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ARTICLE

Role of Imaging in Surgical Decision Making for Patients with Double Outlet Right Ventricle

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ABSTRACT: Background: Double-outlet right ventricle (DORV) encompasses a spectrum of disorders characterized by both great vessels arising from the right ventricle. This study compared the diagnostic accuracy of multislice computed tomography (MSCT) and transthoracic echocardiography (TTE) in predicting the optimal surgical strategy by evaluating the concordance between preoperative imaging-based decisions and intraoperative findings. **Methods:** This single-center, retrospective study included 112 patients with DORV (56 MSCT + TTE and 56 TTE only) who underwent surgical correction between January 2010 and December 2024. Agreement between preoperative and intraoperative surgical decisions was assessed by weighted kappa (κ). Diagnostic accuracy was calculated using sensitivity, specificity, positive predictive value, and negative predictive value. **Results:** Median weight was 8.40 kg in the combined MSCT + TTE group and 9.56 kg in the TTE-only group. TTE demonstrated high concordance with intraoperative surgical findings (κ = 0.93), whereas the combined MSCT + TTE group demonstrated lower concordance (κ = 0.761). Macro average sensitivity and specificity were 95.8% and 98.8% for the TTE-only group, compared to 83.9% and 97.1% for the combined MSCT + TTE group. The lower concordance observed in the combined imaging group likely reflects the greater anatomical complexity of patients selectively referred for adjunctive MSCT imaging. **Conclusions:** TTE demonstrated stronger agreement with intraoperative surgical findings (κ = 0.93), whereas the combined MSCT + TTE group demonstrated lower concordance (κ = 0.761). The lower concordance observed in the combined imaging group likely reflects the greater anatomical complexity of patients selectively referred for adjunctive MSCT imaging.

KEYWORDS: Double outlet right ventricle; multislice computed tomography; transthoracic echocardiogram; ventricular septal defects

1 Introduction

Double outlet right ventricle (DORV) comprises a spectrum of congenital heart defects in which both great arteries originate from the right ventricle. It accounts for 1% of all congenital heart defects, or approximately 1 in 10,000 live births [1]. The morphological variability of DORV leads to diverse surgical strategies. Transthoracic echocardiography (TTE) remains the standard modality for diagnosis and preoperative evaluation. Advanced techniques such as multislice computed tomography (MSCT), three-dimensional echocardiography (3D), 3D printing, and cardiac magnetic resonance imaging (CMR) can further delineate anatomy and assist surgical planning [2]. However, their application may be constrained by radiation exposure, technical challenges, cost, and limited availability in resource-limited settings.

However, limited data exist on how accurately preoperative imaging-based surgical planning correlates with intraoperative decision-making in patients with DORV.

This study aimed to evaluate the role of TTE and selective adjunctive MSCT in preoperative surgical planning for patients with DORV by assessing concordance between preoperative imaging-based surgical decisions and intraoperative findings. In addition, we sought to identify scenarios in which MSCT provided incremental anatomical information that influenced surgical decision-making.

2 Methods

2.1 Study Design and Patient Selection

This retrospective, single-center study was conducted at Institut Jantung Negara (IJN) in Kuala Lumpur, Malaysia, including all consecutive patients diagnosed with DORV who underwent surgical correction between January 2010 and December 2024. DORV was defined as both great arteries arising predominantly (>50%) from the morphologic right ventricle [3]. DORV was classified based on the location of the ventricular septal defect (VSD) into subaortic, subpulmonic (Taussig-Bing), doubly committed subarterial, and remote/non-committed types [3]. Clinical records, TTE findings, MSCT thorax imaging, and surgical notes were recorded in a structured proforma. Patients were divided into two groups: those who underwent combined MSCT and TTE before surgery (case group) and those evaluated with TTE alone (control group). MSCT was preferentially performed in patients with complex anatomy or inconclusive echocardiographic findings, per clinical decision-making. To facilitate meaningful comparison of imaging-based surgical planning approaches, the first 56 patients who underwent combined MSCT and TTE and the first 56 patients who underwent TTE alone during the study period were selected for analysis. This selection strategy ensured balanced group sizes while maintaining the consecutive nature of case identification within each imaging subgroup. Consequently, the two groups were inherently non-equivalent with respect to anatomical complexity, introducing potential selection bias, which represents an important limitation of this retrospective observational study. Because all patients in the combined MSCT and TTE group also underwent TTE, an intra-group comparative analysis between TTE and MSCT findings was also performed. Parameters compared included the type and location of VSD, presence of right ventricular outflow tract (RVOT) obstruction, great vessel relationship, and associated extracardiac anomalies. Atrioventricular valve straddling and VSD commitability were also assessed based on standard echocardiographic criteria. The intermodality concordance was measured using Cohen's kappa (κ) statistic. Patients with atrioventricular discordance, DORV with single-ventricle physiology, or without surgical data were excluded.

All preoperative surgical decisions were made by consensus among a multidisciplinary team at IJN, comprising pediatric cardiologists, pediatric intensivists, and congenital cardiac surgeons. These decisions were compared with the intraoperative surgical decisions made at the operating table to assess the imaging accuracy and to analyze the discrepancies between preoperative and intraoperative decisions. For analysis, surgical strategies were additionally categorized into broader clinically meaningful groups, including biventricular repair and single-ventricle palliation pathways. Cases demonstrating discrepancies between preoperative and intraoperative surgical decisions were further reviewed to identify the underlying anatomical factors contributing to modification of surgical strategy, including VSD commitability, atrioventricular valve straddling, ventricular outflow tract geometry, and associated extracardiac anomalies. This study was reviewed and approved by the Institutional Review Board of Institut Jantung Negara in Kuala Lumpur, Malaysia, with approval number IJNREC/639/2023; informed consent was waived owing to the retrospective design. This study was conducted in accordance with the Declaration of Helsinki.

2.2 Study Objective

Primary Objective

To evaluate the role of TTE and selective adjunctive MSCT in preoperative and surgical planning for patients with DORV by assessing concordance between preoperative imaging-based surgical decisions and intraoperative findings. Secondary objectives:

1. To compare the demographic and anatomical characteristics, including the type of VSD, right ventricular outflow tract obstruction (RVOTO), and great vessel relationships between the two groups.
2. To evaluate the differences in intracardiac anomalies detected by TTE and MSCT.
3. To describe the details of discrepancies between preoperative and intraoperative surgical strategies.

2.3 MSCT Thorax Protocol

All scans were acquired on dual-source CT systems (Siemens Somatom Force, Siemens Healthineers, Forchheim, Germany) or single-source (GE Revolution, GE HealthCare, Chicago, IL, USA). Intravenous Iomeron 350 contrast (1–2 mL/kg) was injected via antecubital vein (22–24 G in younger children, 18–20 G in older children), followed by a 2–3 mL/kg saline flush. Bolus tracking used an LV region-of-interest (100–150 HU threshold; 15–20 s delay) or manual triggering upon full chamber opacification. Biphasic/triphasic injection and, when indicated, delayed venous-phase (60–90 s) acquisition were performed [4]. For patients requiring hepatic venous assessment (e.g., single-ventricle pathway), a delayed venous phase scan (60–90 s) was performed [5]. Image acquisition was either prospective or retrospective ECG gating, depending on the patient's heart rate. Acquisition parameters were: tube voltage: 70–80 kV; tube current (mAs): 250 (adjusted based on patient weight and height); gantry rotation time: 0.25 s; pitch: 3.0–3.5. Images were processed on dedicated workstations (syngo.via VB60, Siemens Healthineers, Forchheim, Germany, or AW Server 3.2, GE HealthCare, Chicago, IL, USA) with multiplanar reformation, maximum-intensity projection, and volume-rendering techniques. Each study was independently reviewed by a pediatric imaging cardiologist for classification of great-vessel relationship, VSD location, RVOT obstruction, and associated anomalies.

2.4 Diagnostic Accuracy and Statistical Analysis

Intraoperative surgical findings were considered the reference (gold) standard because they represent the direct anatomical assessment upon which the definitive surgical procedure was based. Diagnostic indices were calculated as [6]:

Sensitivity: True positive (TP)/True positive (TP) plus false negative (FN)
Specificity: True negative (TN)/True negative (TN) plus false positive (FP)
Positive predictive value (PPV): TP/TP + FP
Negative predictive value (NPV): TN/TN + FN
Overall accuracy: TP + TN/all (sample)

Statistical analyses were performed using IBM SPSS Statistics for Windows, Version 18.0 (IBM Corp., Armonk, NY, USA). Categorical variables were expressed as frequency (%) and continuous variables as mean ± SD or median (IQR). Between-group comparisons applied χ^2 or Fisher's exact test for categorical data and t-test or Mann-Whitney U for continuous data. $p < 0.05$ was considered significant. Agreement between imaging modalities and between pre- and intraoperative decisions was assessed using weighted κ statistics with quadratic weights using the sample size (interpreted as 0–0.20 slight, 0.21–0.40 fair, 0.41–0.60 moderate, 0.61–0.80 substantial, 0.81–1.00 almost perfect) [7].

3 Results

A total of 112 patients were included, with 56 patients each in the MSCT/TTE and TTE groups. Baseline demographic characteristics were comparable between the groups. The median age at repair was 1.9 (IQR: 0.8–4.9) years in the MSCT/TTE group and 2.0 (IQR: 0.9–5.6) years in the TTE group (p = 0.126). Male patients comprised 53.6% and 67.8% of the two groups, respectively (p = 0.106). Median weight and height at repair were also similar (8.40 vs. 9.56 kg, p = 0.062; 87.0 vs. 85.0 cm, p = 0.740).

No significant differences were observed in anatomical characteristics between the groups, including DORV diagnosis subtype (p = 0.332), presence of RVOT obstruction (57.1% vs. 66.1%, p = 0.331), VSD type (p = 0.217), additional VSDs (17.9% vs. 21.4%, p = 0.810), or great vessel relationship (p = 0.616), indicating well-balanced baseline clinical and anatomical profiles (Table 1).

Associated cardiovascular anomalies were largely comparable between the MSCT/TTE and TTE groups. There were no significant differences in the prevalence of bilateral superior vena cava with persistent left SVC draining to the coronary sinus (16.1% vs. 17.9%, p = 0.801), pulmonary venous anomalies (5.4% vs. 0%, p = 0.243), systemic venous anomalies (1.8% vs. 0%, p = 0.999), coronary anomalies (8.9% vs. 1.8%, p = 0.206), ASD secundum (23.2% vs. 25.0%, p = 0.825), or small right or left ventricles (both p = 0.999). Aortic anomalies were significantly more frequent in the MSCT/TTE group than in the TTE group (30.4% vs. 7.1%, p = 0.002), while the prevalence of PDA showed a borderline difference between groups (17.9% vs. 33.9%, p = 0.052) (Table 2).

Table 1: Baseline characteristics of DORV patients in the combined MSCT and TTE (cases) and TTE (control) groups.

Demographic	MSCT/TTE (Cases) (n = 56)	TTE (Control) (n = 56)	p Value
Age at repair (years) [Median, IQR]	1.9 (0.8–4.9)	2.0 (0.9–5.6)	0.126
Gender Male [n (%)]	30 (53.6%)	38 (67.9%)	0.106
Gender Female [n (%)]	26 (46.4%)	18 (32.1%)	
Weight (kg) at repair [Median, IQR]	8.40 (6.80–10.85)	9.56 (6.50–10.25)	0.062
Height (cm) at repair [Median, IQR]	87.0 (49.0–68.0)	85.0 (51.0–66.0)	0.74
Diagnosis			0.332
DORV, Subaortic VSD, PS	11 (19.6%)	18 (32.1%)	
DORV, Subaortic VSD, No PS	9 (16.1%)	9 (16.1%)	
DORV, Subpulmonic VSD, PS	9 (16.1%)	9 (16.1%)	
DORV, Subpulmonic VSD, No PS	15 (26.7%)	6 (10.7%)	
DORV, Inlet VSD, PS	7 (12.5%)	6 (10.7%)	
DORV, Inlet VSD, No PS	3 (5.4%)	2 (3.6%)	
DORV, DCSA VSD, PS	1 (1.8%)	4 (7.1%)	
DORV, DCSA VSD, No PS	1 (1.8%)	2 (3.6%)	
RVOT obstruction			0.331
No	24 (42.9%)	19 (33.9%)	
Yes	32 (57.1%)	37 (66.1%)	
Type of VSD			0.217
Subaortic	20 (35.7%)	27 (48.2%)	
Subpulmonic	24 (42.9%)	15 (26.8%)	
DCSA	2 (3.6%)	5 (8.9%)	
Inlet	10 (17.9%)	9 (16.1%)	
Additional VSDs			0.810
No	46 (82.1%)	44 (78.6%)	
Yes (any)	10 (17.9%)	12 (21.4%)	
Subtype (among those with additional VSDs)	(n = 10)	(n = 12)	
Apical	2 (20.0%)	3 (25.0%)	
Muscular	3 (30.0%)	3 (25.0%)	

Table 1: *Cont.*

Demographic	MSCT/TTE (Cases) (*n* = 56)	TTE (Control) (*n* = 56)	*p* Value
Inlet and muscular	2 (20.0%)	3 (25.0%)	
Apical and muscular	2 (20.0%)	2 (16.7%)	
Inlet, apical, and muscular	1 (10.0%)	1 (8.3%)	
Great vessels relationship			0.616
Normal	22 (39.3%)	31 (55.4%)	
Side by side	8 (14.3%)	6 (10.7%)	
Anteroposterior	1 (1.8%)	1 (1.8%)	
Aorta anterior and to the right of PA	23 (41.1%)	17 (30.4%)	
Aorta anterior and to the left of PA	2 (3.6%)	1 (1.8%)	

Median (IQR, 25th–75th), *n* (percentage %). MSCT: Multislice computed tomography, TTE: Transthoracic echocardiography, DORV: Double outlet right ventricle, PS: Pulmonary stenosis, RVOT: Right ventricular outflow tract obstruction, DCSA VSD: Doubly committed subarterial ventricular septal defect, PA: Pulmonary artery, IQR: Interquartile range.

Table 2: Comparison of combined MSCT and TTE (cases) and TTE (control) in identifying the pattern of associated anomalies in patients with DORV.

Variables	MSCT/TTE (Cases) (*n* = 56)	TTE (Control) (*n* = 56)	*p* Value
Bilateral SVC, Left SVC to CS			0.801
No	47 (83.9%)	46 (82.1%)	
Yes	9 (16.1%)	10 (17.9%)	
Pulmonary venous anomalies			0.243
No	53 (94.6%)	55 (98.2%)	
Yes	3 (5.4%)	0 (0.0%)	
Systemic venous anomalies (unroofed CS)			0.999
No	55 (98.2%)	56 (100%)	
Yes	1 (1.8%)	0 (0.0%)	
Aortic anomalies			0.002
No	39 (69.6%)	52 (92.9%)	
Yes	17 (30.4%)	4 (7.1%)	
Coronary anomalies			0.206
No	51 (91.1%)	55 (98.2%)	
Yes	5 (8.9%)	1 (1.8%)	
ASD secundum			0.825
No	43 (76.8%)	42 (75.0%)	
Yes	13 (23.2%)	14 (25.0%)	
PDA			0.052
No	46 (82.1%)	37 (66.1%)	
Yes	10 (17.9%)	19 (33.9%)	
Small ventricles			
Small RV			0.999
No	55 (98.2%)	56 (100%)	
Yes	1 (1.8%)	0 (0.0%)	
Small LV			0.999
No	55 (98.2%)	56 (100%)	
Yes	1 (1.8%)	0 (0.0%)	

n (percentage %). MSCT: Multislice computed tomography, TTE: Transthoracic echocardiography, SVC: Superior vena cava, CS: Coronary sinus, PDA: Patent ductus arteriosus, LV: Left ventricle, RV: Right ventricle, ASD: Atrial septal defect.

Table 3 summarizes the concordance between preoperative imaging-based surgical plans and intraoperative findings. In the TTE-only group, 53 of 56 patients (94.6%) had the same surgical plan preoperatively and intraoperatively, yielding an almost perfect weighted κ of 0.929 ($p < 0.001$). In the combined MSCT + TTE group, 45 of 56 patients (80.4%) had concordant plans, with a substantial weighted κ of 0.761 ($p < 0.001$). The most common surgical strategies included LV-to-aorta tunneling with RVOT reconstruction (19.6% in the MSCT + TTE group vs. 33.9% in the TTE-only group), VSD-to-pulmonary artery tunneling with arterial switch (19.6% vs. 12.5%), and single-ventricle palliation (16.1% vs. 25.0%). The lower concordance in the combined imaging group likely reflects the greater anatomical complexity of patients selectively referred for adjunctive MSCT imaging rather than a limitation of the modality itself.

Table 3: Comparison of combined MSCT/TTE and TTE groups regarding the level of agreement between the pre-operative plan and intra-operative decisions.

Pre-Operative Plan	MSCT/TTE (*n* = 56) Patients with Same Plan [n (%)]	Kappa	*p* Value	TTE (*n* = 56) Patients with Same Plan [n (%)]	Kappa	*p* Value
Aortic root translocation	2 (3.6%)			0 (0.0%)		
LV-to-AO tunnelling	6 (10.7%)			10 (17.9%)		
LV-to-AO tunneling + Rastelli	4 (7.1%)			3 (5.4%)		
LV-to-AO tunneling + RVOT Reconstruction	11 (19.6%)			19 (33.9%)		
Single Ventricle	9 (16.1%)			14 (25.0%)		
VSD-to-PA tunneling + Arterial switch	11 (19.6%)			7 (12.5%)		
VSD-to-PA tunneling + Rastelli	0 (0.0%)			0 (0.0%)		
VSD-to-PA tunneling + Arterial switch + Rastelli	2 (3.6%)			0 (0.0%)		
Overall	45 (80.4%)	0.761	<0.001	53 (94.6%)	0.929	<0.001

n (percentage %). MSCT: Multislice computed tomography, TTE: Transthoracic echocardiography, LV: Left ventricle, AO: Aorta, VSD: Ventricular septal defect, PA: pulmonary artery, RVOT: Right ventricular outflow tract.

Overall, TTE demonstrated higher diagnostic performance than MSCT/TTE across all evaluated parameters. The macro (weighted) average sensitivity was 95.8 (94.6)% for TTE compared with 83.9 (80.4)% for MSCT/TTE, while specificity was 98.8 (99.5)% and 97.1 (96.1)%, respectively. TTE also achieved higher positive predictive value (89.5% vs. 76.0%), negative predictive value (98.5% vs. 97.1%), and diagnostic accuracy based on AUC (0.98 vs. 0.91) (Table 4).

Table 4: Diagnostic accuracy of combined MSCT and TTE and TTE groups based on pre-operative surgical plan versus intra-operative surgical decision.

Diagnostic Parameters	MSCT/TTE (Weighted Average)*	TTE (Weighted Average)*
Sensitivity	83.9 (80.4)	95.8 (94.6)
Specificity	97.1 (96.1)	98.8 (99.5)
Positive Predictive Value	76.0 (83.6)	89.5 (96.3)
Negative Predictive Value	97.1 (95.6)	98.5 (98.0)
Accuracy based on AUC	0.91 (0.88)	0.98 (0.98)

*Values outside parentheses are macro averages; values inside parentheses are weighted averages. MSCT: Multislice computed tomography, TTE: Transthoracic echocardiography, AUC: Area under the curve.

Intragroup Comparison of TTE and MSCT Findings

Among patients who underwent both modalities (n = 56), inter-modality agreement was excellent across all parameters ($\kappa > 0.9$, $p < 0.001$; Supplementary Table S3). The most common VSD morphologies were subpulmonic (41.1% by MSCT; 39.2% by TTE) and subaortic (37.5% by MSCT and 35.7% by TTE) (Supplementary Table S3). RVOTO was identified in 57.1% by both modalities ($\kappa = 1.0$). Great-vessel and associated anomalies also showed high concordance, with MSCT providing additional systemic venous and aortic details in complex cases.

Discrepancies between pre- and intraoperative surgical decisions (Supplementary Table S4) were primarily related to challenges in assessing VSD commitability and spatial relationships with the great arteries. In several cases, a long VSD-to-aortic distance and complex geometry limited the accurate preoperative prediction of biventricular repair feasibility. Atrioventricular valve straddling and chordal attachments were also difficult to fully appreciate preoperatively in some cases. MSCT contributed to the identification of extracardiac and vascular anomalies, including arch abnormalities and coronary variants, which occasionally influenced surgical planning. These findings suggest that discrepancies were multifactorial and related to both intracardiac anatomical complexities and inherent limitations of individual imaging modalities.

4 Discussion

DORV encompasses a spectrum of congenital cardiac anomalies in which both great arteries arise predominantly from the right ventricle, fulfilling the "200% rule" (both entirely from the RV) or the "150% rule" (one entirely and ≥50% of the other from the RV) [8]. Despite the wide variation in DORV, advances in multimodality imaging, particularly TTE and MSCT, have significantly improved preoperative planning [5,9]. The present study evaluated the role of TTE and selective adjunctive MSCT in real-world surgical planning for DORV by assessing concordance between preoperative imaging-based decisions and intraoperative findings.

4.1 Gaps in the Literature and the Existing Literature Reviews

Although previous studies have described DORV morphology and surgical outcomes, few have compared TTE and MSCT in guiding surgical strategy. Because DORV constitutes only about 1% of congenital heart defects and exhibits wide anatomic variability, such comparisons remain scarce. TTE remains the first-line modality for its accessibility and low radiation exposure, despite its operator dependence and limited acoustic windows [10]. MSCT offers high spatial resolution, detailed extracardiac anatomy, and 3D reconstruction capability but requires sedation, iodinated contrast, and radiation exposure [5]. Recent expert consensus statements have emphasized the importance of radiation optimization and justification of cardiovascular CT use in pediatric congenital heart disease, supporting selective and clinically targeted use of CT imaging in children [11]. MRI provides complementary data but is time-consuming, often requires sedation, is costly, is less available in resource-limited settings, and carries the risk of gadolinium-induced nephrogenic systemic fibrosis [12,13]. Emerging 3D visualization technologies, including 3D printing, virtual reality, and advanced digital reconstruction techniques, have further enhanced understanding of complex spatial intracardiac relationships in congenital heart disease and may improve surgical planning in anatomically complex DORV cases [14].

4.2 Comparison with Previous Studies

In our cohort, the TTE-only group demonstrated higher concordance with intraoperative findings than the combined MSCT + TTE group. However, MSCT was preferentially utilized in patients with more complex anatomy or inconclusive echocardiographic findings, and therefore, the lower concordance observed in the combined imaging group likely reflects increased anatomical complexity rather than a limitation of MSCT itself. These findings are consistent with those of Saraya et al., who reported high diagnostic accuracy of echocardiography in DORV surgical planning [2]. Similarly, Kun-Jing Pang et al. reported echocardiographic classification guiding successful repair in the majority of DORV cases [15]. In contrast, Shi et al. highlighted the value of CT in defining complex intracardiac and extracardiac anatomy but did not evaluate concordance with intraoperative surgical decision-making [16]. More recently, Peek et al., in a multicenter pilot study of 5 DORV patients evaluated by 12 surgeons and cardiologists, reported that surgical plans based on 2D CT and ultrasound matched the actual performed surgery in only 66% of cases, whereas 3D printing (78%) and virtual reality (80%) models significantly improved this concordance, further underscoring the limitations of conventional 2D imaging alone for complex DORV [17]. Our findings support the complementary role of multimodality imaging, with TTE serving as the primary imaging modality and MSCT providing additional anatomical information in selected complex cases.

4.3 Interpretation of Findings

In this study, intragroup comparison of patients who underwent both TTE and MSCT showed excellent agreement across all parameters ($\kappa > 0.9$), confirming the high diagnostic reliability of echocardiography in defining intracardiac anatomy. MSCT mainly served as a complementary tool for assessing the extracardiac vascular structures. The lower concordance observed in the combined MSCT + TTE group likely reflects the greater anatomical complexity of patients selectively referred for adjunctive MSCT imaging rather than a limitation of MSCT itself. The strong concordance in identifying the VSD type, great vessel relationship, and RVOT obstruction supports TTE as a primary modality, reserving MSCT for complex or ambiguous cases. These results align with the prior studies emphasizing the adjunctive role of MSCT when acoustic windows are limited or additional spatial detail is needed, particularly in neonatal and early infant repairs, except those involving root translocations. In younger children, echocardiographic windows generally offer superior resolution, enhancing interpretation and surgical planning. Accurate assessment of VSD commitability and atrioventricular valve straddling, key determinants of biventricular versus single-ventricle repair, can be comprehensively achieved by TTE through evaluation of VSD–valve spatial relations and tricuspid-to-pulmonary-valve distance (Figs. 1 and 2) [18,19]. It is well established that the intraventricular baffle from the VSD to the arterial valve may be compromised when the infundibulum is long, and the VSD is located such that it involves more than two-thirds of the tricuspid valve annulus [8,18].

The tricuspid–pulmonary valve distance is a key imaging parameter for assessing the feasibility of intraventricular baffle repair (Figs. 1 and 2). When this distance equals or exceeds the aortic root diameter, biventricular repair is feasible; if smaller, alternative strategies such as LV–PA tunneling, arterial switch (without pulmonary stenosis), Rastelli, root translocation, or Nikaidoh procedures are considered [19–21].

4.4 Supplementary Use of MSCT

Our findings suggest that TTE provides sufficient anatomical information for surgical planning in many anatomically straightforward DORV cases, while MSCT remains valuable in selected patients requiring detailed assessment of coronary anatomy, aortic arch anomalies, extracardiac vascular structures, or complex spatial relationships. Although ECG-gated MSCT can provide additional information regarding VSD commitability and spatial anatomy, concerns regarding radiation exposure and the need for contrast administration may limit its routine use in pediatric patients. Therefore, a tailored multimodality imaging strategy based on anatomical complexity and clinical requirement may represent the most practical approach in contemporary DORV surgical planning.

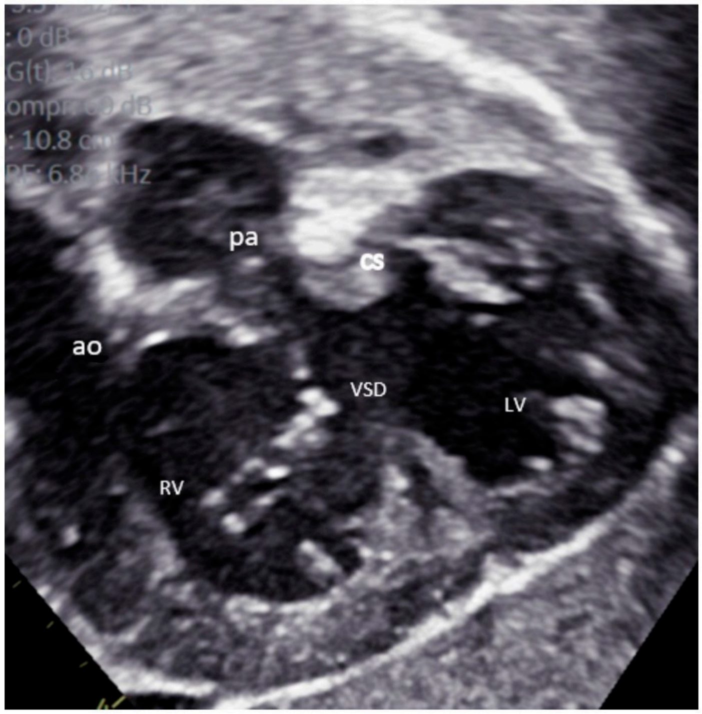

Figure 1: Subcostal view of a transthoracic echocardiogram demonstrating both the great vessels from the right ventricle, pulmonary mitral discontinuity, large inlet VSD, aorta to the right of the pulmonary artery, and the relationship of the pulmonary valve with the tricuspid valve. PA: pulmonary artery, AO: aorta, CS: conal septum, RV: right ventricle, LV: left ventricle, VSD: Ventricular septal defect.

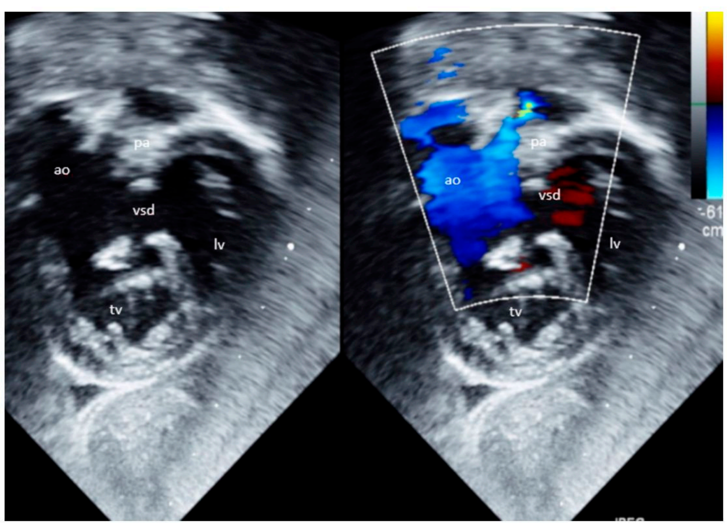

Figure 2: Subcostal transthoracic echocardiogram demonstrating subpulmonic VSD, a tricuspid pulmonary distance almost equal to the aortic annulus, fulfilling one of the criteria for the left ventricle to aorta commitability, aorta to the right of the pulmonary artery, and subvalvular and valvular pulmonary stenosis. AO: aorta, PA: pulmonary artery, TV: tricuspid valve, VSD: ventricular septal defect.

4.5 Discrepancies between Preoperative and Intraoperative Decision-Making

Discrepancies between preoperative imaging-based planning and intraoperative findings were primarily driven by limitations in assessing VSD commitability and spatial relationships within the ventricular outflow tracts. This is particularly relevant in patients with remote or non-committed VSDs, where increased distance between the VSD and the arterial valve, often exceeding the aortic annulus dimension, limits the feasibility of direct intraventricular baffling and contributes to intraoperative modification of surgical strategy [18]. Al Kindi et al., using 3D printing in two cases of DORV with remote interventricular communication, demonstrated that the additional spatial information from 3D models directly altered the surgical strategy, converting a planned univentricular repair to a one-and-a-half-ventricle repair in one case and enabling a complex left ventricle-to-aorta baffle in another [22]. Similar findings have been reported by Valverde et al., who demonstrated that three-dimensional printed models improved surgical understanding and preoperative planning in complex congenital heart disease by enhancing visualization of spatial intracardiac relationships [23]. In addition, subtle atrioventricular valve straddling and complex chordal attachments were not always fully delineated on preoperative imaging.

While TTE provided excellent intracardiac anatomical details and reliably assessed VSD morphology in most patients, MSCT contributed complementary information regarding extracardiac structures, including aortic arch abnormalities and coronary artery variants, which occasionally influenced surgical decisions. These findings suggest that discrepancies are multifactorial and reflect anatomical complexity and modality-specific limitations. In resource-limited settings, reliance on TTE as the primary imaging modality may remain a practical and cost-effective strategy, with selective use of MSCT in cases where additional anatomical detail is required. These results support a tailored, multimodality imaging approach rather than a modality-specific preference.

5 Limitations

This study is limited by its retrospective, single-center design and small sample size, which restrict generalizability. Importantly, MSCT was preferentially used in patients with more complex anatomy or inconclusive echocardiographic findings, introducing selection bias and making the two groups not directly comparable. Reliance on existing records may have introduced data inconsistencies, and unmeasured confounders, such as surgeon experience and evolving imaging protocols, could not be controlled. Imaging interpretation was not performed in a blinded fashion, and inter-observer variability was not formally assessed. These findings should therefore be interpreted with caution, and larger prospective multicenter studies are needed to validate our observations.

6 Conclusions

TTE demonstrated high reliability in preoperative planning for anatomically straightforward DORV cases, with strong concordance with intraoperative findings. In complex cases, MSCT provided complementary anatomical detail, particularly regarding extracardiac vascular structures and spatial relationships that enhanced surgical decision-making. These findings support a tailored imaging strategy, with MSCT reserved for patients with complex anatomy or inconclusive echocardiographic findings. However, the non-equivalent comparison groups and inherent selection bias limit direct comparisons. Larger prospective studies are needed to further define the optimal imaging approach for DORV.

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