial mixing by widening the patent foramen ovale or restrictive ASD. This increases oxygen saturation. The Raskind procedure was applied in 42 of our patients. (63.8%) Thirty of these patients (%71.43) had nonrestrictive ASD and increased saturation. This saves time for surgery.

In addition to these interventions, medical support is often needed to stabilize the clinical situation. Mechanical ventilation and oxygen are required to resolve resistant hypoxia. However, oxygen supplementation accelerates ductal closure and reduces mixing. It triggers intercirculatory shunts by increasing alveolar tension in high-pressure ventilations. Sodium bicarbonate is important in the treatment of metabolic acidosis, and inotropic agents and diuretics can be added to the treatment when heart failure develops.

Accompanying lesions determine the surgical treatment of TGA. Many methods have been tried in the history of TGA treatment. In 1950, Blalock-Hanlon aimed to increase the mixing at the atrial level with atrial septectomy. Today, this procedure has been replaced by BAS. In our clinic BAS is the first choice in these patients with insufficient mixing.

Other surgeries performed in TGA pathology are atrial baffle surgeries described by Mustard and Senning.[17] This operation is basically physiological correction operations. Since the ventricle providing the systemic circulation is the RV, it is not an anatomical correction. In these operations, systemic and pulmonary venous return is directed to the associated ventricles via the atrial baffle. While fresh pericardium is used for baffle in Mustard operation, baffle is provided with right atrial flap in Senning operation. In this way, oxygenated blood enters the systemic circulation through the pul-

monary vein-RA-RV and aorta. Complications of these procedures are superior vena cava obstruction, baffle leak, atrial and ventricular arrhythmias, tricuspid valve insufficiency, RV failure.[17,18] Today, these operations have been replaced by ASO. In this study, we preferred to implement ECMO support with single stage ASO or two stage ASO in delayed patients.

ASO was accepted as the most appropriate treatment option in TGA patients after the first successful repair by Jatene et al.[13] In IVS-TGA patients, surgery should be performed within the first 2 weeks. Because in these patients, the pulmonary pressure returns to normal within 2–3 weeks, and accordingly, the LV pressure decreases in cases that exceed two weeks. Two-stage arterial switch surgery is performed in patients who have undergone the neonatal period for various reasons. In cases longer than 3 weeks, if the IVS is deviated to the left on ECHO, the ratio of left ventricular systolic pressure to right ventricular systemic pressure is below 70%, and the LV posterior wall thickness is less than 4 mm, arterial switch surgery should be performed with a two-stage approach.[19] In the first stage, banding and systemic-pulmonary arterial shunt are applied to the PA.

In ECHO after this operation, the IVS is curved to the right and the LV has a spherical structure, synergistic contraction with the IVS, the LV and RV systolic pressures are close to each other (left ventricular systolic pressure / right ventricular systolic pressure > 70%), and In case of detection of posterior wall thickness, LV volume and muscle mass which is appropriate to the patient's age, arterial switch surgery can be performed by proceeding to the second stage.[20,21]

The incidence of coronary anomaly in TGA patients is between 30–45%. In our series, this rate was found to be 18%. Coronary translocation is the most critical part of Jatene surgery. A possible malposition results in myocardial ischemia due to coronary perfusion deterioration. This may cause death due to myocardial ischemia. In our series, the incidence of coronary anomaly in patients with mortality was 28.6%. The most common coronary anomaly in patients with coronary anomaly with mortality was the anomaly in which the Cx originates from the RCA.

While preparing the coronary arteries, the coronary arteries should be freed by very careful dissection. In some cases, thin conal branches may be sacrificed during this preparation. The sinuses in the PA to which the coronary arteries will be transferred can be prepared by removing the piece or using the linear incision technique (trap-door). In some cases, coronary artery transfer after neoaortic anastomosis reduces distortion. We did not use this method in any of our patients.

The most common reason for reoperation in arterial switch surgery is neo-pulmonary artery stenosis. The risk factors for PA stenosis are age, previous pulmonary banding operation, the patch material and shape used in the reconstruction, and the surgical technique applied. Neo-PA stenosis is not associated with complex cardiac and coronary anomalies. It is directly related to the surgical technique and patch material used.[22]

Treatment alternatives in complex transpositions depend on the type and severity of pulmonary stenosis, and the size and location of the VSD. In patients with severe pulmonary stenosis and small VSD, cyanosis is serious from the neonatal period and palliative operations are preferred instead of corrective operations. (BAS and/or systemic-pulmonary shunt operations). More balanced combinations can be expected for corrective operations. The classical corrective procedure applied in these patients is the Rastelli Procedure, which directs the left ventricular flow to the aorta through an intraventricular tunnel and ensures the continuity of the right ventricular outflow tract with a valved conduit. To prevent tunnel-related subaortic stenosis, the VSD should be wide and associated with both major vessels. The most important late complication in this procedure is stenosis developing in the conduit and the need for conduit replacement.[23]

To avoid repetitive operations for conduit replacement, the REV procedure for the right ventricular outflow tract without the use of a conduit was described by Lecompte.[24] In this procedure, an intraventricular tunnel is created to divert left ventricular flow to the aorta after infundibular resection to widen the VSD. Afterwards, the Lecompte maneuver is performed and the PA is directly connected to the RV by widening it with a patch.[23]

The logic of the Nikadioh procedure is to eliminate the shortcomings of the Rastelli procedure. The Rastelli procedure has disadvantages such as requiring septal resection during the expansion of the VSD for the intraventricular tunnel, risk of developing subaortic stenosis or stenosis in the tunnel due to tunnel malposition, and reduction of the RV cavity. In the aortic translocation type repair, that is, the Nikadioh procedure, a path free of stenosis is created between the LV and the neoaorta, reducing the need for septal resection and wide right ventriculotomy required in the Rastelli operation. Although this technique seems effective, limited experi-

ence in the literature limits its use. Long-term complications of this technique include neo-aortic regurgitation, coronary obstructions, and pulmonary regurgitation.[23]

The life expectancy of newborns with transposition is mostly less than 1 year and the mortality rate in the first year is 89.3%.[25] These rates have been reversed with new surgical methods and developments in intensive care. Survival over a 15-year period is around 90%. In addition, reintervention rates in a 10-year period are 6% and event-free survival is 88%.[24,25]

Conclusion

In conclusion, ASO, which provides anatomical and complete correction in TGA, can be performed with appropriate timing, good preoperative, per operative and postoperative management with low mortality and morbidity. When appropriate left ventricular functions are examined in detail in the light of the literature, ASO surgery can be performed even outside the neonatal period, and full correction is successfully performed with the help of close postoperative follow-up and left ventricular support devices when necessary. Coronary artery anomaly is not a contraindication for ASO, and with the detailed and careful evaluation of the appropriate coronary artery anatomy, transpositions with coronary anomalies are often uneventful.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

All authors contributed equally to protocol/project development, data collection, data analysis, manuscript writing/editing.

Ethics Approval

The study was carried out in compliance with the Declaration of Helsinki's guiding principles and the protocol was accepted by the ethics committee of the Institution (No: E2-23-3743).

Funding

The authors declare no financial support.

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Conflict of interest statement: No conflicts declared.