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ORIGINAL ARTICLE / ÖZGÜN MAKALE

A rare spatial relation of the great arteries in patients with transposition of the great arteries: Posterior aorta and its effect on outcomes

Büyük arterlerin transpozisyonu tanılı hastalarda büyük arterlerin nadir uzaysal ilişkisi: Posterior aorta ve sonuçlara etkisi

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ABSTRACT

Background: This study aimed to evaluate patients diagnosed with posterior transposition of the great arteries (TGA) in detail.

Methods: This retrospective study included 192 patients (155 males, 37 females; mean age: 0.4±0.9 month; range, 0.1 to 6 month) with TGA who were followed between August 1, 2016, and August 1, 2022. Patients with ventriculoarterial discordance, normal vessel relationship, and mitral-aortic continuity were considered posterior TGA. Demographic features, clinical findings, echocardiographic data, and surgical results of each patient were recorded.

Results: Posterior TGA was present in 11 (5.7%) of the patients. The median age of patients with posterior TGA at the time of surgery was two months (interquartile range [IQR], 1-3 months), and their median body weight was 6.2 kg (IQR, 5-7.2 kg). The median oxygen saturation of the patients was 85% (IQR, 80-90%). A ventricular septal defect was present in all patients on echocardiography. There was also nonrestrictive atrial septal defect and patent ductus arteriosus in four patients, and one patient had arcus aorta hypoplasia. A coronary anomaly was determined in eight of the patients during surgery. These were 1LRCA2Cx in three cases, 1LRCx in three cases, 1R2LCx in one case, and 1L2RCx in one case. Arterial switch operation and ventricular septal defect closure was performed in 10 patients initially and in one patient after a pulmonary banding operation. The median cardiopulmonary bypass time was 190 min (IQR, 170-210 min). The Lecompte maneuver was not performed in any of the patients. The median stay in the intensive care unit and the hospital was 7 days (IQR, 5-10 days) and 16 days (IQR, 14-18 days), respectively. Two patients died in the early postoperative period.

Conclusion: In patients with suspected congenital heart disease, a segmental echocardiographic evaluation should be performed, and it should be kept in mind that the aorta may be located posteriorly as a rare spatial relationship in patients with TGA.

Keywords: Echocardiography, posterior aorta, transposition of the great arteries.

ÖZ

Amaç: Bu çalışmada posterior büyük arterlerin transpozisyonu (BAT) tanılı hastaların detaylı değerlendirilmesi amaçlandı.

Çalışma planı: Bu retrospektif çalışmaya 1 Ağustos 2016 - 1 Ağustos 2022 tarihleri arasında izlenen, BAT tanılı 192 hasta (155 erkek, 37 kadın; ort. yaş: 0.4±0.9 ay; dağılım, 0.1-6 ay) dahil edildi. Ventriküloarteriyel uyumsuzluk, normal damar ilişkisi ve mitral-aortik devamlılığı olan hastalar posterior BAT olarak kabul edildi. Her bir hastanın demografik özellikleri, klinik bulguları, ekokardiyografik verileri ve cerrahi sonuçları kaydedildi.

Bulgular: Hastaların 11'inde (%5.7) posterior BAT mevcuttu. Posterior BAT'li hastaların ameliyat sırasındaki medyan yaşı iki ay (çeyrekler açıklığı [IQR], 1-3 ay) idi ve medyan vücut ağırlığı 6.2 kg (IQR, 5-7.2 kg) idi. Hastaların medyan oksijen satürasyonu %85 (IQR, %80-90) idi. Ekokardiyografide tüm hastalarda ventriküler septal defekt mevcuttu. Ayrıca dört hastada nonrestriktif atrial septal defekt ve patent duktus arteriosus ve bir hastada arkus aorta hipoplazisi vardı. Ameliyat sırasında sekiz hastada koroner anomali saptandı. Bunlar üç hastada 1LRCA2Cx, üç hastada 1LRCx, bir hastada 1R2LCx ve bir hastada 1L2RCx idi. On hastada başlangıçta ve bir hastada pulmoner banding operasyonu sonrası arteriyel switch ameliyatı ve ventriküler septal defekt kapatılması işlemi yapıldı. Medyan kardiyopulmoner baypas süresi 190 dk (IQR, 170-210 dk) idi. Lecompte işlemi hiçbir hastaya uygulanmadı. Medyan yoğun bakım ve hastane kalış süreleri yedi gün (IQR, 5-10 gün) ve 16 gün (IQR, 14-18 gün) idi. Erken ameliyat sonrası dönemde iki hasta kaybedildi.

Sonuç: Konjenital kalp hastalığı düşünülen hastalarda ekokardiyografide segmentar değerlendirme yapılmalı ve BAT tanılı hastalarda uzaysal ilişkide nadir bir yerleşim olarak aortun posteriorda yerleşebileceği akılda tutulmalıdır.

Anahtar sözcükler: Ekokardiyografi, posterior aorta, büyük arterlerin transpozisyonu.

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Transposition of the great arteries (TGA) is one of the most common congenital heart diseases in the neonatal period. It is an important reason for hospitalization in neonatal and cardiac intensive care units in the first two weeks of life.[1] Arterial switch operation (ASO) is the first choice of treatment.[2] Some clinical and anatomical factors affect the success of ASO. The preoperative knowledge of the origin and proximal course of the coronary arteries, the spatial relation of the great arteries, and the morphology, function, and commissural features of the semilunar valves revealed by diagnostic methods is beneficial for the surgeon to facilitate the operation.[2]

Echocardiography is the most important noninvasive diagnostic tool to evaluate congenital heart diseases. It can also be helpful to determine the origin and course of the coronary arteries and the spatial relation of the great arteries besides complete anatomical information.[3] There is an atrioventricular concordance and ventriculoarterial discordance on the segmental analysis of a TGA. Great arteries usually run in parallel, with the aorta in the anterior position and to the right of the pulmonary artery (PA). The posterior artery is the PA, and there is mitral-semilunar valve continuity. In TGA, the aorta is usually placed anteriorly and to the right of the PA; an anterior, left-sided aorta is less common. Posterior TGA, where the aorta is on the right and posterior with mitral-aortic valve continuity, is the most uncommon anatomical variation of the TGA.[1,4]

Many studies in the literature cover the diagnosis, follow-up, and surgery of TGA. However, there are few studies on posterior TGA, and they are mostly case-based.[5,6] This study aimed to evaluate cases with the diagnosis of TGA in which the aorta shows a rare posterior location in spatial vessel relationship (posterior TGA).

PATIENTS AND METHODS

This retrospective study included 192 patients (155 males, 37 females; mean age: 0.4±0.9 month; range, 0.1 to 6 month) diagnosed with TGA, who were hospitalized in the pediatric cardiac intensive care unit of the İstanbul Mehmet Akif Ersoy Thoracic Cardiovascular Surgery Training and Research Hospital between August 1, 2016, and August 1, 2022. Premature babies, patients with suboptimal echocardiographic view, complex TGA (presence of subaortic stenosis or pulmonary stenosis), and Taussig-Bing anomaly were excluded from the study. The study protocol was approved by the İstanbul Mehmet Akif Ersoy Thoracic Cardiovascular Surgery Training and Research Hospital Ethics Committee (date: 27.09.2022, no: 2022.08-51). The study was conducted in accordance with the principles of the Declaration of Helsinki. A written informed consent was obtained from the parents and/or legal guardians of the patients.

Echocardiographic evaluations were performed using the Philips Epic 7C Cardiac Ultrasound system (Philips, Bothell, WA, USA) with an 8 MHz probe. All the patients underwent echocardiography with standardized protocols as per the American Society of Echocardiography guidelines.[3] Standard pediatric echocardiographic views were recorded, including parasternal long and short axis, apical four- and five-chamber, and subcostal and suprasternal views. Atrial situs, venoatrial connections (systemic and pulmonary venous return), atrioventricular connections, ventricles, ventriculoarterial connection, the spatial position of great arteries, intracardiac defects, and extracardiac vascular anomalies were reviewed as the main components of this approach (Figure 1).

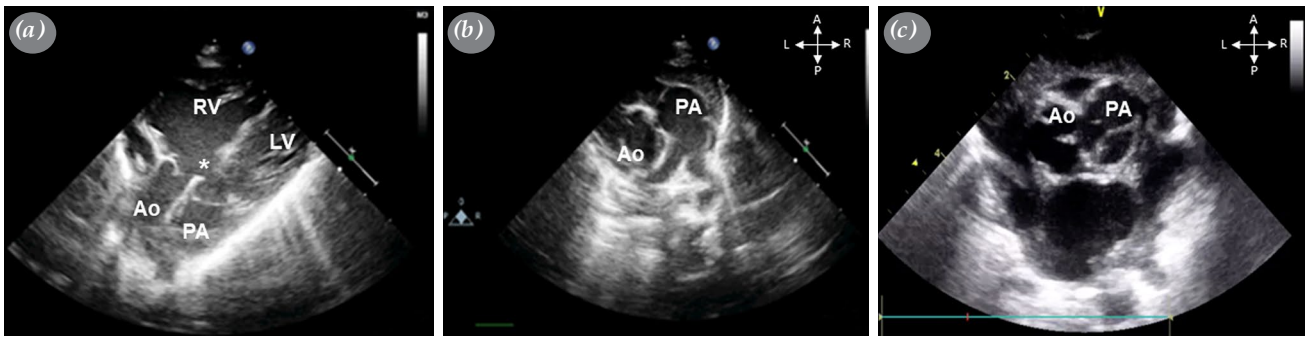

Figure 1. A 30 day old male patient with transposition of great arteries and posterior aorta. **(a)** Modified subcostal chamber view on echocardiographic examination. **(b)** Parasternal short axis chamber view on echocardiographic examination. **(c)** Modified parasternal short-axis chamber view on echocardiographic examination

Ao: Aorta; LV: Left ventricle; PA: Pulmonary artery; RV: Right ventricle.

Spatial relationships of the great vessels were defined as D-malposition, L-malposition, side-by-side, anterior-posterior, and posterior aorta. The pattern of coronary artery anatomy in patients with TGA was identified in the parasternal short-axis views as described by the American Society of Echocardiography.[3] Optimal images were defined as those in which both semilunar valves were observed in cross-sectional views and both coronary artery origins were visualized. The coronary artery pattern was also confirmed by the surgeons' intraoperative assessment. Kim et al.'s[6] commissural malalignment definition was used for classification. Additional imaging was performed with computed tomography or conventional angiography in cases with inadequate anatomical and hemodynamic echocardiographic data. Patients with ventriculoarterial discordance, normal vessel relationship, and mitral-aortic continuity were accepted as posterior TGA and included in the study.

A study form, including preoperative data (demographic features, cardiac diagnosis, and echocardiographic information), operative data (cardiopulmonary bypass and operation time), and postoperative data (extubation time, length of stay in the intensive care unit and hospital, mortality, vasoactive inotrope score, and major complications (low cardiac output syndrome, arrhythmia, infection, and acute kidney injury), was prepared for each patient.

Surgical technique

The operation was conducted with cardiopulmonary bypass through standard aortic and bicaval cannulae under mild hypothermia. Cold blood cardioplegia was utilized approximately every 20 min during cross-clamping. Cardioplegia was given into the aortic root before opening the aorta. A retrograde approach via the coronary sinus was used for the maintenance of cardioplegia. More recently, the cardioplegia strategy was replaced with a single dose of Custadiol HTK solution (Köhler Chemie GmbH, Bensheim, Germany) application. Ventricular septal defect (VSD) closure was performed before the arterial switch procedure, either using a Dacron patch or a pericardial patch. Following the preparation of coronary arteries as small buttons, the Lecompte maneuver was not performed, and the ascending aorta was reconstructed by an end-to-end anastomosis. The aortic cross-clamp was then released to allow the neoaortic root to be distended. The ideal locations for coronary arteries on the neoaorta were marked with a sterile pen. A stab wound was made at the marked site taking care not to injure the anterior neoaortic commissure previously marked with a prolene suture. The aortic cross-clamp was reapplied. Through this small opening, the location of the neoaortic commissure was confirmed, and the opening was enlarged to accommodate the coronary buttons. In all patients, PA reconstruction was performed after the removal of the cross-clamp. The pulmonary trunk was reconstructed with a single, 3-min glutaraldehyde-treated autologous pericardial patch. Ultrafiltration during bypass and modified ultrafiltration after bypass were used. The chest was left open at the end of surgery in all patients, except for two patients, due to safer early intensive care unit follow-up in terms of hemodynamic stability and pulmonary dynamics. The chest was closed at the end of surgery at the discretion of the surgeon similar to the early ASO patients.[7]

Intensive care unit management

For all patients, central venous pressure, electrocardiogram, invasive arterial blood pressure, end-tidal carbon dioxide, and cerebral near-infrared spectroscopy monitoring were conducted. Inotropic support typically included milrinone (0.5 μg/kg/min) and a low dose of norepinephrine (0.05 μg/kg/min) for the first postoperative hours. Epinephrine treatment was added if necessary. Fentanyl and midazolam were used for sedation and analgesia, and 100 mg/kg/day of cefazolin was started for surgical infection prophylaxis. In case of infection, an appropriate antibiotic regimen was started according to blood culture results and acute phase reactants. On the first postoperative day, total parenteral nutrition support and minimal enteral feeding by nasogastric tube were started for all patients. Daily postoperative echocardiography was performed in the pediatric cardiac intensive care unit.[2]

Statistical analysis

Descriptive values were obtained using the IBM SPSS version 21 software (IBM Corp., Armonk, NY, USA) and expressed as median [interquartile range (IQR)], frequency, and percentage.

RESULTS

Posterior TGA was diagnosed in 11 (5.7%) of all cases. The median age of patients with posterior TGA at operation was two months (IQR, 1-3 months), and the median body weight was 6.2 kg (IQR, 5-7.2 kg). The most common complaint at admission was cardiac murmur (81%). The median oxygen saturation was 85% (IQR, 80-90%). All

patients had VSD. Nine of these VSDs were classified as doubly committed, and two were perimembranous outlet. All VSDs had a hemodynamically significant shunt. In echocardiographic examination, semilunar-atrioventricular valve continuity was demonstrated in all patients. Four patients had nonrestrictive atrial septal defect and patent ductus arteriosus, while one patient had aortic arch hypoplasia. A coronary anomaly was detected in four patients with echocardiography, in seven patients with cardiac computed tomography or conventional angiography. Coronary abnormality was diagnosed in eight patients during intraoperative evaluation. These were 1LRCA2Cx in three patients, 1LRCx in three patients, 1R2LCx in one patient, and 1L2RCx in another patient. Commissural malalignment was determined in three patients. Coronary abnormality was present in all patients with malalignment. The patient characteristics are given in Table 1.

Arterial switch operation and VSD closure was performed in 10 patients and in one patient after pulmonary banding operation. In the patient with initial pulmonary banding, a large VSD and coronary anomaly were present. Four months after the banding procedure, total correction was performed. The Lecompte maneuver was not used in any of the

Table 1. General characteristics of the great arteries in patients with transposition of the great arteries: Posterior aorta patients (n=11)

	n	%	Median	IQR
Symptoms				
Respiratory distress	5	45		
Heart murmur	9	81		
Cyanosis	4	36		
Age at surgery (mo)			2	1-3
Weight (kg)			6.2	5-7.2
Sex				
Male	9			
Female	2			
Genetic syndrome	-			
Saturation			85	80-90
Prostaglandin E1 infusion	3	27		
Inotropic support	2	18		
Mechanical ventilation	2	18		
Balloon atrial septostomy	-	-		
Ventricular septal defect	11	100		
Atrial septal defect (non-restrictive)	4	36		
Patent ductus arteriosus	4	36		
Coarctation of the aorta	1	9		
Commissural malalignment	3	27		
Additional imaging method				
None	3	27		
Cardiac CT	8	72		
Conventional angiography	3	27		
Presence of coronary anomaly in echocardiography				
Yes	4			
No	7			
Presence of coronary anomaly in cardiac CT or conventional angiography				
Yes	7			
No	4			

IQR: Interquartile range; CT: Computed tomography.

Table 2. Intraoperative and postoperative data

No	Operation	CPB hypothermia	CPB time	XC time	Delayed sternal closure (h)	Sternal closure duration (days)	Peak VIS within 72 h	MV day	ICU day	Hospital stay day	Complication	Outcomes
1	ASO+VSD repair	34	200	165	-	-	12	2	7	18	LCOS	Discharged
2	ASO+VSD repair	34	180	140	24	1	17	3	10	25	AKI LCOS Arrhythmia Septisemia	Discharged
3	ASO+VSD repair	35	197	177	-	-	15	1	3	8	-	Discharged
4	ASO+VSD repair+arcus reconstruction	28	222	137	-	-	12	2	7	14	-	Discharged
5a	ASO+VSD repair	32	260	166	ECMO	ECMO	15	8	8	8	LCOS	Exitus
6	ASO+VSD repair	34	153	118	72	3	10	4	7	13	-	Discharged
7	ASO+VSD repair	35	276	144	120	5	24	7	21	40	AKI LCOS Septisemia	Discharged
8	ASO+VSD repair	35	220	154	-	-	25	24	40	51	AKI LCOS Septisemia	Discharged
9	ASO+VSD repair	34	250	119	24	1	17	2	9	13	-	Discharged
10	ASO+VSD repair	34	164	123	-	-	7	1	8	16	LCOS	Discharged
11	ASO+VSD repair	34	256	172	ECMO	ECMO	45	7	7	7	AKI LCOS Arrhythmia	Exitus

CPB: Cardiopulmonary bypass; XC: Aortic cross clamping; VIS: Vasoactive inotrope score; MV: Mechanical ventilation; ICU: Intensive care unit; ASO: Arterial switch operation; VSD: Ventricular septal defect; LCOS: Low cardiac output syndrome; AKI: Acute kidney injury; ECMO: Extracorporeal membrane oxygenation.

cases. The median cardiopulmonary bypass time of patients who underwent ASO and VSD repair was 190 min (IQR, 170-210 min). The median duration of intensive care unit and hospital stays were seven days (IQR, 5-10 days) and 16 days (IQR, 14-18 days), respectively. Two patients needed extracorporeal membrane oxygenation support postoperatively, and both of these patients died. The operative and postoperative data of the cases are summarized in Table 2.

DISCUSSION

In this study, the clinical features and surgical results of the cases with posterior TGA were evaluated. We observed that posterior TGA constituted 5.7% of TGA cases. All patients had VSD, and 72% had a coronary anomaly. There was no need for the Lecompte maneuver during the ASO. Our study is one of the few that analyzes posterior TGA with the largest number of patients reported in the literature.

As previously postulated, abnormal morphogenesis of both the outflow tracts and great arteries likely leads to posterior TGA. Following cardiac looping, both outflow tracts are connected to the trabeculated right ventricle in one of three patterns. The outflow tracts can be related to each other in a side-by-side relationship, an anterolateral to posteromedial relationship, or an anteromedial to posterolateral relationship. The great arteries then connect to an outflow tract. In case of TGA with a posterior aorta, the pulmonary trunk connects to an anteromedial outflow tract, causing the PA to be anterior to the aorta. The anteromedial outflow tract and PA then become incorporated into the morphologic left ventricle, resulting in TGA with a posterior aorta.[5]

The TGA with posterior aorta was first described by Van Praagh et al.[4] in 1971, after reviewing four cases of pathological specimens. The term "posterior transposition" refers to the aorta originating from the right ventricle but retaining fibrous mitroaortic continuity, and the PA originating from the left ventricle with bilateral conus.[8] The main morphologic characteristics, as described by Wilkinson et al.[9] in 1975, are as follows: *(i)* posterior origin of the aorta from the right ventricle; *(ii)* presence of complete subpulmonary conus; *(iii)* fibrous mitroaortic continuity through a VSD;[4] *(iv)* malpositioning of the conal septum with the interventricular septum.[4,8] Normally, the subaortic conus is absorbed in its central portion, forming a fibrous area (mitroaortic continuity).[9] In posterior TGA, absorption is only partial, and the fibrous part lies posterior and to the left; hence, the aortic root is in fibrous continuity with the mitral valve via the central fibrous body.[4,8]

Only a few cases of posterior TGA have been reported, most of them were discovered in pathological examinations.[4-6] All of them presented with mitropulmonary discontinuity and maintained mitroaortic continuity through subaortic VSD. Pulmonary stenosis was the most common associated anomaly. Only one case presented with subaortic stenosis.[8]

Echocardiography is the key diagnostic method to define the appropriate surgical procedure. Double-outlet left ventricle should be considered in differential diagnosis. There is a variant of this anomaly, in which the aorta is posterior and to the right of the PA, with subaortic VSD. In this condition, the aorta emerges mainly from the left ventricle and overrides the interventricular septum by more than 50%. In most of our cases, the aorta fully emerged from the right ventricle (72%). None of these patients were classified as posterior TGA. One patient was classified as double-outlet left ventricle, another as double-outlet right ventricle, and one patient as a large VSD.

It is important to be aware of this rare anatomical variant of TGA, since in a neonate with cyanosis and alleged ventriculoarterial concordance, a pulmonary pathology may be assumed as the cause of the cyanosis, which would delay the surgical repair, increasing morbidity and mortality.

The presence of VSD and the location of the aorta may mask cyanosis and lead to a delay in diagnosis. Localization or overriding of the aorta reduces desaturation by receiving more blood from the left ventricle, or the existing VSD may cause this condition. In addition, it is vital for the surgeon to know the anatomy beforehand to plan the surgical strategy. Arterial switch operation is currently the treatment of choice for TGA. In most of these cases, the Lecompte maneuver is performed due to the spatial relationship of the great vessels. While these patients are treated with the ASO, the Lecompte maneuver, which brings the PA to the anterior position, is not required.[10,11] Reported surgical interventions for TGA with posterior aorta and VSD include ASO with VSD closure or VSD creation/enlargement with interventricular baffling. Some cases of transposition require PA banding before the switch operation (premature newborns, multiple VSDs, preparation of

the left ventricle, and inexperienced surgical center). In contrast to the usual pattern, banding of the left anterior vessel should be performed in this variant of TGA. The Lecompte maneuver was not required in any of our cases. Our patients were repaired with VSD enlargement, creation of a left ventricle-to-aorta baffle, transection of the main PA, closure of the pulmonary valve, reconstruction of the right ventricular outflow tract with ventriculotomy, and primary anastomosis of the main PA to the right ventricle.

While it has been suggested that coronary artery anomaly may increase mortality rates in newborns with TGA, some other studies show different results.[1,2] However, the common opinion in all studies is that appropriate and safe coronary artery transfer has a key role in a successful ASO. Therefore, it is important to define the coronary artery anatomy precisely.[1,2]

Different coronary artery patterns have been described in TGA. The most common one is the usual pattern (1L2R), followed by the origin of the circumflex artery from the right coronary artery (1L2RCx).[1,2,12] Moll et al.,[13] in their series of 715 cases, found the usual coronary artery pattern in 67.8% and the unusual coronary artery pattern in 32.8%. They found that 50% of the cases with unusual coronary artery patterns were the origin of the circumflex coronary artery from the right coronary artery (1L2RCx). In our study, in contrast to the cases with simple TGA, the majority (72%) of patients with posterior TGA had abnormal coronary artery patterns, predominantly comprised of 1LRCA2Cx (38%) and 1LRCx (38%). Unfortunately, only 50% of the cases with coronary anomaly could be detected by echocardiography and 88% by computed tomography or conventional angiography.

Commissural malalignment was suggested as another potential risk factor for coronary artery anomaly.[6] A coronary anomaly was present in all patients with commissural malalignment. Therefore, it may be useful to use additional imaging methods to guide the surgeon during the operation.

The coronary pattern described for posterior TGA is a mirror image of the usual pattern of TGA with the anterior aorta. It is associated with coronary anomaly (anterior descending artery originating from the right coronary artery). The double-button technique is usually adequate for the transfer of the usual pattern of coronary arteries. However, alternative techniques are needed for coronary transfer in unusual coronary patterns.

Today, the mortality of ASO is below 5% in the literature. In their series of 556 cases, Fricke et al.[14] reported the mortality as 3.1%. Kitamura et al.,[15] in their series evaluating 1,084 cases of TGA with and without VSD, reported that the 90-day mortality was 1.6 times higher than the 30-day mortality (5.2% *vs*. 3.2%) and that VSD did not increase mortality. Two cases (18%) died in our series. This relatively high mortality rate may be due to the prolonged bypass time due to the difficulty of existing coronary translocation.

The main limitation of this study was its single-center, retrospective design and the inclusion of a limited number of cases. Another limitation was the lack of simple TGA subgroups for the comparison of surgical outcomes.

In conclusion, it should be kept in mind that the aorta may be located posteriorly as a rare spatial relationship in TGA. The correct anatomical diagnosis of the cases guides the surgeon in terms of planning an ASO without the use of the Lecompte maneuver.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions: Idea/concept, writing the article, references and fundings, materials: P.A., F.S.S., E.D., E.O.; Design, control/supervision: P.A., F.S.S., E.O.; Data collection and/or processing, analysis and/or interpretation, literature review: P.A., F.S.S., E.D., E.O., S.H., A.G.; Critical review: P.A., E.O., S.H., A.G.; Other: P.A.

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