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Systematic Review

A Systematic Review and Meta-Analysis of the Valvular Insufficiency Status after Surgical Closure of Ventricular Septal Defects

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Abstract

Objective: This article aims to provide a reference for assessing surgical safety by comparing postoperative outcomes of various degrees of valve insufficiency associated with different surgical approaches after ventricular septal defect (VSD) repair. **Methods**: We conducted a database search using the following methods: querying the PubMed database through National Center for Biotechnology Information (NCBI), querying the Embase database through Ovid, and querying the Web of Science database. This article focused on comparing the improvement in aortic regurgitation (AR), analyzing the incidence of tricuspid regurgitation (TR) following exposure of the VSD through a right atrial approach using tricuspid valve detachment (TVD) or conventional exposure (non-TVD), and pulmonary regurgitation (PR) via a pulmonary artery approach. **Results**: AR was included in nine studies, involving 329 children with VSDs. The combined improvement rate of AR across these studies was approximately 0.487 (I^2 = 50.3%; p = 0.041). The proportion of patients who underwent aortic valve repair or replacement (p = 0.029) and the preoperative severity of AR $\geq$ moderate (p = 0.007) may have contributed to heterogeneity. There were 245 cases in the isolated VSD repair group, while the remaining 84 cases underwent combined aortic valve repair or replacement. There was a significant difference in the improvement rate of AR between the two groups during follow-up (I^2 = 63.3%, Relative Risk (RR) = 0.51, 95% CI = 0.34–0.76, p = 0.005). RR: The ratio of the probability of the outcome event occurring in the exposed group to the probability of the outcome event occurring in the unexposed group. A total of 12 studies were related to TR and residual shunting. A total of 1338 children with VSD were included in 10 studies of TR, where the TVD group had 599 cases and the non-TVD group had 739 cases. No significant difference was noted in the rates of TR $\geq$ mild between these groups during the follow-up (I^2 = 14.4%, RR = 1, 95% CI = 0.82–1.21; p = 0.311). Additionally, no significant difference existed in the residual shunting rate through the ventricular septum during follow-up (I^2 = 0.0%, RR = 0.72, 95% CI = 0.37–1.40; p = 0.785). A total of 285 children were included in three studies on PR, with a combined rate of PR during follow-up of 23.0% (I^2 = 46.567%; p = 0.154). **Conclusion**: The improvement rate of AR during follow-up was lower in the isolated VSD-repair group compared to the group undergoing concomitant aortic valve repair or replacement. The proportion of preoperative AR $\geq$ moderate showed a positive correlation with the improvement rate of AR, whereas the percentage of isolated VSD repairs exhibited a negative correlation with AR. Additionally, the TR status during follow-up was similar between the TVD and non-TVD groups for VSD repair. Furthermore, patients who underwent VSD repair via the pulmonary artery approach had a higher incidence of PR in the long term. **The PROSPERO Registration**: CRD42025630254 (https://www.crd.york.ac.uk/PROSPERO/view/CRD42025630254).

Keywords

ventricular septal defect; aortic insufficiency; tricuspid insufficiency; pulmonary insufficiency; meta-analysis

Introduction

Congenital heart disease is a common condition, present in approximately 1% of live-born infants, with ventricular septal defects (VSDs) being one of the most prevalent congenital heart defects. Of these, double-committed subarterial ventricular septal defects (DCSA VSDs) account for about 10–30% [1]. Different surgical approaches are chosen for the repair of VSDs based on the location, including the right atrial approach and the pulmonary artery approach. Moreover, it is essential to consider that incomplete repair through various approaches may impact the closure function of surrounding valves, as well as assess the effectiveness of VSD repair [2].

Firstly, one of the most common complications associated with a VSD is aortic regurgitation (AR), which has an incidence of approximately 2.5%–7% in the United States and 8.2% in Japan [3]. The current international consen-

sus recommends the early management of VSDs to prevent the progression of AR. However, limited literature exists that has analyzed the long-term outcomes regarding the improvement of AR in patients with VSDs undergoing isolated repair versus those undergoing combined aortic valve repair or replacement. Therefore, this paper aims to summarize and analyze existing research findings to enhance the investigation into this issue further.

Secondly, advancements in tricuspid valve surgical techniques have shown the effectiveness of tricuspid valve detachment (TVD) as an innovative instrument to expose VSD. However, given that the sample sizes of individual studies are limited, there is a risk of obtaining negative results for tricuspid regurgitation (TR) during postoperative follow-up. Therefore, summarizing these findings remains essential to provide necessary evidence regarding the long-term efficacy of TVDs.

Finally, the standard surgical route for patients with upper VSDs, such as DCSA VSD, is through pulmonary artery incision [4,5]. However, compared to the common occurrence of pulmonary regurgitation (PR) following complete repair of tetralogy of Fallot, little attention has been paid to the potential damage to the pulmonary valve ring from downward traction during the repair of isolated VSD via pulmonary artery incision. Thus, this study will also report the incidence of PR in patients who underwent repair of DCSA VSD through the pulmonary artery approach, along with postoperative follow-up statistics.

Methods

The review adhered to and complied with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [6,7] and has been registered in the PROSPERO public database (CRD42025630254).

Literature Search Strategy

Two independent researchers conducted a literature search in the PubMed (MEDLINE), Web of Science, and Embase databases for studies published in English from the starting date to October 2024. The search terms used were as follows: ventricular septal defect, double-committed subarterial ventricular septal defect, aortic regurgitation, tricuspid regurgitation, pulmonary regurgitation, infracristal ventricular septal defect, and infundibular ventricular septal defect. The specific literature search process is outlined in **Supplementary Data 1**. From the search results, studies were identified that reported on the surgical repair of a VSD and outcomes related to valve regurgitation. Further examination was conducted to include articles that met the inclusion criteria in the reference list. A third researcher was employed to list the excluded articles, along with the reasons for their exclusion (Samples that do not meet the following inclusion criteria).

Study Characteristics

Inclusion criteria for the meta-analysis are as follows:

(1) Provision of demographic data and comorbid conditions of the patients (including country, age $\leq$18 years, gender, weight, and follow-up duration).
(2) Preoperative diagnosis of VSD confirmed by transthoracic echocardiography (TTE) or transesophageal echocardiography (TEE).
(3) Comparison of TVD and non-TVD in retrospective cohort studies, with at least 10 patients in each group.
(4) Provision of at least one primary outcome measure (rate of AR progression during follow-up, postoperative TR, and residual shunting of VSD repair, as well as rate of pulmonary regurgitation (PR) during follow-up).

To maintain consistency and reduce the impact of technological variations on the heterogeneity of results in the meta-analysis, studies employing different approaches for repairing VSDs should try to be consistent across different publication years. Furthermore, literature published and identified through various search routes was excluded to eliminate potential duplicate events related to the same population.

Study Selection, Data Extraction, and Outcome Measures

Two reviewers (LL and MHZ) independently screened the titles, abstracts, and full texts of the articles. For articles with discrepancies in content and types, a third reviewer (AJL) was designated to resolve the issues, and eligible literature was integrated into a literature management system. The extracted data were then compiled into a pre-designed Excel spreadsheet.

The extracted data included:

(1) Demographic information: study year, sample size, country, age at operation, and weight.
(2) Types and number of VSD, preoperative and follow-up echocardiographic assessment of valve regurgitation (AR, TR, PR), presence of residual shunts, follow-up duration, and subgroup patient counts (based on whether aortic valve repair or replacement was performed, or whether TVD was used for VSD repair).
(3) Cases of death during the follow-up period were not included, and cases aged $>$18 years at the time of surgery were not included.

The main results included:

(1) The improvement rate of AR during follow-up in the isolated VSD repair group compared to the group with combined aortic valve repair or replacement (the im-

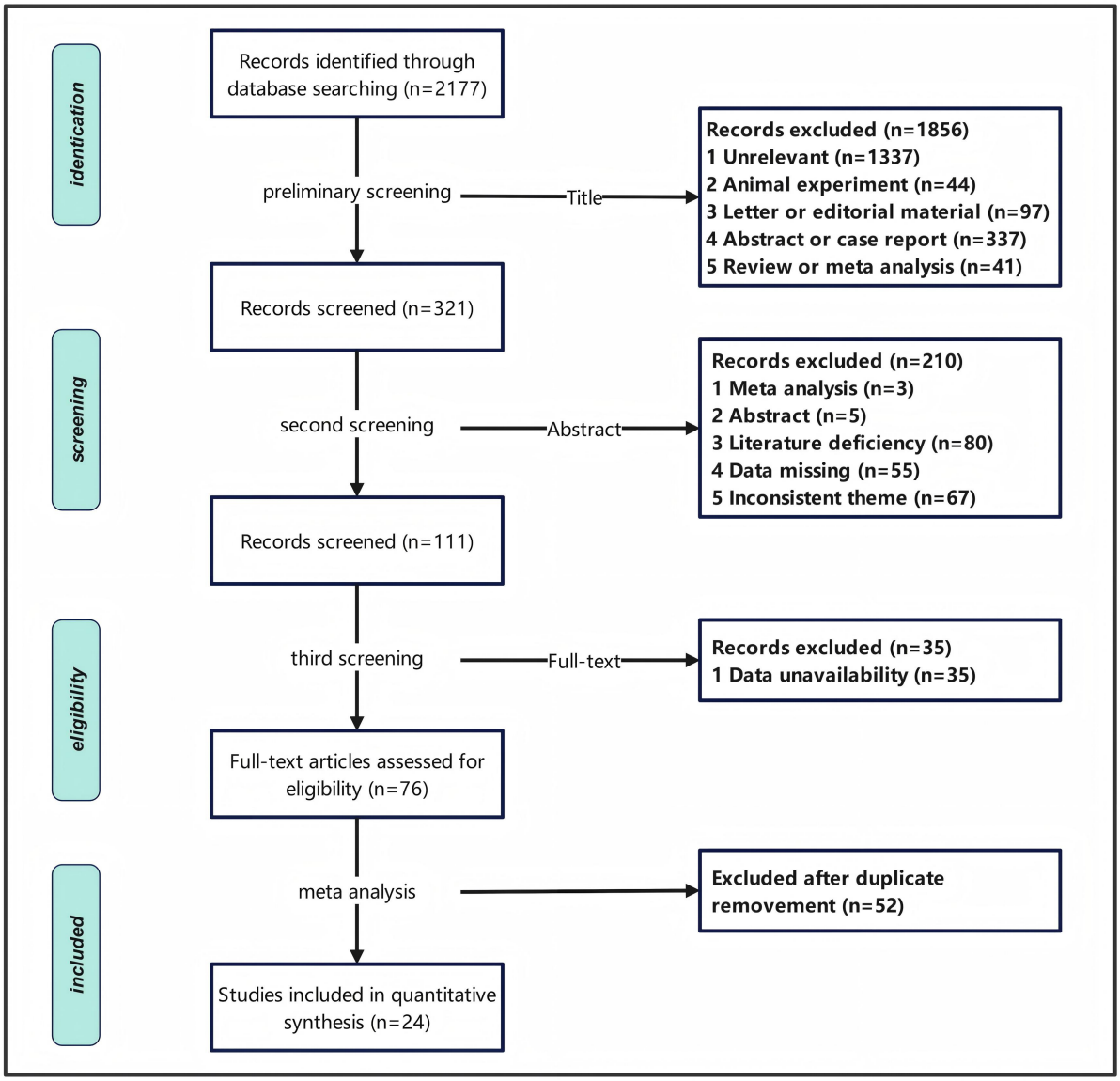

Fig. 1. Flowchart of literature selection.

provement rate was defined as the ratio of patients with a reduction in the echocardiographic degree of aortic regurgitation compared to preoperative levels to the total sample size of each group, excluding those with no change or worsening of AR).

(2) A comparison of the incidence of tricuspid regurgitation (TR $\geq$ mild, assessed by TTE or TEE with a grade $\geq$1) during follow-up between the TVD and non-TVD groups following VSD repair.

(3) A comparison of the incidence of pulmonary regurgitation (PR $\geq$ moderate, assessed by TTE or TEE with a grade $\geq$3) during follow-up following VSD repair via the pulmonary artery incision.

Secondary results included:

(1) The overall improvement rate of AR after VSD repair combined with aortic valve incompetence, and the analysis of influencing factors on the AR improvement rate.

(2) A comparison of the incidence of residual shunting (assessed by TTE or TEE with $>$2 mm residual shunt) during follow-up between the TVD and non-TVD groups after VSD repair.

Quality Assessment

This study comprised 24 articles, including 11 case series and 13 case–control studies. We used the Newcastle–Ottawa scale (NOS) to evaluate case–control studies, with studies scoring $>$6 stars considered high-quality literature [8–10]. Additionally, we employed 18 validated assessment tools to assess the case series studies [11], with scores of $\geq$14 regarded as high-quality literature.

Table 1. Study characteristics.

No.	First author (year)	Geographic location (country)	Selection reason	Study type	Quality	Sample number	Age (years)	Weight (kg)	Follow-up (years)	With DCSA VSD	Preparation AR grade ≥ moderate proportion	Simple VSD repair proportion
1	K. A. Hallidie-Smith 1969 [12]	Britain	AR	Case series	14	14	5.265	NR	NR	N	0.786	0.929
2	R. J. Moreno-Cabral 1977 [13]	America	AR	Case series	14	17	4.444	NR	6.060	Y	0.529	0.529
3	P. P. Karpawich 1981 [3]	America	AR	Case series	14	22	4.194	NR	3.000	N	0.500	0.409
4	R. Brauner 1995 [14]	Israel	AR	Case series	15	23	2.963	NR	NR	Y	0.174	0.652
5	H. Komai 1997 [15]	Japan	AR	Case series	15	27	2.708	15.000	3.000	Y	0.074	0.926
6	H. Tomita 2001 [16]	Japan	AR	Case series	15	12	4.231	NR	4.920	Y	1.000	0.250
7	Y. F. Cheung 2002 [17]	China	AR	Case series	15	56	2.233	NR	3.555	Y	0.250	0.696
8	R. Aeba 2003 [18]	Japan	TR	Case–control	7 stars	87	0.675	6.201	2.833	Y	NR	NR
9	L. Sasson 2006 [19]	Israel	RS	Case–control	7 stars	179	2.650	NR	NR	N	NR	NR
10	H. M. Russell 2011 [20]	America	TR	Case–control	7 stars	366	1.691	9.591	3.478	N	NR	NR
11	Shao-Ju Chien 2011 [5]	China	PR	Case–control	7 stars	77	4.758	18.200	10.000	Y	NR	NR
12	Y. J. Lin 2012 [21]	China	TR	Case–control	7 stars	177	6.860	20.268	6.794	Y	NR	NR
13	A. Weymann 2013 [22]	Germany	TR	Case–control	7 stars	35	0.500	NR	1.250	N	NR	NR
14	P. J. Devlin 2014 [23]	America	PR	Case series	14	70	3.900	13.700	4.900	Y	NR	NR
15	M. U. Riaz 2017 [24]	Pakistan	RS	Case–control	7 stars	236	11.617	NR	NR	N	NR	NR
16	C. D. Fraser 2018 [25]	America	TR	Case–control	7 stars	166	0.663	NR	5.980	N	NR	NR
17	K. K. Pourmoghadam 2018 [26]	America	TR	Case–control	7 stars	130	0.424	5.226	2.155	N	NR	NR

Table 1. Continued.

No.	First author (year)	Geographic location (country)	Selection reason	Study type	Quality	Sample number	Age (years)	Weight (kg)	Follow-up (years)	With DCSA VSD	Preparation AR grade ≥ moderate proportion	Simple VSD repair proportion
18	Ç. Bilen 2020 [27]	Turkey	TR	Case–control	7 stars	170	2.029	10.150	2.971	N	NR	NR
19	J. Schittek 2021 [28]	Germany	TR	Case–control	7 stars	40	0.900	6.800	2.500	N	NR	NR
20	V. Amaral 2021 [29]	China	AR	Case series	16	86	8.300	NR	18.900	Y	0.128	0.895
21	T. Waqar 2021 [30]	India	AR	Case series	15	72	6.750	29.040	2.229	Y	0.236	0.764
22	A. Ashry 2023 [31]	Britain	TR	Case–control	7 stars	50	0.519	5.505	3.000	N	NR	NR
23	M. Çelik 2023 [32]	Turkey	TR	Case–control	7 stars	117	0.374	5.594	1.022	N	NR	NR
24	K. Miwa 2023 [33]	Japan	PR	Case series	16	138	2.080	11.178	5.000	Y	NR	NR

AR, aortic regurgitation; TR, tricuspid regurgitation; PR, pulmonary regurgitation; DCSA VSD, double committed subarterial ventricular septal defect; N, no; Y, yes; NR, not reported.

Meta-Analysis

Baseline data are presented using the mean. For the statistical treatment of the incidence rates of valve regurgitation, a replacement of 1/4 times the sample size was applied for zero event incidence rates to avoid division by zero, thus making the statistical calculation of incidence rates feasible. In contrast to studies that reported zero events, those that did not mention whether events occurred were excluded from the analysis.

We performed the meta-analysis using Stata version 18 (Stata Corp, Belmont, CA, USA), assessing the presence of publication bias through funnel plots, Egger's test, and Begg's test. After statistically analyzing the data from the three categories of eligible studies, we employed a random-effects model to estimate the improvement rate in aortic regurgitation, the incidence rate of pulmonary regurgitation, and the incidence rates of tricuspid regurgitation and residual shunts. Considering that this study investigates the improvement rates or incidence rates of regurgitation in each heart valve, the relative risk (RR) was selected to represent the results. The I^2 statistic was used to indicate the degree of heterogeneity; $I^2 > 50\%$ was considered indicative of significant heterogeneity. A two-sided significance level of 5% was used to determine statistical significance. If significant publication bias was detected, the trim and fill method was used to account for potential missing studies.

Results

Included Studies

A total of 2177 articles were retrieved from the electronic database based on the search criteria. Initially, 1856 articles were excluded based on their titles, with reasons including irrelevance to the topic, animal studies, letters or editorial materials, abstracts or case reports, and reviews or meta-analyses, leaving 321 articles. Subsequently, 210 articles were further excluded based on their abstracts, resulting in 111 articles, for reasons such as second screening of meta-analyses or abstracts, missing literature, missing data, or topic irrelevance. Then, 35 articles were excluded based on full-text content, primarily due to useless data, leaving 76 articles. Finally, 52 duplicate articles were removed in the direction of AR, resulting in 24 articles that were included for both qualitative and quantitative analyses (Fig. 1).

Study Characteristics

A total of 24 studies involving 2367 patients were included to investigate the improvement rates or incidence of AR (9 studies), TR and residual shunt (12 studies), and PR (3 studies) following surgical intervention for VSD (Table 1; Ref. [3,5,12–33]). The average age of the patients ranged from 0.374 years to 11.617 years, with an average follow-up duration ranging from 1.022 years to 18.9 years. In the nine studies focusing on AR, the proportion of patients with preoperative AR $\geq$ moderate ranged from 0.074 to 1.0, while the proportion of patients undergoing isolated VSD repair ranged from 0.409 to 0.926.

Main Outcomes

AR Improvement During Follow-up

In a meta-analysis involving nine studies on the postoperative follow-up of patients with VSDs, the improvement rate of AR was evaluated, including 245 patients in the isolated VSD repair group and 84 patients in the group undergoing concomitant aortic valve repair or replacement. The analysis revealed significant heterogeneity in the AR improvement rates ($I^2 = 63.3\%$; $p = 0.005$), with an overall the relative risk (RR) of 0.51 (95% CI: 0.34, 0.76) (Fig. 2a). The improvement rate of AR in the isolated VSD repair group was lower than in the group with concomitant aortic valve repair or replacement. A subgroup analysis based on the inclusion of patients with DCSA VSD showed that the DCSA subgroup had an I^2 of 0%, while the non-DCSA subgroup had an I^2 of 79.5% (Fig. 3), suggesting that the presence of DCSA VSD patients may contribute to the observed heterogeneity.

TR $\geq$ Mild During Follow-up

A meta-analysis of 10 studies on patients undergoing a postoperative follow-up for VSDs revealed no significant difference in the incidence of TR $\geq$ mild ($I^2 = 14.4\%$; $p = 0.311$) between the 599 patients in the TVD group and the 739 patients in the non-TVD group (Fig. 2b).

The Prevalence of PR $\geq$ Moderate During Follow-up

A total of three studies recorded the incidence of PR in 285 patients with VSDs after transpulmonary artery repair and were included in the analysis. The average age of patients at the time of surgery ranged from 2.080 years to 4.758 years, and the average follow-up time ranged from 4.9 years to 10 years. The combined incidence was 0.231 ($I^2 = 46.567\%$; $p = 0.154$) (Fig. 4b), indicating low heterogeneity. The funnel plot (Fig. 5b) showed a symmetrical distribution, and Egger's test ($p = 0.714$) suggested no publication bias.

Secondary Outcomes

The Proportion of the Improvement of AR During Follow-up

A total of nine studies investigated the improvement rate of AR in 329 patients with VSDs combined with AR

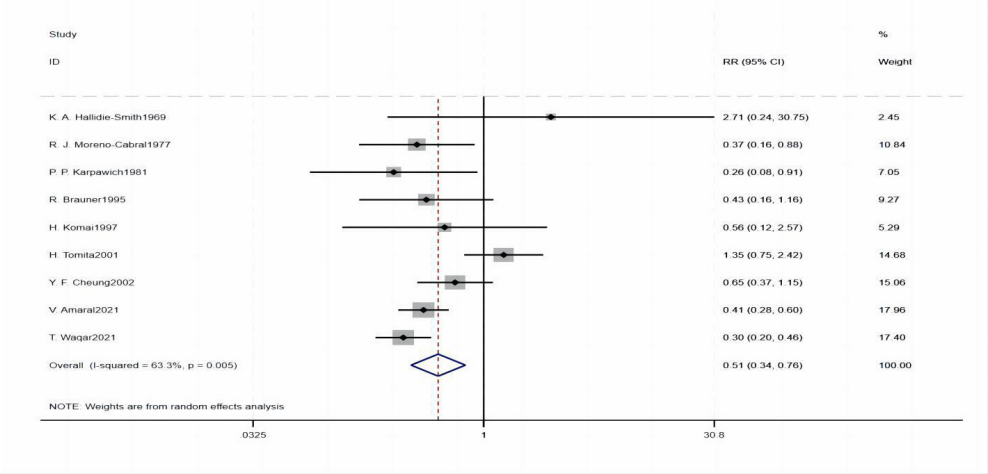

Fig2a The improvement in aortic regurgitation.

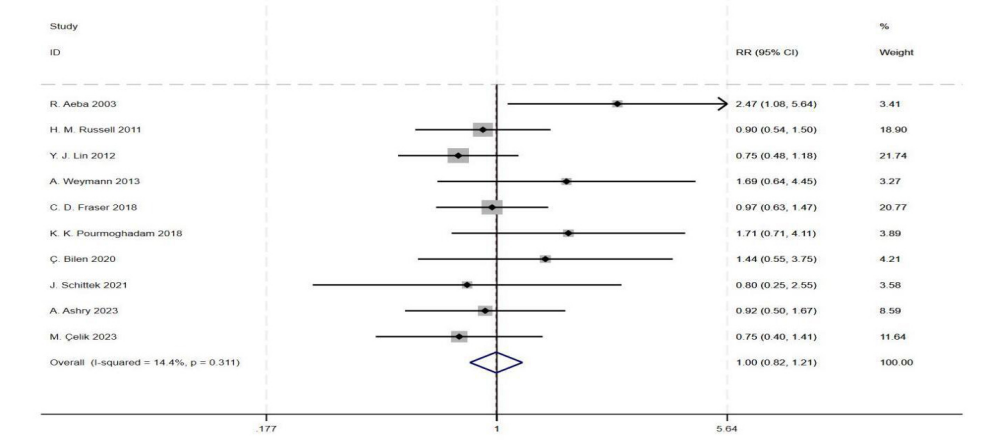

Fig2b The improvement in tricuspid regurgitation.

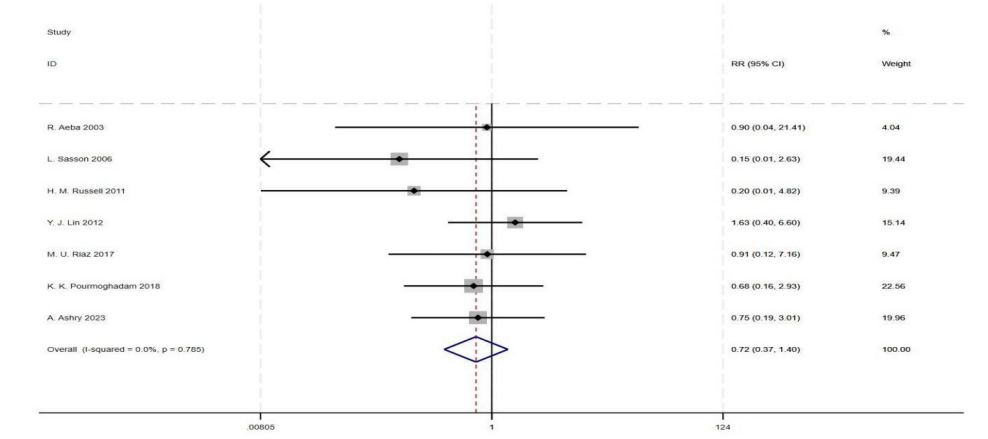

Fig2c The improvement in residual shunting.

Fig. 2. Forest plot of procedural outcomes. (a) The improvement in aortic regurgitation, (b) tricuspid regurgitation, and (c) residual shunting. Relative risk (RR): The ratio of the probability of the outcome event occurring in the exposed group to the probability of the outcome event occurring in the unexposed group.

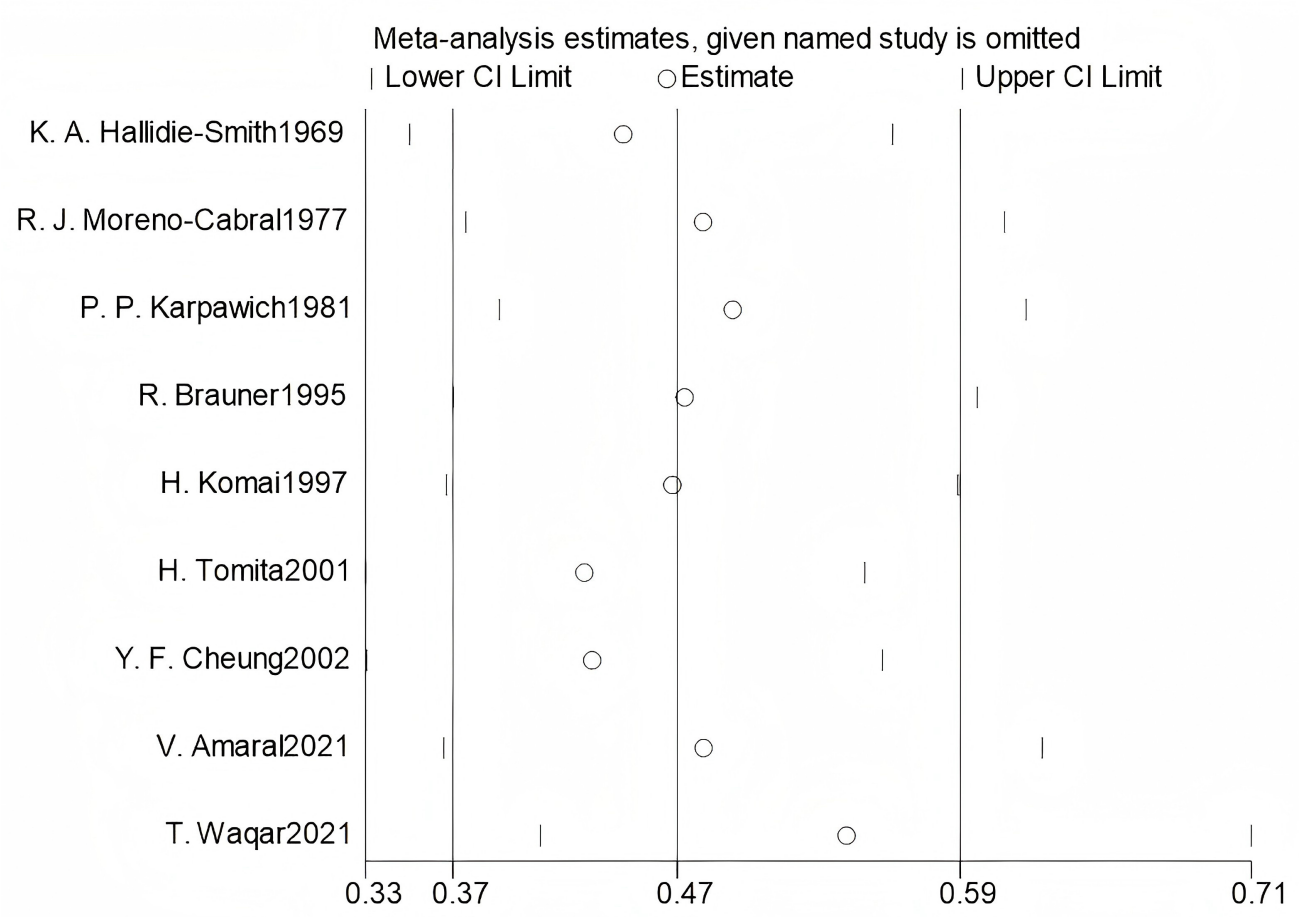

Fig. 3. Sensitivity analysis based on the improvement in aortic regurgitation.

during postoperative follow-up and were included in the analysis. The average age of patients at the time of surgery ranged from 2.233 years to 8.300 years, and the average follow-up time ranged from 2.229 years to 18.900 years. The combined improvement rate was 0.487 (I^2 = 50.3%; p = 0.041) (Fig. 4a), indicating a high level of heterogeneity. The funnel plot showed a symmetrical distribution (Fig. 5a), and Egger's test (p = 0.076) suggested no publication bias. A meta-regression analysis revealed no significant correlation ($p > 0.05$) between the improvement rate and publication year, sample size, study design, average age, country, or inclusion of patients with DCSA VSD, while a significant correlation was found with the preoperative percentage of AR $\geq$ moderate (p = 0.007) and the percentage of patients undergoing isolated VSD repair (p = 0.029).

$\geq$ Small Residual VSD During Follow-up

A meta-analysis of postoperative follow-up for VSDs included seven studies with 463 patients in the TVD group and 656 patients in the non-TVD group. The analysis revealed no significant difference in the incidence of residual shunt $\geq$ small (I^2 = 0%; p = 0.785) (Fig. 2c).

Sensitivity Analysis

We chose to conduct a random-effects model analysis on the improvement rate of AR after VSD repair to summarize the differences in results from various study designs. Sensitivity analyses were applied based on different design factors, including the year of publication, VSD suturing methods, geographical distribution of patients, and types of VSD (Table 2). Analysis by year of publication reveals that the AR improvement rate after VSD repair was slightly higher before 2000 compared to after 2000 (0.50 vs. 0.48). Given that the results before 2000 exhibited significant heterogeneity ($I^2 > 50\%$; $p < 0.05$), the results remain controversial. When analyzing by VSD suturing methods, the AR improvement rate was higher following direct suturing repair compared to patch repair (0.62 vs. 0.44). Based on geographical distribution, studies were categorized into the Americas, Asia, and Europe, with only one study from Europe included, leading to significant heterogeneity. The AR improvement rate in the Americas was greater than that in Asia (0.62 vs. 0.44). Finally, analysis by type of VSD indicated that the AR improvement rate was higher in the group without subaortic VSDs compared to the group with subaortic VSDs (0.54 vs. 0.43).

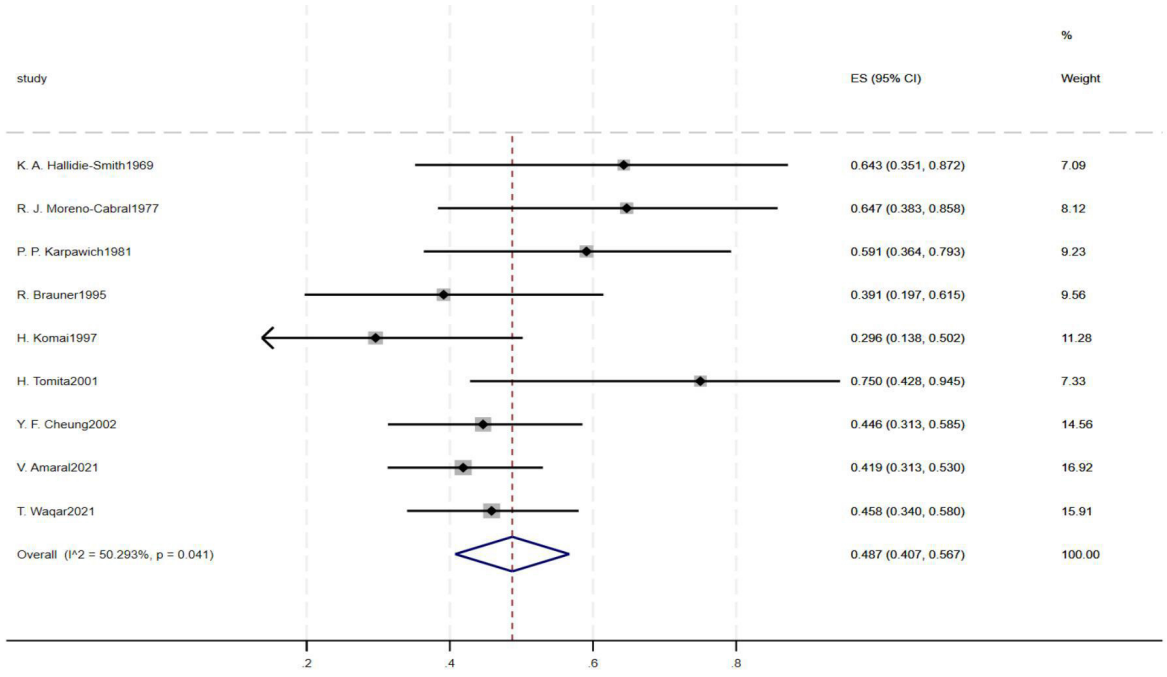

Fig4a The improvement in aortic regurgitation.

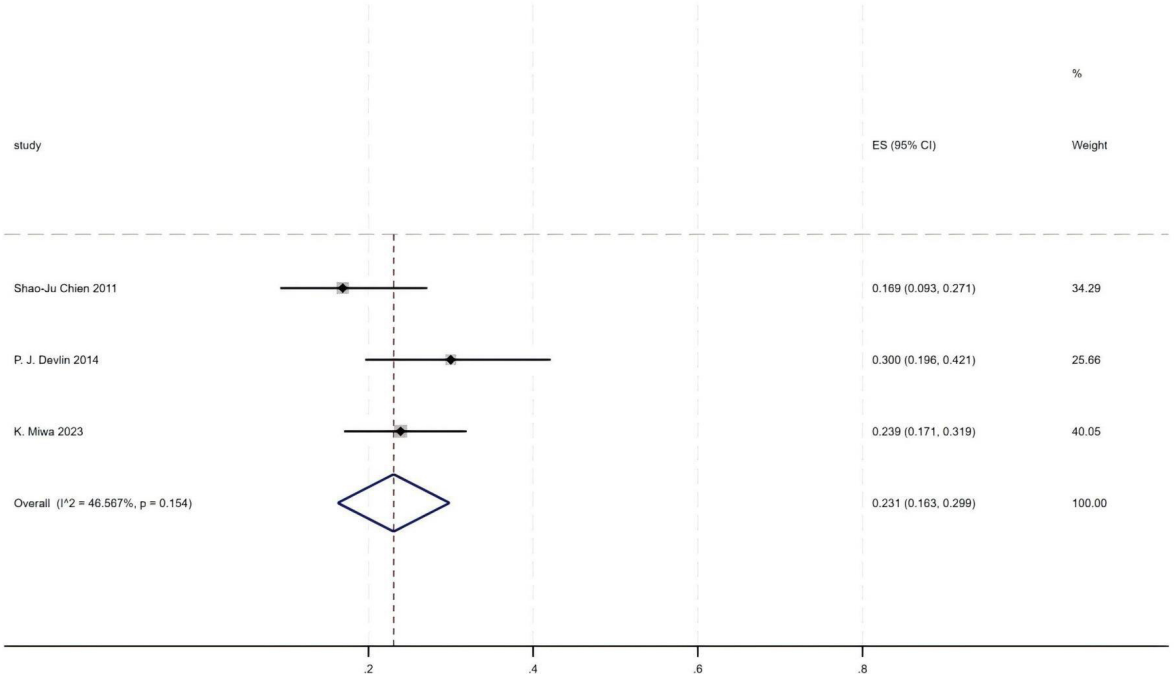

Fig4b The improvement in pulmonary regurgitation.

Fig. 4. Forest plot based on the incidence of procedural outcomes. (a) The improvement in aortic regurgitation and (b) pulmonary regurgitation. Effect size (ES): Effect size is a quantitative measure of the strength or direction of study results.

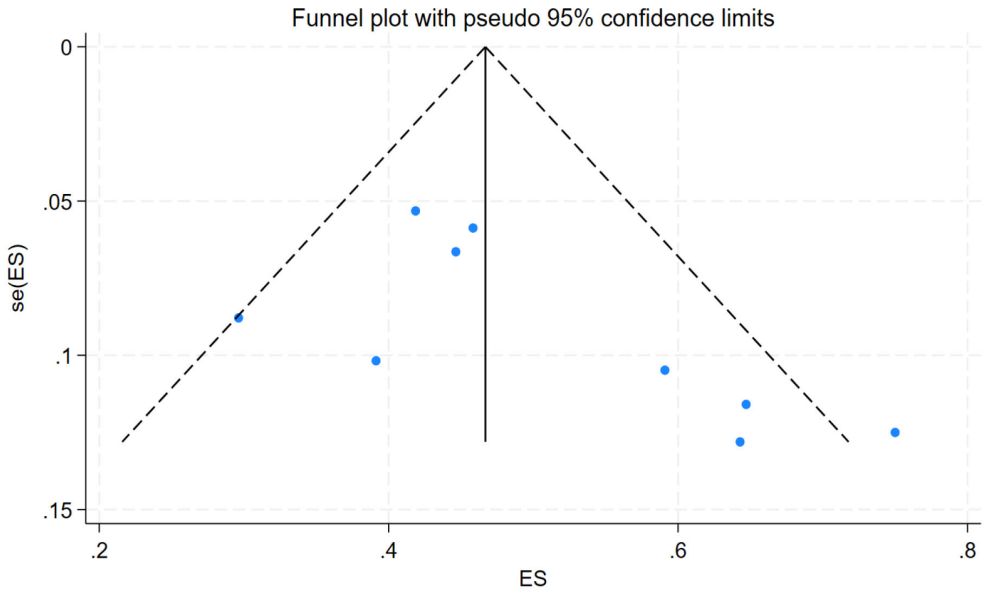

Fig5a The improvement in aortic regurgitation.

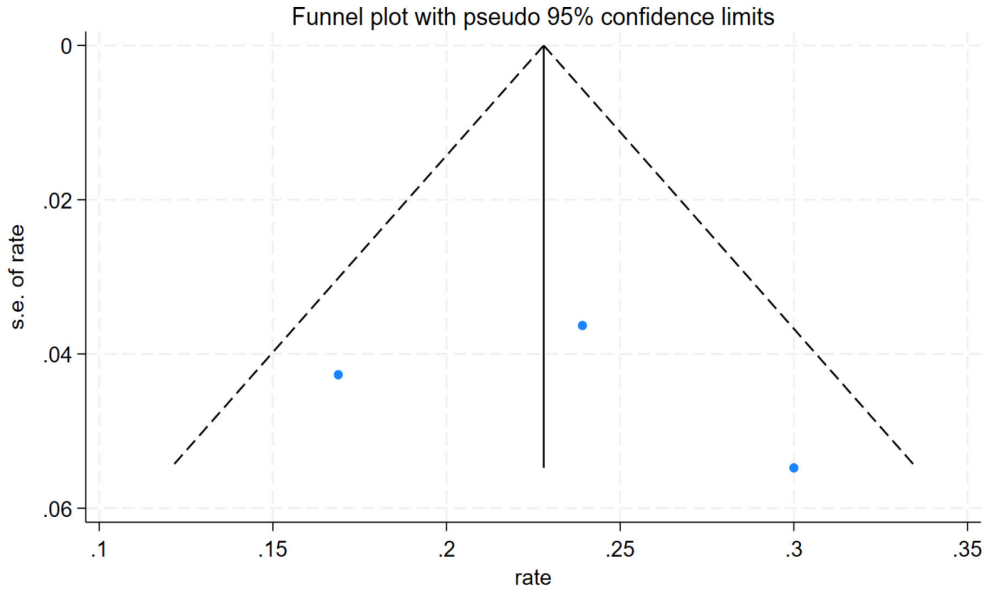

Fig5b The improvement in pulmonary regurgitation.

Fig. 5. Funnel plot based on the incidence of procedural outcomes. (a) The improvement in aortic regurgitation and (b) pulmonary regurgitation. Effect size (ES): Effect size is a quantitative measure of the strength or direction of study results.

Discussion

VSDs are one of the most common congenital heart diseases [34]. Currently, widely accepted surgical indications include the prevention of progressive AR [35,36]. With the continuous development of medical technology, various approaches and incisions for VSD repair have emerged, addressing the challenges of exposure due to anatomical variations. However, the solutions to VSD exposure have also introduced new issues. This paper aimed to evaluate the long-term follow-up of common postoperative complications associated with VSD repair and the incidence of valvular regurgitation resulting from different surgical approaches.

Table 2. Sensitivity analysis.

Overall AR	Prevalence
Including all studies	0.49 (95% CI: 0.41; 0.57)
Direct suture	0.62 (95% CI: 0.49; 0.75)
Patch suture	0.44 (95% CI: 0.36; 0.52)
Recent data (>2000)	0.48 (95% CI: 0.38; 0.57)
Past data (<2000)	0.50 (95% CI: 0.35; 0.65)
America	0.62 (95% CI: 0.46; 0.77)
Europe	0.64 (95% CI: 0.39; 0.89)
Asia	0.44 (95% CI: 0.36; 0.52)
With DCSA VSD	0.43 (95% CI: 0.33; 0.54)
Without DCSA VSD	0.54 (95% CI: 0.42; 0.66)

CI, confidence interval.

The Improvement of AR During Follow-up

This meta-analysis assessed the improvement rate of AR during follow-up by categorizing the patients based on whether they underwent concomitant aortic valve repair or replacement. The group with concomitant aortic valve procedures showed a better improvement rate in AR. A subgroup analysis was conducted to address the significant heterogeneity observed, revealing that the inclusion of patients with subaortic VSDs might represent the source of the noted heterogeneity. This phenomenon can be explained by the fact that subaortic VSDs, due to the Venturi effect [23], may more readily lead to aortic valve prolapse and incompetence compared to VSDs located in other regions. As a result, patients with subaortic VSDs typically exhibit a higher degree of AR at the time of near diagnosis, leading to a greater proportion requiring concomitant aortic valve repair or replacement during surgery, thereby reducing heterogeneity. Additionally, the larger sample size in the subgroup with concomitant subaortic VSDs, combined with the relatively uniform surgical approach for repairing VSDs, also contributes to the heterogeneity of the results.

$\geq$ Mild TR and $\geq$ Small Residual VSDs During Follow-up

This meta-analysis revealed no significant difference in the occurrence of TR and residual shunting during follow-up between the TVD group and the non-TVD group; however, it suggests that the residual shunting situation is better in the TVD group compared to the non-TVD group. The advantage of TVD lies in providing improved exposure of VSDs, which facilitates surgical repair and suturing. Tighter suture spacing can also help reduce the postoperative residual shunt rate to some extent, as evidenced by several studies [19,21,27,37]. Mixed reviews exist regarding the impact of TVDs on tricuspid valve function in both domestic and international research. Some studies have shown that the occurrence of postoperative TR in the TVD group is approximately equal to or even less than that in the conventional group [38–40], whereas other relevant meta-analyses have reported a higher incidence of postoperative TR $\geq$ mild in the TVD group [2]. Currently, there is no clear explanation for these discrepancies. However, ensuring consistency in the basic operation of the TVD technique across various studies and standardizing the ultrasound assessment criteria for TR are fundamental for enhancing the reliability of the conclusions.

The Proportion of the Improvement of AR During Follow-up

This meta-analysis shows that the overall improvement rate of AR following VSD repair is 0.487. The percentage of patients with preoperative AR $\geq$ moderate and the percentage of patients undergoing isolated VSD repair are both significantly correlated with the improvement rate. A positive correlation was found between the percentage of preoperative AR $\geq$ moderate and the improvement rate, whereas the percentage of isolated VSD repairs exhibited a negative correlation with the improvement rate. As the AR grade in the sample increases, the proportion of patients requiring concomitant aortic valve repair or replacement also rises, which aligns with the previously mentioned conclusion regarding the categorization based on the presence of concomitant aortic valve procedures. Additionally, relevant literature indicates that a higher preoperative AR grade is associated with a significantly greater improvement rate in postoperative AR compared to samples with lower grading [29,41].

The Prevalence of PR $\geq$ Moderate During Follow-up

This meta-analysis identified an incidence rate of postoperative PR of 0.231. Although AR remains the primary complication of interest in current research, the occurrence of PR following repair via the pulmonary artery approach is becoming increasingly recognized over extended follow-up periods. Both the impact of suture fixation of the patch on the growth of the pulmonary valve annulus [42] and the number of sutures used in the procedure [23,33] are closely associated with the occurrence of PR. Therefore, continued close monitoring is essential to prevent right heart dysfunction caused by PR.

Relevant literature has studied the impact of preoperative aortic valve prolapse or regurgitation severity on the progression of postoperative AR. Meanwhile, patients with preoperative AR $<$ moderate or isolated right coronary cusp prolapse who undergo isolated VSD repair have been found to tend to have good long-term outcomes. Conversely, for the population with preoperative AR $>$ mild and with non-coronary cusp prolapse, early surgical intervention is encouraged to prevent adverse outcomes [43–46]. Considering the junction of the anterior and lateral tricuspid valve leaflets as a weak point, surgical manipulation may cause occult damage. Therefore, the conclusion that the incidence of PR is relatively high in patients undergoing VSD repair via the pulmonary artery approach still requires verification

with a larger sample size. Additionally, further discussion is needed regarding the progression rate of PR before and after surgery, as well as the long-term changes in right heart function. This information will help assess the safety of the pulmonary artery approach and determine the necessity for any future reoperation on the pulmonary valve.

Conclusion

In children with VSDs associated with aortic valve prolapse or regurgitation, the improvement rate of AR during follow-up was lower in the isolated VSD repair group compared to the group undergoing concomitant aortic valve repair or replacement. Two related factors were identified: The proportion of preoperative AR $\geq$ moderate showed a positive correlation with the improvement rate of AR during follow-up, whereas the percentage of isolated VSD repairs exhibited a negative correlation with the improvement rate of AR. Additionally, TR status during follow-up was similar between the TVD and non-TVD approaches for VSD repair. Furthermore, patients who underwent VSD repair via the pulmonary artery approach had a higher incidence of PR in the long term.

Availability of Data and Materials

The study's original contributions are contained within the article and supplementary material. For additional information, please contact the corresponding authors.

Author Contributions

LL, conception, design, screening, analysis, writing. MHZ screening, analysis. AJL, acquisition and analysis of data. JWS, analysis and interpretation of data and critically reviewing the manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript.

Ethics Approval and Consent to Participate

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Conflict of Interest

The authors declare no conflict of interest.

Supplementary Material

Supplementary material associated with this article can be found, in the online version, at https://doi.org/10.59958/hsf.8771.

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