Natural Resources for Human Health
eISSN: 2583-1194

Original Research

Received 22 July 2026
Revised 24 Aug 2026
Accepted 05 Sep 2026

Natural Resources for Human Health 2026, Vol.6(22s):1178–1194

KEYWORDS:
Heart Septal Defects, Ventricular, Heart Septal Defects, Atrial, Echocardiography, ROC Curve, Pediatric Cardiology, Cardiac Surgical Procedures.

Echocardiographic Parameters Associated with the Recommendation for Operative Treatment in Children with Ventricular and Atrial Septal Defects: An Observational Study

Rakhmonova Gulbahor Ergashovna[1], Khodjibekova Yulduz Maratovna[2], Khamidova Mohinur Abrakul kizi[3], Sultanova Laylo Rustamjonovna[4], Rakhmanova Muhayyo Davronbek kizi[5], Khodjamova Gulbakhor Adkhamjon kizi[6], Matniyazova Gulnozakhon Atabayevna[7], Abrorov Zokhidjon Khamitovich[8], Valiev Yunusjon Yusup ugli[9]

[1] Doctor of Medical Sciences, Professor, Department of Medical Radiology No. 1, Tashkent State Medical University, Tashkent, Uzbekistan.
ORCID: 0000-0002-1550-5031
[2] Doctor of Medical Sciences, Professor, Department of Medical Radiology No. 3, Tashkent State Medical University, Tashkent, Uzbekistan.
ORCID: 0000-0002-0058-5905
[3] Assistant of Department of Medical Radiology No. 1, Tashkent State Medical University, Tashkent, Uzbekistan. mkhamidova1604@gmail.com
[4] Doctor of Philosophy, Department of Medical Radiology No. 2, Tashkent State Medical University, Tashkent, Uzbekistan. Orcid:0000-0002-1551-0981
[5] Doctoral Student, Department of Medical Radiology No. 1, Tashkent State Medical University, Tashkent, Uzbekistan. ORCID: 0009-0007-4372-1843, rahmanovamuhayyo3@gmail.com
[6] Assistant of Department of Medical Radiology No. 1, Tashkent State Medical University, Tashkent, Uzbekistan. Baxoroy1515@mail.ru
[7] Assistant of Department of Natural Sciences, Mamun University, Khorezm, Uzbekistan. ORCID: 0009-0003-0581-4126
[8] Assistant of Department of Medical Radiology No. 1, Tashkent State Medical University, Tashkent, Uzbekistan. ORCID: 0009-0003-3168-4281
[9] Assistant of Department of Medical Radiology No. 1, Tashkent State Medical University, Tashkent, Uzbekistan. ORCID: 0009-0004-4238-4951

ABSTRACT:

Background: Ventricular septal defect (VSD) and atrial septal defect (ASD) are common congenital heart defects in children. Although echocardiography is central to anatomical and haemodynamic assessment, the contribution of routinely reported parameters to real-world treatment recommendations remains insufficiently quantified.

Aim: To identify clinical and echocardiographic parameters associated with a recommendation for operative treatment and to evaluate the discriminatory performance of defect diameter in children with VSD and ASD.

Methods: This database-based observational study included 135 children with VSD and/or ASD selected from a paediatric cardiology database of 231 children. Children

Natural Resources for Human Health
eISSN: 2583-1194

recommended for operative treatment were compared with those managed conservatively. Major associated structural lesions were excluded from defect-specific analyses. Continuous and categorical variables were compared with appropriate parametric or non-parametric tests, and receiver operating characteristic analysis was used to evaluate VSD and ASD diameter.

Results: Operative treatment was recommended in 90 children. In isolated VSD (n = 71), mean defect diameter was larger in the operative group than in the conservative group (5.6 ± 1.6 vs 4.0 ± 1.5 mm; $p < 0.001$); the AUC was 0.770, with an exploratory cut-off of ≥4.3 mm. In isolated ASD (n = 38), median defect diameter was 10.6 [8.8–14.0] vs 5.5 [4.5–7.3] mm ($p < 0.001$); the AUC was 0.920, with a cut-off of ≥8.8 mm. RV dilatation was more frequent among children recommended for treatment.

Conclusion: Defect diameter, defect location, ventricular loading and body size were associated with treatment recommendations. The proposed thresholds are exploratory and require external validation before clinical use.

1. INTRODUCTION

Congenital heart disease (CHD) remains a major contributor to childhood morbidity and health-care use worldwide. Updated Global Burden of Disease analyses continue to show substantial prevalence, mortality and disability attributable to CHD, with the burden distributed unevenly across regions and socioeconomic settings [1,2]. Access to specialist diagnosis, catheter intervention and surgery is particularly variable in low- and middle-income countries, where workforce, infrastructure, referral pathways and affordability can influence the timing of definitive care [3–5]. In this context, reproducible echocardiographic assessment is important not only for diagnosis but also for prioritising children who may require closer surveillance or intervention.

Ventricular septal defect (VSD) and atrial septal defect (ASD) are among the most frequently encountered congenital cardiac lesions in paediatric practice. Their physiological consequences differ despite both commonly producing left-to-right shunting. A VSD may expose the pulmonary circulation and left-sided chambers to increased flow, with the clinical effect determined by defect size, ventricular pressure difference, pulmonary vascular resistance and associated lesions. Contemporary reviews emphasise that small VSDs, particularly muscular defects, frequently become smaller or close spontaneously, whereas larger or haemodynamically important defects are more likely to persist or require intervention [13,14]. In ASD, chronic interatrial shunting predominantly produces right atrial and right ventricular (RV) volume loading. Recent population-based neonatal echocardiographic data demonstrate that larger RV dimensions and atrial volumes may be detectable within the first month of life, while follow-up studies confirm that spontaneous closure is strongly influenced by defect size and maturity at diagnosis [24,25].

Transthoracic echocardiography (TTE) is therefore central to the evaluation of septal defects. A comprehensive paediatric examination defines segmental anatomy, defect location and dimensions, shunt direction, atrioventricular and semilunar valve relationships, ventricular size and systolic function, and Doppler-derived haemodynamic information [6]. When alternative imaging is needed for complex anatomy or procedural planning, modality selection should be guided by the clinical question and the expected diagnostic yield [11]. In growing children, interpretation of chamber and vessel dimensions also requires attention to body size. Paediatric z-score models can differ materially, and newer multicentre models aim to reduce residual confounding by body size, age and body habitus [7-9].

The choice between observation, surgery and transcatheter intervention is not determined by a single anatomical number. Contemporary interventional literature increasingly emphasises integrated patient selection, including defect anatomy, haemodynamic consequences, chamber loading, body size, associated valve findings, procedural feasibility and the expected natural history [12]. For selected VSDs, a range of surgical, hybrid, perventricular and transcatheter techniques is now reported, with outcomes depending on defect type, size, relationship to the conduction system and aortic valve, and the device used [15-21]. For secundum ASD, transcatheter closure is widely used when anatomy is suitable, and recent paediatric

studies describe favourable mid-term results, reverse remodelling and increasingly echocardiography-guided approaches [22,23,26–28].

Despite these advances, the extent to which individual routine echocardiographic variables distinguish children recommended for operative treatment from those managed conservatively remains incompletely described in real-world paediatric datasets. Absolute defect diameter is attractive because it is simple and widely available, but its meaning changes with age, body size, defect location and the accompanying ventricular response. Moreover, pooling VSD and ASD can obscure lesion-specific physiology. The present study therefore aimed to identify clinical and echocardiographic parameters associated with a recommendation for operative treatment in children with septal defects and to quantify the discriminatory performance of defect diameter separately for VSD and ASD. The analysis was designed to describe associations within the study dataset rather than to establish stand-alone intervention thresholds.

2. MATERIALS AND METHODS

2.1. Study design and population

This was a database-based observational study of children aged 0–18 years who had undergone paediatric echocardiographic assessment. The source database contained 231 children, one record per child. Children originated from all administrative regions of Uzbekistan, and one child was from Tajikistan. CHD was recorded in 203 children, while 28 children had structurally normal hearts. All eligible records available in the database were analysed; no formal a priori sample-size calculation was performed.

Study setting and period: The study was conducted at the Republican Mother and Child Screening Center, Tashkent, Uzbekistan, from January to March 2026.

2.2. Inclusion and exclusion criteria

Children were eligible for the primary cohort (Cohort A) if echocardiography documented a VSD of any recorded location and/or an ASD of any recorded type. Children without CHD and children whose CHD did not include a VSD or ASD were excluded from Cohort A.

For the pre-specified sensitivity cohort (Cohort B), children with a major associated structural lesion that could itself determine the need for surgery were additionally excluded. These lesions were tetralogy of Fallot, double-outlet right ventricle, transposition of the great arteries, coarctation of the aorta, total or partial anomalous pulmonary venous drainage, Ebstein anomaly, pulmonary or mitral atresia, hypoplastic left heart syndrome, anomalous origin of the left coronary artery from the pulmonary artery, and aortic stenosis. Pulmonary valve stenosis (PS) and patent ductus arteriosus (PDA) were retained in Cohort B because their severity was not graded in the source database. A further strict cohort (Cohort B2) excluded valvular PS and PDA. No child was excluded on the basis of the study outcome.

2.3. Echocardiographic assessment

TTE variables were interpreted within the framework of contemporary American Society of Echocardiography recommendations for comprehensive paediatric transthoracic echocardiography [6]. The source database contained LV dimensions and wall thicknesses, LV end-diastolic volume and ejection fraction, aortic and pulmonary valve annuli, ascending aorta, main and branch pulmonary arteries, and peak aortic and pulmonary valve gradients as absolute measurements. VSD and ASD diameters were also recorded.

The source database did not contain a standardised record of the imaging plane, cardiac-cycle phase, or whether defect diameter was measured by two-dimensional imaging or colour Doppler. Consequently, defect diameter was analysed as recorded by the examiner. This limitation is important because reproducible paediatric quantification requires standardised acquisition and reporting, and body-size adjustment is recommended for many cardiac dimensions [6–9].

2.4. Definitions and study variables

VSD location was coded in the database as perimembranous, subaortic, mid-muscular, apical, inlet or outlet. Because the database categories do not map perfectly onto all contemporary nomenclature systems, location was analysed as perimembranous versus all other recorded locations for the principal subgroup comparison. ASD was coded as secundum,

primum or coronary sinus type. Children were classified as having VSD only, ASD only, or both. Atrioventricular septal defect was recorded as a separate database field.

Clinical variables included sex; age category (1–27 days, 28 days–1 year, 1–5 years, 6–11 years and 12–18 years); weight; height; body surface area (BSA) as recorded in the database; weight-for-sex category; transcutaneous oxygen saturation (SpO_2); main complaint; and postnatal intensive care. Exact age was not available, so age was dichotomised at 1 year for selected subgroup analyses. Symptoms were defined as cyanosis, dyspnoea, fatigue, or all three. A heart murmur was retained as a separate recorded complaint.

Candidate echocardiographic variables were VSD and ASD diameter, VSD location, ventricular status as recorded by the examiner, shunt direction, pulmonary hypertension as recorded in the database, associated PDA, valvular stenosis or regurgitation, and valve gradients. Standardised quantitative definitions for the recorded labels of ventricular dilatation and pulmonary hypertension were not available. Exploratory indexed measures included ASD diameter/BSA and the ratio of VSD diameter to aortic annulus. Because z-scores were not available in the source database, absolute chamber and great-artery dimensions were used descriptively; this is relevant because z-score choice can affect interpretation in children [7-9].

The primary outcome was the database recommendation for operative treatment. In the source data, procedure type was coded as an 'open' operation or a 'closed' procedure. The term operative treatment is retained here because it represents the original study endpoint; the label 'closed procedure' is reported exactly as recorded and should not be interpreted as a specific catheter technique unless confirmed from the source records.

2.5. Statistical analysis

Continuous variables were summarised as mean ± standard deviation when distributional assumptions were appropriate, or as median [interquartile range] otherwise. Categorical variables were presented as counts. Between-group comparisons used Student's t-test or the Mann–Whitney U test for continuous variables and the χ^2 test or Fisher's exact test for categorical variables. Statistical significance was defined as a two-sided p value <0.05.

Receiver operating characteristic (ROC) analysis was used to assess how well VSD and ASD diameter distinguished children with and without a recommendation for operative treatment. The area under the ROC curve (AUC) and a data-derived cut-off were reported. The cut-offs were treated as exploratory markers because they were derived and evaluated in the same dataset and were not externally validated. Analyses were performed in Python 3.11.

3. RESULTS

3.1. Study cohort and baseline characteristics

Of 231 children in the source database, 28 had no CHD and 68 had CHD without a septal defect, leaving 135 children with VSD and/or ASD in Cohort A (Figure 1). There were 66 girls. Age distribution was 1 neonate aged 1–27 days, 54 children aged 28 days–1 year, 61 aged 1–5 years, 15 aged 6–11 years and 4 aged 12–18 years. Median BSA was 0.470 [0.377–0.655] m^2. A heart murmur was the most frequently recorded complaint, occurring in 87 children. Operative treatment was recommended in 90 children; an open operation was recorded in 52 and a closed procedure in 38. Apart from structurally absent defect diameters, there were no missing data in the analysed variables.

Natural Resources for Human Health
eISSN: 2583-1194

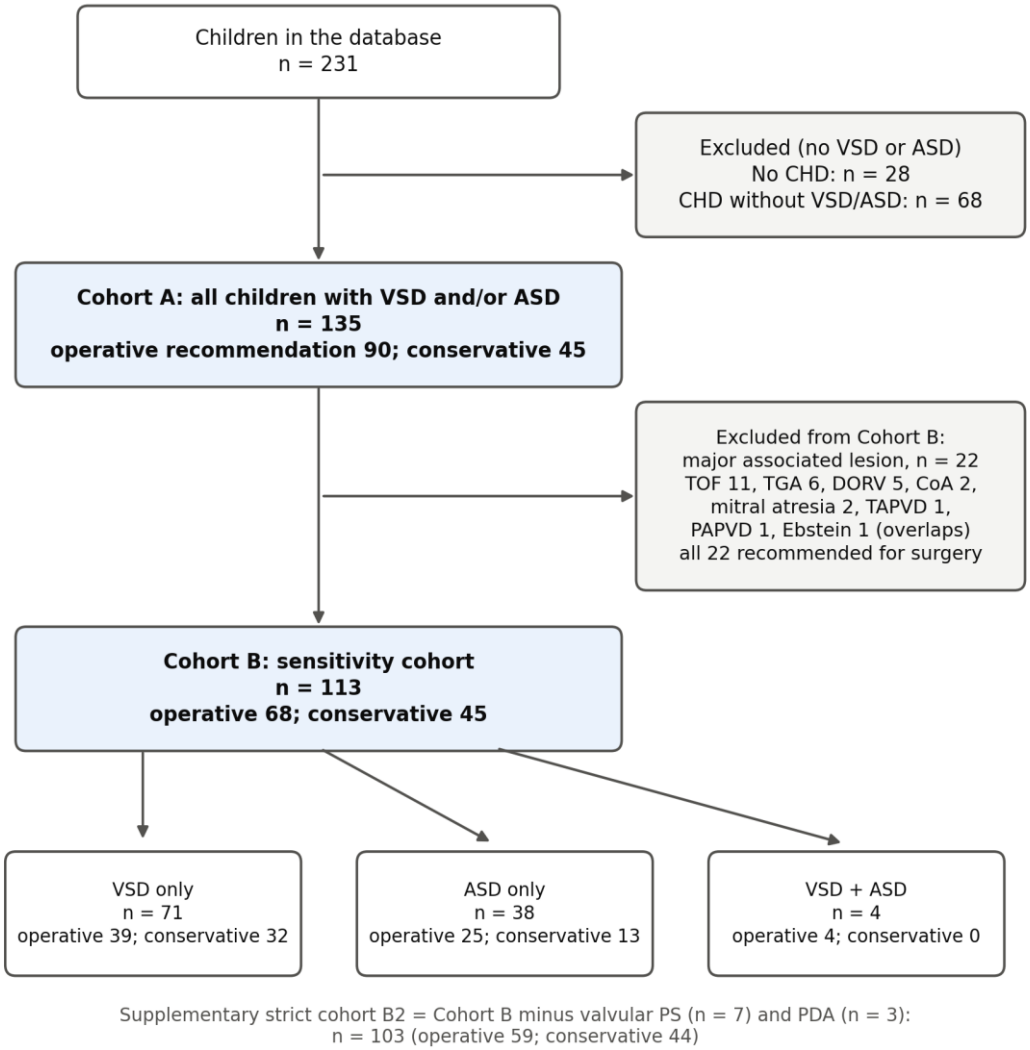

Figure 1. Derivation of the study cohorts (patient selection diagram). CHD, congenital heart disease; CoA, coarctation of the aorta; DORV, double-outlet right ventricle; PAPVD/TAPVD, partial/total anomalous pulmonary venous drainage; PDA, patent ductus arteriosus; PS, pulmonary valve stenosis; TGA, transposition of the great arteries; TOF, tetralogy of Fallot.

Table 1. Baseline clinical and echocardiographic characteristics of children with septal defects according to the recommendation for operative treatment (Cohort A)

Characteristic	Total (n = 135)	Operative (n = 90)	Conservative (n = 45)	p
Demographic and clinical characteristics	Demographic and clinical characteristics	Demographic and clinical characteristics	Demographic and clinical characteristics	Demographic and clinical characteristics
Female sex	66	45	21	0.715
Age group				0.002
1–27 days	1	1	0	

Characteristic	Total (n = 135)	Operative (n = 90)	Conservative (n = 45)	p
28 days–1 year	54	27	27	
1–5 years	61	44	17	
6–11 years	15	14	1	
12–18 years	4	4	0	
Weight, kg	10.2 [7.3–15.8]	11.5 [7.7–19.1]	8.8 [6.1–10.8]	0.002
Height, cm	81.0 [68.0–100.0]	87.5 [70.2–114.2]	72.0 [67.0–86.0]	0.003
BSA, m^2	0.470 [0.377–0.655]	0.536 [0.393–0.780]	0.434 [0.332–0.500]	0.002
Low weight-for-sex category	56	36	20	0.621
Symptoms (cyanosis, dyspnoea and/or fatigue)	44	29	15	0.897
Main recorded complaint				0.180
None	4	1	3	
Cyanosis	7	5	2	
Dyspnoea	22	13	9	
Fatigue	9	5	4	
All of these	6	6	0	
Murmur	87	60	27	
Postnatal intensive care	28	25	3	0.004
Septal anatomy and shunt	Septal anatomy and shunt	Septal anatomy and shunt	Septal anatomy and shunt	Septal anatomy and shunt
Defect configuration				0.092
VSD only	85	53	32	
ASD only	42	29	13	
VSD+ASD	8	8	0	
VSD diameter, mm (n =	4.8 [3.6–6.7]	5.8 [4.4–7.2]	3.8 [3.1–4.8]	<0.001

Characteristic	Total (n = 135)	Operative (n = 90)	Conservative (n = 45)	p
93; 61/32)				
VSD location (children with VSD, n = 93; 61/32)				<0.001
Perimembranous	35	13	22	
Subaortic	36	30	6	
Mid-muscular	17	14	3	
Apical	1	0	1	
Inlet	3	3	0	
Outlet	1	1	0	
ASD diameter, mm (n = 50; 37/13)	8.8 [6.3–11.4]	10.0 [7.6–13.0]	5.5 [4.5–7.3]	<0.001
Shunt direction				0.044
Left-to-right	124	79	45	
Right-to-left	4	4	0	
Bidirectional	7	7	0	
Ventricular loading and haemodynamics	Ventricular loading and haemodynamics	Ventricular loading and haemodynamics	Ventricular loading and haemodynamics	Ventricular loading and haemodynamics
Ventricular status				0.004
Normal	66	38	28	
LV dilated	37	23	14	
RV dilated	32	29	3	
Pulmonary hypertension (recorded)	12	6	6	0.214
Pulmonary valve gradient, mmHg	4.0 [2.0–8.0]	5.0 [2.0–15.0]	4.0 [2.0–5.0]	0.041
Aortic valve gradient, mmHg	2.0 [1.0–4.0]	2.0 [2.0–4.0]	1.2 [1.0–2.8]	0.016

Characteristic	Total (n = 135)	Operative (n = 90)	Conservative (n = 45)	p
Associated lesions	Associated lesions	Associated lesions	Associated lesions	Associated lesions
Major associated structural lesion*	22	22	0	<0.001
PDA	10	10	0	0.030
Pulmonary valve stenosis	22	21	1	0.002
Tricuspid regurgitation	22	18	4	0.099
Mitral regurgitation	5	5	0	0.169
Aortic regurgitation	5	5	0	0.169
Pulmonary regurgitation	8	5	3	1.000

Values are counts, mean ± SD or median [Q1–Q3]. Group comparisons used Student's t-test or Mann–Whitney U test for continuous variables and χ^2 or Fisher's exact test for categorical variables. *Tetralogy of Fallot, double-outlet right ventricle, transposition of the great arteries, coarctation, anomalous pulmonary venous drainage, Ebstein anomaly or mitral atresia. ASD, atrial septal defect; BSA, body surface area; LV, left ventricular; PDA, patent ductus arteriosus; RV, right ventricular; VSD, ventricular septal defect.

3.2. Spectrum of septal defects

VSD alone was present in 85 children, ASD alone in 42, and both defects in 8 (Table 2). Among the 93 children with VSD, the recorded location was perimembranous in 35, subaortic in 36, mid-muscular in 17, inlet in 3, apical in 1 and outlet in 1. Among 50 children with ASD, 49 defects were recorded as secundum and one as coronary sinus type. Neither primum ASD nor atrioventricular septal defect was recorded in this cohort.

Associated findings included pulmonary valve stenosis in 22 children, tricuspid regurgitation in 22, PDA in 10 and recorded pulmonary hypertension in 12. A major associated structural lesion was present in 22 children, and all 22 were recommended for operative treatment. Among children recommended for treatment, a closed procedure was recorded in 20 of 29 with isolated ASD and in 16 of 53 with isolated VSD.

Table 2. Distribution of septal defects, associated cardiac abnormalities and recommended procedure type (Cohort A)

Characteristic	Total (n = 135)	Operative (n = 90)	Conservative (n = 45)
Defect configuration	Defect configuration	Defect configuration	Defect configuration
VSD only	85	53	32
ASD only	42	29	13
VSD+ASD	8	8	0
VSD location (as coded)	VSD location (as coded)	VSD location (as coded)	VSD location (as coded)

Characteristic	Total (n = 135)	Operative (n = 90)	Conservative (n = 45)
Perimembranous	35	13	22
Subaortic	36	30	6
Mid-muscular	17	14	3
Apical	1	0	1
Inlet	3	3	0
Outlet	1	1	0
ASD type (as coded)	ASD type (as coded)	ASD type (as coded)	ASD type (as coded)
Secundum	49	36	13
Coronary sinus	1	1	0
Associated lesions	Associated lesions	Associated lesions	Associated lesions
PDA	10	10	0
Pulmonary valve stenosis	22	21	1
Tricuspid regurgitation	22	18	4
Pulmonary regurgitation	8	5	3
Mitral regurgitation	5	5	0
Aortic regurgitation	5	5	0
Pulmonary hypertension (as recorded)	12	6	6
Tetralogy of Fallot	11	11	0
DORV	5	5	0
TGA	6	6	0
Coarctation of aorta	2	2	0
TAPVD	1	1	0
PAPVD	1	1	0
Ebstein anomaly	1	1	0

Characteristic	Total (n = 135)	Operative (n = 90)	Conservative (n = 45)
Mitral atresia	2	2	0
Critical CHD flag	21	21	0
Any major associated structural lesion*	22	22	0
Recommended procedure type	Recommended procedure type	Recommended procedure type	Recommended procedure type
"Open" operation (code 0)	52	52	0
"Closed" operation (code 1)	38	38	0

Values are counts. A child may have more than one associated lesion. *Children with any major associated structural lesion. The term "closed operation" reflects the original database coding. DORV, double-outlet right ventricle; PAPVD/TAPVD, partial/total anomalous pulmonary venous drainage; TGA, transposition of the great arteries.

3.3. Comparison between treatment groups

Children recommended for operative treatment were generally older and larger than those managed conservatively (Table 1). Median BSA was 0.536 [0.393–0.780] versus 0.434 [0.332–0.500] m^2 ($p = 0.002$), and 62 children in the operative group versus 18 in the conservative group were aged 1 year or older. In children with VSD, defect diameter was larger in the operative group (5.8 [4.4–7.2] vs 3.8 [3.1–4.8] mm; $p < 0.001$). The same pattern was observed in children with ASD (10.0 [7.6–13.0] vs 5.5 [4.5–7.3] mm; $p < 0.001$).

Perimembranous VSD was recorded in 13 children recommended for treatment and 22 children managed conservatively. RV dilatation was recorded in 29 versus 3 children, while LV dilatation did not differ clearly between groups. Right-to-left or bidirectional shunting occurred in 11 children recommended for treatment and in none of the conservatively managed children. Associated pulmonary valve stenosis, PDA and postnatal intensive care were also more frequent in the operative group, largely reflecting the contribution of more complex lesions. Symptoms, sex and recorded pulmonary hypertension did not differ clearly between the two groups.

3.4. Echocardiographic findings in isolated defects

After exclusion of major associated structural lesions, 71 children had isolated VSD (39 recommended for treatment and 32 managed conservatively) and 38 had isolated ASD (25 recommended and 13 conservative); four children with both defects were all recommended for treatment. In isolated VSD, children recommended for treatment had larger defects (5.6 ± 1.6 vs 4.0 ± 1.5 mm; $p < 0.001$), fewer perimembranous defects (9 vs 22), higher BSA (0.532 [0.420–0.779] vs 0.415 [0.329–0.504] m^2; $p = 0.009$), and more children aged 1 year or older (26 vs 12). LV dilatation, recorded pulmonary hypertension and symptoms did not differ clearly between these groups.

In isolated ASD, children recommended for treatment had larger defects (10.6 [8.8–14.0] vs 5.5 [4.5–7.3] mm; $p < 0.001$), more frequent RV dilatation (15 vs 3), higher BSA (0.660 [0.542–0.827] vs 0.448 [0.428–0.476] m^2; $p = 0.004$), and more children aged 1 year or older (23 vs 6). Symptoms were recorded in 16 versus 9 children. No child with isolated ASD had recorded pulmonary hypertension.

Table 3. Clinical and echocardiographic characteristics according to the recommendation for operative treatment in isolated VSD and isolated ASD (Cohort B)

Characteristic	VSD: operative (n = 39)	VSD: conservative (n = 32)	p	ASD: operative (n = 25)	ASD: conservative (n = 13)	p
Demographic and clinical	Demographic and clinical	Demographic and clinical	Demographic and clinical	Demographic and clinical	Demographic and clinical	Demographic and clinical
Female sex	12	13	0.387	16	8	1.000
Age ≥1 year	26	12	0.014	23	6	0.003
BSA, m²	0.532 [0.420–0.779]	0.415 [0.329–0.504]	0.009	0.660 [0.542–0.827]	0.448 [0.428–0.476]	0.004
Symptoms	6	6	0.707	16	9	1.000
Postnatal intensive care	3	3	1.000	1	0	1.000
Defect anatomy	Defect anatomy	Defect anatomy	Defect anatomy	Defect anatomy	Defect anatomy	Defect anatomy
VSD diameter, mm	5.6 ± 1.6	4.0 ± 1.5	<0.001	—	—	—
VSD/aortic annulus ratio	0.457 [0.307–0.617]	0.338 [0.258–0.533]	0.085	—	—	—
Perimembra-nous	9	22	<0.001	—	—	—
ASD diameter, mm	—	—	—	10.6 [8.8–14.0]	5.5 [4.5–7.3]	<0.001
ASD diameter/BSA, mm/m²	—	—	—	16.8 [12.1–25.8]	12.5 [8.4–15.3]	0.103
Loading, shunt and associated findings	Loading, shunt and associated findings	Loading, shunt and associated findings	Loading, shunt and associated findings	Loading, shunt and associated findings	Loading, shunt and associated findings	Loading, shunt and associated findings
LV dilatation	22	14	0.288	—	—	—
RV dilatation	2	0	0.498	15	3	0.031
Right-to-left or bidirectional shunt	3	0	0.247	4	0	0.278

Characteristic	VSD: operative (n = 39)	VSD: conservative (n = 32)	p	ASD: operative (n = 25)	ASD: conservative (n = 13)	p
Pulmonary hypertension (recorded)	3	6	0.282	—	—	—
Tricuspid regurgitation	6	2	0.281	6	2	0.689
Aortic regurgitation	4	0	0.122	—	—	—
Pulmonary valve stenosis	4	1	0.370	1	0	1.000
PDA	2	0	0.498	1	0	1.000

Values are counts, mean ± SD or median [Q1–Q3]. Group comparisons used Student's t-test or Mann–Whitney U test for continuous variables and χ^2 or Fisher's exact test for categorical variables. — not applicable or not present. ASD, atrial septal defect; BSA, body surface area; LV, left ventricular; PDA, patent ductus arteriosus; RV, right ventricular; VSD, ventricular septal defect.

3.5. ROC analysis

In isolated VSD, defect diameter showed moderate discrimination between children with and without a recommendation for operative treatment (AUC 0.770; $p < 0.001$). The data-derived cut-off was ≥4.3 mm. When all children with VSD in Cohort A were included, the AUC was 0.766 and the data-derived cut-off was ≥4.2 mm (Table 4).

In isolated ASD, defect diameter showed stronger discrimination (AUC 0.920; $p < 0.001$), with a data-derived cut-off of ≥8.8 mm. In all children with ASD in Cohort A, the AUC was 0.846, with the same cut-off. These thresholds describe the separation achieved in this dataset and are not intended to replace comprehensive haemodynamic assessment or established clinical decision-making.

Table 4. ROC analysis of defect diameter for discrimination of the recommendation for operative treatment

Parameter	AUC	p	Cut-off
Isolated VSD (Cohort B; 39 operative / 32 conservative)	Isolated VSD (Cohort B; 39 operative / 32 conservative)	Isolated VSD (Cohort B; 39 operative / 32 conservative)	Isolated VSD (Cohort B; 39 operative / 32 conservative)
VSD diameter, mm	0.770	<0.001	≥4.3
All VSD (Cohort A; 61/32)	All VSD (Cohort A; 61/32)	All VSD (Cohort A; 61/32)	All VSD (Cohort A; 61/32)
VSD diameter, mm	0.766	<0.001	≥4.2
Isolated ASD (Cohort B; 25 operative / 13 conservative)	Isolated ASD (Cohort B; 25 operative / 13 conservative)	Isolated ASD (Cohort B; 25 operative / 13 conservative)	Isolated ASD (Cohort B; 25 operative / 13 conservative)

Parameter	AUC	p	Cut-off
ASD diameter, mm	0.920	<0.001	≥8.8
All ASD (Cohort A; 37/13)	All ASD (Cohort A; 37/13)	All ASD (Cohort A; 37/13)	All ASD (Cohort A; 37/13)
ASD diameter, mm	0.846	<0.001	≥8.8

AUC, area under the ROC curve. Cut-offs are data-derived and should be interpreted as exploratory rather than as stand-alone indications for intervention.

4. DISCUSSION

4.1. Principal findings

In this cohort of 135 children with VSD and/or ASD, the variables associated with a recommendation for operative treatment differed according to lesion type. For isolated VSD, larger defect diameter and recorded defect location were the most prominent echocardiographic findings, while in isolated ASD, larger defect diameter and RV dilatation were the clearest findings. Body size and age also differed between treatment groups. The ROC analyses showed moderate discrimination for VSD diameter and stronger discrimination for ASD diameter, but the thresholds were generated from the same dataset and should be regarded as exploratory rather than prescriptive.

4.2. VSD diameter, location and the likelihood of intervention

The association between larger VSD diameter and a recommendation for treatment is physiologically plausible and is consistent with contemporary literature. Modern reviews continue to emphasise that VSD management depends on the magnitude of left-to-right shunting, chamber loading, pulmonary pressure, growth and symptoms rather than on diameter alone [13]. A recent population-based neonatal study found that nearly nine of ten VSDs identified in unselected newborns closed during the first year of life; smaller size, muscular location and absence of multiple defects were associated with spontaneous closure [14]. These observations support the idea that anatomical size is informative, but only within the context of location and haemodynamic effect.

4.3. VSD treatment options and anatomical context

The current interventional landscape also illustrates why a single diameter threshold cannot serve as a universal indication. Transcatheter and hybrid approaches are increasingly reported for selected perimembranous and other VSDs, including in small children, but patient selection remains strongly anatomy-dependent [12,15–21]. Recent studies have focused on the relationship between defect morphology, device choice, body weight, residual shunt, aortic valve complications and procedural outcomes [15–19]. A large comparative cohort from Kazakhstan also found that a hybrid off-pump strategy can be effective in selected children when compared with traditional surgical closure [20]. Thus, the present finding that defect location contributed additional information beyond diameter is clinically coherent. The lower proportion of perimembranous defects in our operative group should, however, be interpreted cautiously because the source database used local location categories and did not include standardised documentation of aortic cusp prolapse or the precise relation of each defect to the conduction system.

4.4. ASD diameter and right-heart volume loading

In isolated ASD, defect diameter had stronger discrimination than in VSD, and RV dilatation was more frequent among children recommended for treatment. This pattern is consistent with the physiology of a chronic atrial-level left-to-right shunt, for which right-heart volume loading is a central echocardiographic consequence. Population-based neonatal data have shown larger RV dimensions and atrial volumes in infants with ASD within the first month after birth [25]. A recent neonatal natural-history study further demonstrated that spontaneous closure and the need for ongoing follow-up depend on defect size and gestational maturity [24]. Accordingly, defect diameter in ASD is best interpreted together with right-heart remodelling and the clinical context.

4.5. ASD closure and ventricular remodelling

Recent paediatric intervention studies also support the importance of chamber loading in ASD assessment. Multicentre prospective data have documented changes in ventricular performance after surgical and percutaneous ASD closure [22], while paediatric series have reported favourable mid-term outcomes after transcatheter closure [23]. Newer echocardiography-guided strategies, including closure of anatomically challenging or oval defects, continue to expand the procedural spectrum [26,27]. A 2025 meta-analysis comparing surgical and transcatheter closure in paediatric secundum ASD found similar closure efficacy overall but differences in complication profiles and hospital stay [28]. These studies do not validate the 8.8-mm threshold found in our dataset; rather, they reinforce that anatomy, body size, chamber response and procedural suitability should be considered together.

4.6. Body size and standardisation of paediatric measurements

Children recommended for treatment had higher BSA in both isolated VSD and isolated ASD analyses. This is likely related partly to the timing of referral and intervention, but it also highlights a measurement problem: the same absolute dimension has a different physiological meaning in a small infant and an older child. Contemporary paediatric echocardiography guidance recommends systematic quantitative assessment [6], and z-score literature shows that different normalisation models may produce meaningful differences, particularly at the extremes of body size [7,8]. Newer multicentre equations that account for body size, body mass index and age may further improve standardisation [9]. The lack of z-scores in our source database therefore limits interpretation of absolute chamber and vessel dimensions and supports the use of standardised indexed reporting in future studies.

4.7. Haemodynamics and additional imaging

Recorded pulmonary hypertension was uncommon and did not clearly distinguish the treatment groups. This finding should not be interpreted as evidence that pulmonary haemodynamics are unimportant. The source database did not provide a standardised quantitative definition for pulmonary hypertension or consistently recorded measures such as tricuspid regurgitation velocity, estimated RV systolic pressure, Qp:Qs or pulmonary vascular resistance. Current imaging guidance emphasises comprehensive TTE and the selective use of additional imaging when anatomy or haemodynamics cannot be resolved adequately by routine echocardiography [6,11]. In children with suspected advanced pulmonary vascular disease, treatment decisions require dedicated haemodynamic assessment rather than a categorical database label.

4.8. Clinical interpretation of the ROC-derived cut-offs

The cut-offs of ≥4.3 mm for isolated VSD and ≥8.8 mm for isolated ASD should be viewed as dataset-specific discrimination points, not as intervention criteria. They were selected after observing outcomes in a single dataset and were not validated in an independent cohort. Their apparent performance may also reflect local referral patterns, the age distribution of the sample, body size and the presence of unmeasured clinical variables. Contemporary literature on septal defect closure repeatedly emphasises patient selection rather than isolated diameter thresholds [12,13,23,28]. A practical use of the present results is therefore to identify measurements that deserve closer attention during a complete echocardiographic and clinical assessment, not to replace multidisciplinary judgement.

4.9. Relevance to resource-constrained settings

The study also has relevance for settings in which access to paediatric cardiac intervention is limited. International work from middle-income and resource-constrained environments has shown that infrastructure, specialist availability, referral systems and treatment capacity influence which children receive timely congenital cardiac care [3–5]. In such settings, structured echocardiographic reporting may help make referral decisions more transparent and reproducible. However, resource prioritisation should not lead to oversimplified decision rules: the strongest approach remains a lesion-specific assessment integrating anatomy, ventricular loading, symptoms, pulmonary haemodynamics, age, body size and associated lesions.

4.10. Strengths and directions for future research

A strength of the present analysis is that VSD and ASD were not treated as a single physiological entity in the principal defect-specific comparisons. Excluding major associated structural lesions reduced the extent to which an independent surgical indication could dominate the relationship between routine echocardiographic findings and treatment recommendation. The study also retained a broad range of routinely available clinical and echocardiographic variables, which

reflects the type of information commonly available in everyday paediatric practice. At the same time, the results identify specific priorities for a prospective validation study. Future cohorts should record exact age, weight, height and body surface area at the time of each examination; use a prespecified paediatric TTE acquisition protocol; document the imaging view and cardiac-cycle phase used for defect measurement; report chamber and vessel dimensions as z-scores; and quantify shunt and pulmonary haemodynamics whenever technically feasible [6–9]. For VSD, future work should capture aortic cusp prolapse, aortic regurgitation severity, VSD-to-aortic-annulus ratio and quantitative LV volume loading. For ASD, standardized RV dimensions, right atrial volume, septal rims and indexed defect size should be recorded. Treatment decisions should also be classified explicitly as surgical closure, transcatheter closure, hybrid intervention or observation rather than using a generic operative label [12]. Prospective multicentre validation with prespecified thresholds, blinded outcome adjudication and follow-up of actual interventions would help determine whether the associations found here remain stable across institutions and patient populations.

5. LIMITATIONS

This study has several limitations. First, it was based on a pre-existing clinical database and the source manuscript did not contain the exact study period, study centre, echocardiography equipment or a uniform acquisition protocol. Second, exact age was unavailable and had to be analysed in categories. Third, ventricular dilatation and pulmonary hypertension were categorical examiner-recorded variables without standardised quantitative definitions. Fourth, z-scores were unavailable, limiting body-size-adjusted interpretation of chamber and great-vessel measurements. Fifth, the method used to measure defect diameter was not standardised in the dataset, and interobserver variability could not be assessed. Sixth, the treatment recommendation may have incorporated clinical information not captured in the database, creating the possibility of residual confounding. Seventh, the ROC cut-offs were derived and tested in the same cohort, so optimism and overfitting are possible. Finally, this was not an outcomes study: the analysis describes factors associated with a treatment recommendation and does not establish that the recommendation, or any identified threshold, improves clinical outcomes. External validation in prospectively characterised paediatric cohorts is required.

6. CONCLUSION

In children with isolated septal defects, defect diameter was the echocardiographic measurement most closely associated with a recommendation for operative treatment in this dataset. Discrimination was moderate for VSD and stronger for ASD. VSD location, age and body size provided additional context, while RV dilatation was an important associated finding in ASD. These results support a structured lesion-specific echocardiographic assessment in which defect size is interpreted together with chamber loading, haemodynamics, body size and associated anatomy. The proposed cut-offs are exploratory, dataset-specific markers and should complement, not replace, comprehensive clinical assessment and multidisciplinary decision-making.

Acknowledgments

The authors have no non-author contributors to acknowledge.

Funding

The authors received no external funding for this study.

Conflicts of Interest

The authors declare no conflicts of interest.

REFERENCES

[1] Zhang X, Feng Y, Ren J, Jin X, Li J, Hou Y, et al. Global, regional, and national burden of congenital heart disease, 1990–2021: a systematic analysis for the Global Burden of Disease Study 2021. Eur J Pediatr. 2025;184(4):253. https://doi.org/10.1007/s00431-025-06085-w

[2] Deng L, Li Q, Cheng Z. Evaluating the global, regional, and national burden of congenital heart disease in infants younger than 1 year: a 1990–2021 systematic analysis for the GBD Study 2021. Front Pediatr. 2025;13:1467914. https://doi.org/10.3389/fped.2025.1467914

[3] Hasan BS, Bhatti A, Mohsin S, Barach P, Ahmed E, Ali S, et al. Recommendations for developing effective and safe paediatric and congenital heart disease services in low-income and middle-income countries: a public health framework. BMJ Glob Health. 2023;8(5):e012049. https://doi.org/10.1136/bmjgh-2023-012049

[4] Cheng SPS, Heo K, Joos E, Vervoort D, Joharifard S. Barriers to accessing congenital heart surgery in low- and middle-income countries: a systematic review. World J Pediatr Congenit Heart Surg. 2024;15(1):94–103. https://doi.org/10.1177/21501351231204328

[5] Wamala I, Gongwer R, Doherty-Schmeck K, Jorina M, Betzner A, Zheleva B, et al. Infrastructure availability for the care of congenital heart disease patients and its influence on case volume, complexity and access among healthcare institutions in 17 middle-income countries. Glob Heart. 2021;16(1):75. https://doi.org/10.5334/gh.968

[6] Lopez L, Saurers DL, Barker PCA, Cohen MS, Colan SD, Dwyer J, et al. Guidelines for performing a comprehensive pediatric transthoracic echocardiogram: recommendations from the American Society of Echocardiography. J Am Soc Echocardiogr. 2024;37(2):119–170. https://doi.org/10.1016/j.echo.2023.11.015

[7] Lopez L, Frommelt PC, Colan SD, Trachtenberg FL, Gongwer R, Stylianou M, et al. Pediatric Heart Network echocardiographic Z scores: comparison with other published models. J Am Soc Echocardiogr. 2021;34(2):185–192. https://doi.org/10.1016/j.echo.2020.09.019

[8] Cantinotti M, Scalese M, Danford D, Kutty S. Reference standards in quantitative pediatric echocardiography: a guide to the nuanced world of Z scores and nomograms. J Am Soc Echocardiogr. 2023;36(3):324–326. https://doi.org/10.1016/j.echo.2022.12.003

[9] Lauzon-Schnittka J, Plante V, Dahdah N, Greenway SC, Drolet C, Wong K, et al. Z scores for pediatric echocardiography dimensions adjusted for body size, BMI, and age. Circ Cardiovasc Imaging. 2025;18(8):e017944. https://doi.org/10.1161/CIRCIMAGING.124.017944

[10] Dorobantu DM, Amir NH, Wadey CA, Sharma C, Stuart AG, Williams CA, et al. The role of speckle-tracking echocardiography in predicting mortality and morbidity in patients with congenital heart disease: a systematic review and meta-analysis. J Am Soc Echocardiogr. 2024;37(2):216–225. https://doi.org/10.1016/j.echo.2023.11.003

[11] Krishnamurthy R, Suman G, Chan SS, Kirsch J, Iyer RS, Bolen MA, et al. ACR Appropriateness Criteria® congenital or acquired heart disease. J Am Coll Radiol. 2023;20(11S):S351–S381. https://doi.org/10.1016/j.jacr.2023.08.018

[12] Turner ME, Bouhout I, Petit CJ, Kalfa D. Transcatheter closure of atrial and ventricular septal defects: JACC Focus Seminar. J Am Coll Cardiol. 2022;79(22):2247–2258. https://doi.org/10.1016/j.jacc.2021.08.082

[13] Rao PS. Diagnosis and management of ventricular septal defects. Rev Cardiovasc Med. 2024;25(11):411. https://doi.org/10.31083/j.rcm2511411

[14] Pihl C, Sillesen AS, Norsk JB, Vøgg ROB, Vedel C, Boyd HA, et al. The prevalence and spontaneous closure of ventricular septal defects the first year of life. Neonatology. 2024;121(6):742–751. https://doi.org/10.1159/000538810

[15] Xie L, Zhang G, He J, Shen Y, Liao D, Chen L, et al. Transthoracic device closure of perimembranous ventricular septal defect via a small left intercostal incision in children. Front Cardiovasc Med. 2023;10:1221136. https://doi.org/10.3389/fcvm.2023.1221136

[16] Yildiz K, Narin N, Oksuz S, Ozdemir R, Pamukcu O, Baykan A, et al. Safety and efficacy of Amplatzer duct occluder II and Konar-MF™ VSD occluder in the closure of perimembranous ventricular septal defects in children weighing less than 10 kg. Front Cardiovasc Med. 2023;10:1255808. https://doi.org/10.3389/fcvm.2023.1255808

[17] Godart F, Baudelet JB, Delarue A, Polge AS, Domanski O, Bichali S, et al. Transcatheter closure of perimembranous ventricular septal defects including multifenestrated and Gerbode-type defects using the Lifetech Konar device. J Clin Med. 2023;12(19):6370. https://doi.org/10.3390/jcm12196370

[18] Elmarsafawy H, Hafez M, Alsawah GA, Bakr A, Rakha S. Long-term outcomes of percutaneous closure of ventricular septal defects in children using different devices: a single-centre experience from Egypt. BMC Pediatr. 2023;23(1):381. https://doi.org/10.1186/s12887-023-04194-9

[19] Laha S, Gangopadhyay D, Roy M, Singh A, Nandi D, Dutta J. Procedural outcomes of percutaneous closure of perimembranous and other ventricular septal defects using Konar-MF occluder and short-term follow-up. Ann Pediatr Cardiol. 2024;17(2):101–108. https://doi.org/10.4103/apc.apc_201_23

[20] Adilbekova A, Marassulov S, Baigenzhin A, Kozhakhmetov S, Nurkeyev B, Kerimkulov A, et al. Hybrid versus traditional method closure of ventricular septal defects in children. JTCVS Tech. 2024;24:137–144. https://doi.org/10.1016/j.xjtc.2024.01.015

[21] Yu J, Liufu R, Wang X, Liu X, Zhuang J. Midterm results comparing perventricular device closure with surgical repair for isolated congenital ventricular septal defects: a systematic review and meta-analysis. Rev Cardiovasc Med. 2022;23(8):262. https://doi.org/10.31083/j.rcm2308262

[22] van der Ven JPG, van den Bosch E, Kamphuis VP, Terol C, Gnanam D, Bogers AJJC, et al. Functional echocardiographic and serum biomarker changes following surgical and percutaneous atrial septal defect closure in children. J Am Heart Assoc. 2022;11:e024072. https://doi.org/10.1161/JAHA.121.024072

[23] Özbay YŞ, Eker R, Dindar A, Aydoğan Ü, Nişli K. Transcatheter closure of atrial septal defect in children: single-center experience, mid-term follow-up results. Turk Arch Pediatr. 2022;57(4):406–412. https://doi.org/10.5152/TurkArchPediatr.2022.21307

[24] Heidari N, Kumaran K, Pagano JJ, Hornberger LK. Natural history of secundum ASD in preterm and term neonates: a comparative study. Pediatr Cardiol. 2024;45(4):710–721. https://doi.org/10.1007/s00246-023-03403-7

[25] Dehn AM, Dannesbo S, Sellmer A, Høffner L, Blixenkrone-Møller E, Sillesen AS, et al. Atrial septal defect: larger right ventricular dimensions and atrial volumes as early as in the first month after birth—a case-control study including 716 neonates. Pediatr Cardiol. 2023;44(7):1578–1586. https://doi.org/10.1007/s00246-023-03211-z

[26] Siagian SN, Tandayu KMH Jr, Reno P, Mendel B, Christianto C, Prakoso R. Echocardiography-guided percutaneous closure of oval-shaped secundum atrial septal defects. BMC Cardiovasc Disord. 2024;24(1):534. https://doi.org/10.1186/s12872-024-04165-7

[27] Lwin N, Suursalmi P, Yong S, Kabir S, Jones MI, Savis A, et al. Fluoroscopy-free transcatheter atrial septal defect closure: a simplified approach. Curr Cardiol Rep. 2025;27(1):59. https://doi.org/10.1007/s11886-024-02177-5

[28] de Liyis BG, Kosasih AM, Jagannatha GNP, Dewangga MSY. Complications and efficacies of surgical versus transcatheter closure for pediatric ostium secundum atrial septal defect: a meta-analysis. J Endovasc Ther. 2025;32(6):1906–1919. https://doi.org/10.1177/15266028241245599