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Preoperative echocardiographic determination of the coronary anatomy in patients with transposition of the great arteries - helping or confusing the surgeon?☆

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ABSTRACT

In this single center observational study we aimed to determine the accuracy of echocardiography in diagnosing the coronary artery anatomy in neonates with d-transposition of the great arteries before arterial switch operation and to evaluate the impact of an incorrect echocardiographic diagnosis on the intra- and postoperative course after surgery. Therefore, 131 neonates with (simple) d-transposition of the great arteries, diagnosed from 2004 to 2017, were analyzed. Coronary artery patterns described in preoperative echocardiography were compared to intraoperative findings and accuracy was evaluated concerning impact on the intra- and postoperative course. Intraoperatively, usual coronary artery anatomy (1LCx2R) was described in 90 patients (69%) and coronary artery variants in 41 patients (31%, 1L2RCx $n = 18$, others $n = 23$). Overall, echocardiographic diagnosis was correct in 69% ($n = 90$). When classifying in usual coronary artery anatomy vs. coronary artery variant, echocardiographic diagnosis was correct in 77.1% (92% in usual coronary artery versus 20% in coronary artery variants). While univariate analysis showed significantly longer duration of surgery (261 vs. 276 min, $p = 0.042$) and extracorporeal circulation time (165 vs. 178 min, $p = 0.026$) in patients with an incorrect preoperative echocardiographic diagnosis, multivariate analysis showed no influence of an incorrect diagnosis or of coronary artery pattern on the intraoperative course. The postoperative course was not significantly different in both groups. In conclusion, accuracy of echocardiographic diagnosis of coronary artery anatomy is high in usual coronary pattern (92%) but low in coronary artery variants (20%). A wrong echocardiographic diagnosis is not associated with an unfavorable intra- and postoperative course after arterial switch operation.

1. Introduction

The Arterial Switch Operation - first described by Jatene in 1976 - is currently the standard treatment in simple d-transposition of the great arteries [1,2]. With continued improvement of surgical techniques and medical management, arterial switch operation has been associated with low mortality rates, such as an early mortality rate of 2.8% and a late mortality rate of 0.9% and increased survival in the past years [3,4]. Nevertheless, coronary transfer remains the most sensitive and critical step of the arterial switch operation, especially in the presence of coronary artery anomalies [5]. The branching patterns of the coronary arteries are often variable in patients with d-transposition of the great arteries and studies have shown significantly higher mortality rates especially in single and intramural coronary arteries [6,7]. Usual coronary pattern in d-transposition of the great arteries according to the Leiden classification [8] involves a left coronary artery that bifurcates into the left anterior descending and circumflex originating from the leftward anterior facing aortic sinus and a right coronary artery originating from the rightward posterior facing aortic sinus (1LCx2R) [3]. Other coronary patterns are circumflex from right coronary artery (1L2RCx), intramural course of one coronary artery, a single ostium for both coronary arteries and other variants [9]. A difficult coronary

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transfer during arterial switch operation due to coronary artery abnormalities bares the risk for coronary insufficiency after surgery with life-threatening arrhythmias, myocardial dysfunction or mortality [10]. Several coronary artery variants might even change surgical procedure as the arterial switch operation might not be possible to be performed in some coronary artery variants [3,6]. Nevertheless, surgical techniques have improved in the last decades and arterial switch operation seems to be possible in almost all coronary artery anatomies [11]. Current standard for evaluating coronary artery patterns in d-transposition of the great arteries is 2D transthoracic echocardiography, with an overall echocardiographic accuracy reported between 63 and 95% [9,12]. Most previous studies evaluating coronary arteries by preoperative echocardiography did not evaluate the impact of a correct diagnosis on the postoperative course [9,12,13]. We only found one study from Fundora et al. that showed no influence of echocardiographic diagnosis on the peri- and postoperative course [3]. Thus the aim of our study was to analyze the impact of a preoperatively misdiagnosed coronary artery pattern on the intra- and postoperative course after arterial switch operation. Furthermore, we intended to assess if unusual coronary artery anatomy influenced the surgical outcome and/or the postoperative clinical course.

2. Methods

2.1. Population and study design

This retrospective study was performed at the Heart Center of the University Children's Hospital Zurich, Switzerland - a tertiary care hospital located in Zurich, Switzerland. Medical data of patients admitted between January 2004 and August 2017 with diagnosis of d-transposition of the great arteries were retrospectively reviewed. Patients with missing informed consent or patients older than 6 months of age at diagnosis were excluded from this study. D-transposition of the great arteries may be associated with the following additional congenital heart defects: ventricular septal defect, atrial septal defect ($\geq$3 mm) or persistent foramen ovale ($<$ 3 mm), pulmonary valve stenosis or coarctation of the aorta. Patients with complex transposition of the great arteries cases such as double outlet right ventricle, double outlet left ventricle, pulmonary atresia or tricuspid atresia were not included in the study. Baseline characteristics included gestational age, gender, height, weight, and presence of other echocardiographic findings such as ventricular or atrial septal defects. Transthoracic echocardiography was performed using different ultrasound systems including Sonos 5500, IE 33, Affinity 70 (Philips Co., Amsterdam, Netherlands), Vivid 7 or Vivid 9 (General Electric Company, Fairfield, Connecticut, US). An experienced consultant pediatric cardiologist on duty performed final preoperative echocardiographic evaluation of the coronary arteries at time of admission and/or the following days before surgery. Intra- and perioperative data, including information about the observed coronary artery anatomy during surgery, difficulties in coronary re-implantation, extra corporal circulation time, aortic cross-clamp time, duration of surgery, mechanical ventilator support, inotropic support, delayed sternal closure, total intensive care unit (ICU) stay, total hospital stay and postoperative complications were collected from the medical records of the patients. Complications were defined as ventricular dysfunction without rhythm disturbances, rhythm disturbances requiring treatment, myocardial ischemia (e.g. signs of ischemia in ECG, elevated biomarkers for myocardial ischemia), surgical or catheter-guided reinterventions or others (including sepsis, wound infection, diaphragm paralysis, pneumothorax, pleural or pericardial effusion) [14].

Data regarding coronary artery patterns were extracted from the preoperative transthoracic echocardiographic report and compared to the intraoperative findings described in the surgical notes to determine diagnostic accuracy. Each echocardiographic diagnosis was classified into either group “correct diagnosis” or “incorrect or inconclusive diagnosis”. To analyze the accuracy of diagnosis, patients with inconclusive echocardiographic reports were added to the incorrect group. Different coronary artery patterns were further classified in Group 1 to 5, adapted to the Leiden classification [8], based on the operative report:

Group 1: usual coronary artery anatomy (1LCx2R); Group 2: circumflex artery originates from the right coronary artery (1L2RCx); Group 3: left or right sided single coronary ostium; Group 4: intramural course of the coronary artery; Group 5: other coronary artery variants (e.g. two coronaries originating from the right facing aortic sinus, inverted coronary arteries).

2.2. Statistical analysis

Descriptive data are expressed as mean and standard deviation, median and interquartile range or percentages, as appropriate. Statistical analysis was performed with IBM SPSS statistics software (Version 24.0, IBM, USA) using *T*-Tests, two-tailed Fisher exact tests and multivariate linear regression models. Positive and negative predictive values, sensitivity and specificity were calculated by the chi-square-test. The level of statistical significance was set to $p < 0.05$.

2.3. Ethics

The local ethics committee approved this study.

3. Results

In total, 137 children were admitted with the diagnosis of d-transposition of the great arteries during the study period, from which 131 fulfilled inclusion criteria and could be enrolled in the analysis.

The median gestational age at birth was 39 4/7. One-hundred-twenty-one patients (92%) were born at term and 95 patients (73%) were male. Arterial switch operation was performed at a median age of 8 days (inter quartile range (IQR) 6-11d). Prenatal diagnosis of d-transposition of the great arteries was made in 22 patients (17%). Sixty-four children (49%) had an atrial septal defect (type II), 66 (50%) a persistent foramen ovale, and balloon atrioseptostomy was necessary in 103 patients (79%), with a post interventional increase in blood oxygen saturation of median + 20% (IQR: 12–30%). Forty-two patients (32%) had a ventricular septal defect, which could be closed during arterial switch operation in all cases. The overall mortality rate was 2.3% (n = 3): two term born neonates (38 6/7, 4100 g; 40 1/7, 4700 g) required early surgery at the first and second day of life, due to severely impaired hemodynamics despite optimal medical treatment. The third patient was a preterm baby (36 5/7, 1980 g) that underwent arterial switch operation at the age of 11 days. Causes of death were severe postoperative myocardial dysfunction in all cases. Patient characteristics and associated cardiac anomalies are listed in Table 1.

3.1. Coronary anatomy and echocardiographic accuracy

Intraoperative findings showed a usual coronary artery anatomy (1LCx2R, group 1) in 90 patients (69%). The most frequent coronary artery variant 1L2RCx (group 2) was found in 18 children (14%). Detailed descriptions and distributions of the different coronary artery patterns are presented in Table 3 and Fig. 1. The coronary anatomies in the 3 patients who died were as follows: One patient had usual coronary anatomy (1LCx2R). One patient had a single right coronary artery, which was compromised intraoperatively during mechanical hemostasis, which led to extensive myocardial necrosis. One patient had an intramural course of the left coronary artery and underwent coronary artery patch angioplasty. Postoperatively, the patient developed severe junctional ectopic tachycardia and heart failure. Coronary anatomies in the two patients with coronary artery variants were diagnosed incorrectly during preoperative echocardiography.

Table 1
Baseline characteristics of the study population.

Study population	131 (100)
Median gestational age at birth (wk)	39 4/7
Term births	121 (93)
Male	95 (73)
Normal weight	113 (86)
Weight (g)	3359 (2960–3800)
Height (cm)	50 (48–52)
Prenatal diagnosis	22 (17)
Age at surgery	8 (6–11)
Echocardiographic findings	
PFO	66 (50)
ASD II	64 (49)
VSD	42 (32)
CoA	9 (7)
AV valve regurgitation	8 (6)
Pulmonary valve stenosis	2 (2)
Interventions	
Balloon atrioseptostomy performed	103 (79)
Complications during balloon atrioseptostomy	27 (26)

Data presented as mean (± SD) or median (IQR) as appropriate, categorial data as counts (n) and percentages (%).
wk: weeks; g: gram; cm: centimetre; PFO: persistent foramen ovale; ASD: atrial septal defect; VSD: ventricular septal defect; CoA: coarctation of the aorta; AV: atrio-ventricular.

Table 2
Intra- and postoperative parameters after ASO.

Intraoperative course	
ECC time (min)	175 (± 44.5)
Aortic cross clamp time (min)	109 (91–135)
Duration of surgery (min)	273 (243–315)
Postoperative course	
PICU stay (d)	6 (4–8)
Duration of mechanical ventilator support (d)	3 (2–4)
Inotropic support (d)	4 (3–5)
Re-intubations	13 (10)
Total hospital stay (d)	27 (21–35)
Complications	
Open chest	69 (53)
Time to chest closure (d)	2 (1–3)
Reinterventions	44 (34)
Diagnostic cardiac catheterization	27 (61)
Interventional cardiac catheterization	17 (39)
Redo surgery	62 (47)
Demise	3 (2)

Data presented as mean (± SD) or median (IQR) as appropriate, categorial data as counts (n) and percentages (%).
min: minutes; d: days; ASO: arterial switch operation; ECC: extracorporeal circulation; PICU: pediatric intensive care unit.

In total, preoperative coronary artery anatomy was diagnosed correctly by echocardiography in 90 patients (overall accuracy of 68.7%). The accuracy to diagnose the usual coronary artery pattern (1LCx2R) correctly was 92%, in contrast 20% to describe the exact anatomy of coronary artery variants. The incorrectly diagnosed group included 7 patients (17%) with usual coronary artery anatomy and 34 patients (83%) with coronary artery variants. The most common variant 1L2RCx was diagnosed incorrectly in 16 of 18 cases (89%); however, in 11 of those 16 incorrectly diagnosed patients (69%) with 1L2RCx the echocardiographic examination assumed a normal coronary artery anatomy. Eight patients (6%) had an incomplete echocardiographic diagnosis. Accuracy to discriminate between usual coronary artery anatomy and

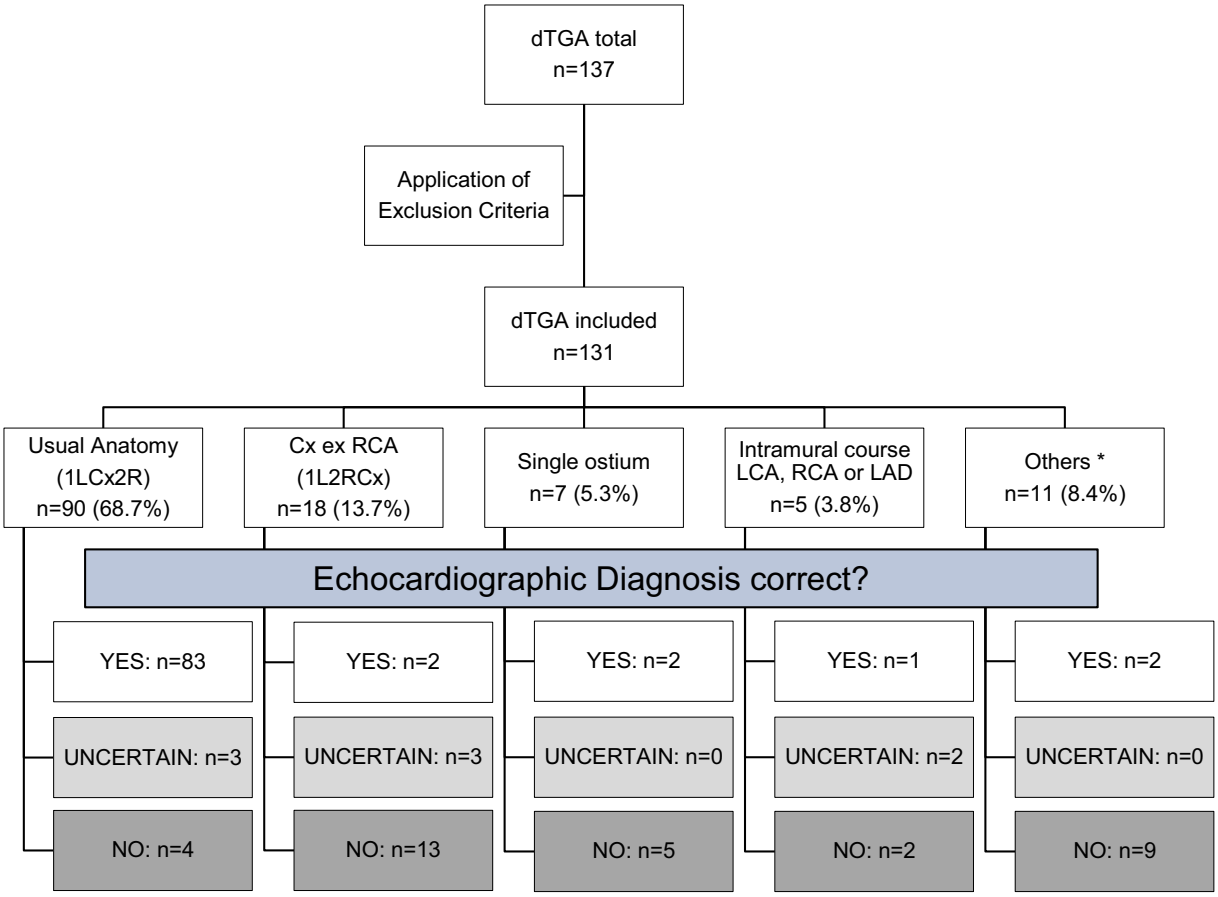

Fig. 1. Distribution and echocardiographic accuracy of coronary artery anatomy.
dTGA: d Transposition of the Great Arteries; RCA: right coronary artery; LCA: left coronary artery; Cx: R. circumflexus; LAD: left anterior descending.

coronary artery variants (without describing the exact anatomical subtype of coronary artery variant) was 77%, leading to a specificity of 92.2% (84.6–96.8%) and a sensitivity of 56.1% (41.0–70.1%) (positive predictive value 82.3%).

3.2. Intra- and postoperative course

Median duration of surgery for the whole study population was 273 min (IQR: 253–315 min). Table 2 shows a detailed description of the parameters of the intra- and postoperative course. Patients with an incorrect preoperative diagnosis concerning exact anatomy of coronary artery had a significantly longer duration of surgery (261 vs 276 min, $p = 0.042$) and extracorporeal circulation time (165 vs 178 min, $p = 0.026$). Nevertheless, an incorrect diagnosis had no impact on the postoperative course, including number of patients with open chest (48 vs 63%, $p = 0.099$), time to chest closure (2 vs 3 days, $p = 0.892$), duration of mechanical ventilator support (3 vs 3 days, $p = 0.458$), inotropic support (4 vs 4 days $p = 0.714$), postoperative ICU stay (6 vs 6 days, $p = 0.976$) and total hospital stay (27 vs 44 days, $p = 0.517$) (Table 4). When comparing correct and incorrect echocardiographic diagnosis concerning usual coronary artery anatomy vs. coronary artery variant in total, no differences for the intra- and postoperative parameters were observed.

Table 5 shows a comparison between the children with normal coronary artery anatomy (group 1) and children with coronary artery variants (group 2–5). Intraoperative parameters, such as duration of surgery (261 vs 295 min, $p = 0.025$), extracorporeal circulation time (166.5 vs 188 min, $p = 0.016$) and aortic cross clamp time (102.5 vs 122 min, $p = 0.004$) were significantly longer in the group with coronary artery variants. An adverse relation to the postoperative clinical course could not be observed. However, multivariate linear regression analysis for surgery duration showed a significant influence of the presence of a ventricular septal defect only (B 41.3 (95% CI 16.7–65.8) $p = 0.001$) but not of an incorrect coronary artery diagnosis before arterial switch operation ($p = 0.543$) or the presence of coronary artery variants ($p = 0.188$). Arterial switch operation could be performed successfully in 100% of cases independently from coronary artery anatomy.

4. Discussion

The arterial switch operation is the surgical technique of choice in patients with d-transposition of the great arteries. Despite a very good outcome, the coronary transfer remains the most sensitive and critical step of the arterial switch operation [5]. Variants of the coronary arteries, especially single coronary arteries and intramural courses of the coronary arteries have been associated with a higher risk for surgical mortality and variable postoperative outcomes [15,16]. Single and multicentre studies reported a higher early mortality in patients with intramural or single coronary arteries but not in the most common coronary artery variant 1L2RCx [15]. A European multicentre study showed similar results with early mortality rates up to 27% in coronary artery variants [17], whereas other studies do not report a substantially increased early mortality [18]. Previous studies suggested that coronary artery variants might enhance the risk of an unsuccessful arterial switch operation, resulting in alternative surgical procedures or in a longer hospital stay [6,19]. In our cohort, arterial switch operation was successfully performed in all cases regardless of coronary artery anatomy. The mortality rate was low at 2% [2,4].

In our retrospective study, coronary artery anatomy has been delineated correctly by preoperative transthoracic echocardiography in 90 out of 131 cases, resulting in an overall accuracy of 69%. Discrimination of usual or unusual coronary artery anatomy was possible with an accuracy of 77%. Pasquini et al. described an accuracy of 95%, however, without including the intramural coronary artery

Table 3
Distribution of coronary artery anatomy.

Group	Anatomy	n (%)
1	Usual anatomy (1LCx2R)	90 (69)
2	Cx ex RCA (1L2RCx)	18 (14)
3	Monocoronary ostium	7 (5)
	Single LCA	3 (43)
	Single RCA	4 (57)
4	Intramural course	5 (4)
	Intramural LCA	5
	Intramural LAD	0
	Intramural RCA	0
5	Others	11 (8)
	Inverted	0
	Inverted RCA and Cx	4
	Other variations	7

Data presented as counts (n) and percentages (%).
LCA: left coronary artery; RCA: right coronary artery; Cx: R. circumflexus.

Table 4
Baseline, intra- and postoperative characteristics based on echocardiographic accuracy.

	Correct ($n = 90$)	Incorrect ($n = 41$)	p
Weight (g)	3348 (± 60.7)	3382 (± 99.2)	0.764
Age at ASO (d)	9.5 (± 0.75)	9.195 (± 0.78)	0.833
Rashkind procedure	72 (80)	31 (75.6)	0.571
SpO_2 prior to surgery (%)	81.8 (80–89)	81.4 (77–89)	0.535
ECC Time (min)	165 (135–198)	178 (139–199)	**0.026**
Aortic cross-clamp time (min)	104 (85–129)	133 (110–160)	0.096
Duration of Surgery (min)	261 (238–306)	276 (238–322)	**0.042**
Open chest	43 (48)	26 (63)	0.099
Duration of open chest (d)	2 (1–3)	3 (2–4)	0.892
Ventilator support (d)	3 (2–4)	3 (2–4)	0.458
Inotropic support (d)	4 (2–5)	4 (3–5)	0.714
PICU stay (d)	6 (4–7)	6 (4–9)	0.976
Hospital stay (d)	27 (21 – 33)	44 (27–259)	0.517
Complications	61 (68)	28 (68)	1.000
Re-Operations	41 (56)	21 (51)	0.595

Data presented as mean (± SD) or median (IQR), as appropriate, categorial data as counts (n) and percentages (%).
g: grams; d: days; SpO_2: oxygen saturation; min: minutes; ASO: arterial switch operation; min: minutes; ECC: extracorporeal circulation; PICU: pediatric intensive care unit. p values < 0.05 are in bold.

Table 5
Baseline, intra- and postoperative characteristics based on coron ary artery anatomy.

	Usual (n = 90)	Variants (n = 41)	p
Weight (g)	3435 (2960–3803)	3460 (2935–3773)	
Age at ASO (d)	8 (6–12)	8 (6–11)	0.660
Rashkind procedure	70 (77.8)	33 (80.5)	0.728
SpO_2 prior to surgery (%)	81.6 (80–89)	81.5 (77–89)	0.926
ECC Time (min)	166.5 (134–197)	188 (155–207)	**0.016**
Aortic cross-clamp time (min)	102.5 (85–129)	122 (103–143)	**0.004**
Duration of Surgery (min)	261 (238–306)	295 (258–336)	**0.025**
Open chest	43 (48)	26 (63)	0.112
Duration of open chest (d)	2 (1–3)	2 (1–3)	0.870
Ventilator support (d)	3 (2–4)	3 (2–5)	0.472
Inotropic support (d)	4 (2–5)	4 (3–5)	0.610
PICU stay (d)	6 (4–7)	6 (4–9)	0.716
Hospital stay (d)	26 (21 – 32)	29 (22–38)	0.563
Complications	58 (64)	29 (71)	0.434
Re-Operations	40 (44)	22 (54)	0.290

Data presented as mean (± SD) or median (IQR), as appropriate, categorial data as counts (n) and percentages (%).
g: grams; d: days; SpO_2: oxygen saturation; min: minutes; ASO: arterial switch operation; min: minutes; ECC: extracorporeal circulation; PICU: pediatric intensive care unit. p values < 0.05 are in bold.

anatomy [12]. Other studies reported accuracy similar to ours with rates between 63 and 86%, even in coronary artery variants, with better accuracy rates when 2 different echocardiographers examine the child [9]. Our accuracy in echocardiographic determination of the coronary patterns was excellent in usual coronary artery anatomy (92%), but low in coronary variants (20%). The most common coronary artery variant 1L2RCx, was diagnosed incorrectly in 89% (16 of 18 cases). However, in 11 of those 16 incorrectly diagnosed patients with 1L2RCx, echocardiography assumed usual coronary artery anatomy, therefore the low accuracy in coronary variants may be biased by the 1L2RCx group, since a normal coronary artery and 1L2RCx might be difficult to distinguish by transthoracic echocardiography.

The coronary artery anatomy distribution found is comparable to other studies focusing on the frequency of different coronary artery anatomies [17]. Analysis of the impact of a correct or incorrect diagnosis of the coronary artery anatomy by univariate analysis showed that an incorrect diagnosis was related to longer duration of surgery and extracorporeal circulation time and that coronary artery variants itself were associated to longer intraoperative parameters. However, multivariate analysis showed no influence of either incorrect diagnosis or presence of coronary artery variants on the intra- and postoperative course. Our results go along with the results in other investigations. Fundora et al. did not find any correlation between echocardiographic accuracy and intraoperative parameters and the postoperative course after arterial switch operation [3]. And concerning coronary anatomy as a risk factor, several other studies confirm our findings [15,20]. Fricke et al. (2016) showed that even long-term outcome in patients with coronary artery variants such as intramural coronary arteries is as good as in children with normal coronary artery anatomy [21]. In contrast, other studies showed higher complication rates and a higher risk of death in patients with an intramural coronary course and a slightly increased risk in other coronary artery variants including single coronary arteries to adverse cardiovascular events [16,22,23]. According to our study there is no higher risk for coronary variants and lower echocardiographic accuracy to have an unfavorable short-term outcome after arterial switch operation, apparently this is a statement other studies have confirmed. Long-term outcomes in coronary artery variants are currently under discussion. There are studies showing excellent survival and functional outcomes of arterial switch operation even in long-term follow-up, nevertheless a strict surveillance is fundamental, particularly in high-risk coronary anatomy [24]. Other studies presented satisfactory early arterial switch operation outcomes as well, with possible late appearance of symptomless coronary lesions [25,26].

Considering the above-mentioned facts, a direct correlation between an incorrect preoperative echocardiographic diagnosis of coronary anatomy or coronary artery variants itself in dTGA and prolonged intraoperative parameters cannot certainly be made. Rather it has to be hypothesized that other cardiac anatomical findings needing treatment during ASO like a ventricular septal defect are partially responsible for the longer duration of surgery. The impact of an incorrect diagnosed coronary artery anatomy during preoperative echocardiography on surgical outcome and procedure is rather low. To describe the correct subtype of coronary anatomy seems to be less reliable and important than predicting a possible coronary artery variant without detailed description of the coronary artery subtype. Therefore, other modalities like angiography, which showed similar accuracy rates in diagnosing coronary anatomy correctly, are not necessary [19].

5. Limitations

The retrospective nature of this study is a possible subject of limitation. As such, diagnostic examinations, therapeutic decisions and follow-ups were not standardized and represent the best clinical judgement. Further it is a single centre study with two surgical teams (2004–2012 and 2012–2017) being involved in performing arterial switch operation throughout the reviewed study period. Preoperative evaluation of coronary artery was not performed by a dedicated imaging team but by an experienced consultant pediatric cardiologist. Nowadays, better imaging technologies and transducer may provide better images and accuracy rates.

6. Conclusion

Accuracy of preoperative echocardiographic diagnosis of coronary artery anatomy in d-transposition of the great arteries is high in usual coronary artery pattern (92%) but low in coronary artery variants (20%). A correlation between an incorrect diagnosis and an unfavorable intra- and postoperative course is not evident. Exact description of the correct subtype of coronary artery anatomy seems to be less important than detecting the presence of a coronary artery variant itself. Therefore, even if echocardiographic diagnosis is incomplete, further advanced imaging modalities may not be required.

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Conflicts of interest

None.

Ethical standards

The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national guidelines on human experimentation and with the Helsinki Declaration of 1975, as revised in 2008, and has been approved by the institutional committees (Kantonale Ethikkomission Zürich).

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