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Systematic Review

Safety and Effectiveness of Transthoracic Echocardiography and Transesophageal Echocardiography in the Interventional Closure of Atrial Septal Defects in Children: A Systematic Review and Meta-Analysis

Haiyan Lu[1], Jindong Wang[2], Lingjuan Zhou[1], Lian Liu[3,*]

[1]Department of Ultrasound, Taizhou Hospital of Zhejiang Province Affiliated to Wenzhou Medical University, 318050 Taizhou, Zhejiang, China
[2]Quality Improvement Office, Taizhou Hospital of Zhejiang Province Affiliated to Wenzhou Medical University, 318050 Taizhou, Zhejiang, China
[3]Department of Pediatrics, Taizhou Hospital of Zhejiang Province Affiliated to Wenzhou Medical University, 318050 Taizhou, Zhejiang, China
*Correspondence: liulian1232023@163.com (Lian Liu)

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Abstract

Objective: Through this meta-analysis, a systematic review was conducted on the effects of transthoracic echocardiography (TTE) and transesophageal echocardiography (TEE) in the interventional closure of atrial septal defects (ASDs) in children. **Methods**: We searched papers in the PubMed, Web of Science, Cochrane Library, Google Scholar, CNKI, Wanfang, Embase, and VIP databases. The search time limit was from the establishment of the database to May 2023. Randomized controlled trials on the effect of TTE and TEE in the interventional closure of ASD in children were screened. The included results were integrated and analyzed, and ReviewManager 5.4 was used for the meta-analysis. **Results**: Six studies with a total of 253 patients with ASD were included in this meta-analysis. Results showed that the surgical success rate in each study was more than 90%, with no difference between TEE and TTE (p = 0.11; risk ratio (RR) = 0.96, 95% confidence interval (CI): 0.89 to 1.04). The surgery time of TTE was significantly shorter than that of TEE (standard mean difference (SMD) = –1.52, 95% CI: –2.30 to –0.74). The fluoroscopy time of TTE was shorter than that of TEE (SMD = –0.69, 95% CI: –1.08 to –0.30). We found no significant difference in complication rates (RR = 0.36, 95% CI: 0.09 to 1.39). **Conclusion**: The combination of TTE and TEE is important during surgery, and postoperative complications are relatively small. The surgery time and fluoroscopy time of TTE are shorter than those of TEE.

Keywords

atrial septal defect; meta-analysis; randomized controlled trial; transthoracic echocardiography; transesophageal echocardiography

Introduction

Atrial septal defect (ASD) is due to the abnormal absorption and fusion of the atrial septum during heart development, resulting in the left and right atria to remain open. This disease accounts for about 10% of all cases of congenital heart disease and accounting for 20%–30% of adult congenital heart disease. ASD is more common among women than among men, and the ratio of men and women is 1:1.5–1:3. ASD embryos are classified based on the pathogenesis of the anatomy. It can be divided into secondary holes and primary holes. Ostium primum type-ASD, also known as lack of type I atrial septum, is located at the junction between the endocardial cushion and the atrioventricular septum. Such a defect is often associated with either bicuspid aortic valve or tricuspid valve abnormalities [1]. Ostium secundum type-ASD accounts for about 75% of cases; this defect is located in the ovarian ball nest region, also known as central atrial septal defect [2]. It is also the primary choice for intervention therapy [3]. The primary hole in ASD is located in the front and lower of the coronary vein sinus, and the lower edge of the defect is close to the large valve petals. The hair hole in ASD is located above the coronary vein sinus. Depending on the anatomical location, it can be divided into central type (oval-cylinder type), upper cavity (venous sinus type), lower cavity type, and hybrid; most of them are single holes. Given the small number of pores, small central room septal defects are easy to confuse with ovarian round holes [4,5].

In the early days after birth, patients with ASD exhibit a progressive increase in the pressure of the right atrium. At this time, left-handed and right-handed diversion occur in the body. The diversion is related to the pressure difference between the atrial room and the compliance of the ventricle. With age, the height of the pulmonary arteries develops to the obstructive lesions of the pulmonary arteries of the instrument, and the right to the left is shifted to form the Eisenmenger syndrome [6,7]. Studies have shown that the heart of patients with ASD is in an overloaded state for a long time, and the structure of the heart can be easily induced to reshape the structure. The longer this reshaping occurs, the less the chance of reshaping after surgery, which eventually leads to high pressure on the pulmonary arteries and even heart failure [7,8]. Therefore, for such patients, the room section should be sealed as soon as possible. At present, room seal blocking has been widely used in clinical practice, and it is also considered one of the most effective means for patients with ASD. For patients with ASD, blocking can not only improve its clinical symptoms but also prevent further expansion of the heart [9].

Ultrasound technology is the primary method for detecting atrial septal defects due to its convenient operation method and relatively low cost. The assessment of defect type and size is the main basis for clinicians to make decisions. The continuous development of ultrasound imaging provides increasingly diversified technical support for the diagnosis and treatment of congenital heart defects [10]. The primary treatment for ASD is the use of a dermal conductor to seal the ventricular septum during cardiac surgery, and transesophageal echocardiography (TEE) and transthoracic echocardiography (TTE) have become common methods for the treatment of ASD [11]. Detailed information about the disasters of the interval is needed before surgery, such as the maximum measurement diameter of the defect, the location, the shape of the defect, and the nearby relationship with the surrounding tissue.

At present, numerous studies at home or abroad have investigated TEE or TTE. However, studies comparing the two are lacking. At present, there is no systematic collection and analysis of ultrasound electrocardiograms (ECGs) at home and abroad. Ultrasound-guided intervention is extensively utilized in clinical settings to collect data and perform minor incisions in the chest, thereby reducing surgical trauma and advancing postoperative rehabilitation research. This study aimed to systematically explore the safety and effectiveness of TEE and TTE in pediatric ASD. This work may lay the foundation for a deep exploration on ways to permanently seal ASD in children.

Data and Methods

Literature Search Strategy

Specific and systematic searches were carried out on the webpage and the PubMed, Embase, Web of Science, Google Scholar, CNKI, Wanfang, and VIP databases. The search terms were as follows: "transthoracic echocardiography", "transesophageal echocardiography", "atrial septal defect", "random", and "children". The search time limit was from the establishment of the database to May 2023. The search results were limited to clinical research and not restricted by language or race. Manual searches were performed by reading relevant works and summarizing references. Search strategies were adjusted to comply with the relevant regulations in every database.

Literature Inclusion Criteria

(1) Randomized clinical trial (RCT), regardless whether it is single-blind, double-blind, or non-blind.

(2) In the same study, the effects of TTE and TEE were compared in the interventional closure of ASD in children.

(3) Study targets were pediatric patients.

Literature Exclusion Criteria

P (Population): Study targets were adults.

I (Intervention): Those who did not use TTE or TEE to intervene closure of ASD in children.

C (Comparison): Those that did not compare TTE and TEE for the closed treatment of ASD in children.

O (Outcome): Outcome measures were incomplete or data duplication. Statistical methods and data analysis had obvious errors. There were less than two outcome measures.

S (Study design): Non-randomized trials. The test results and conclusions were inconsistent with the reality.

Literature Screening and Data Extraction

Literature Screening

On the basis of the inclusion and exclusion criteria, two researchers independently screened the literature and targeted titles and abstracts, including primary screening, secondary screening, and cross-checking to determine possible relevant studies. Firstly, a preliminary screening was conducted, in which the researchers read and analyzed the titles and the abstracts of the articles and eliminated the literature that did not meet the inclusion criteria or were duplicate studies. Secondly, re-screening was performed by reading the full text of the papers obtained from the primary screening and further screening the literature according to the inclusion criteria. Finally, the papers were checked via cross-checks of the obtained literature. For documents with incomplete or questionable information, the corresponding authors were contacted for detailed information. Finally, the researchers determined whether the literature was included in the study. If the two researchers had different opinions on some articles, they discussed them together until a consensus was reached; if no consensus could be reached, a third researcher participated in the judgment. Finally, the selected documents were included in the table for extraction and summary.

Data Extraction

The content of data extraction included title, first author, year of publication, research type, and observation indicators.

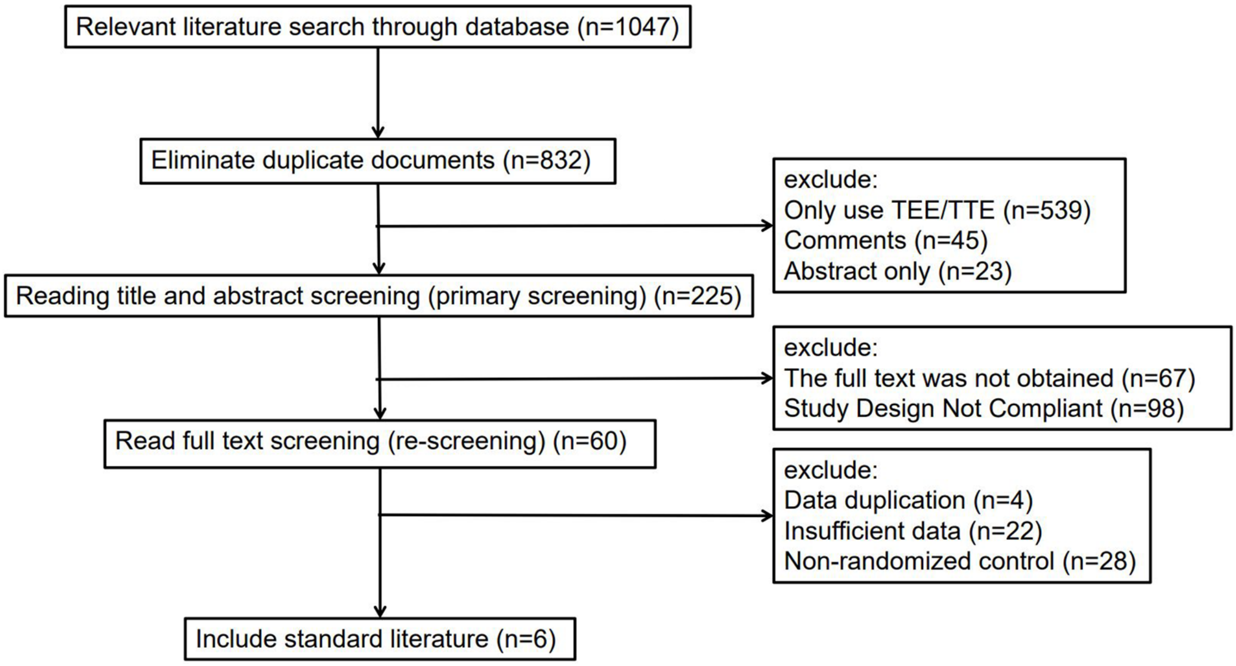

Fig. 1. Flow chart of literature search.

Efficacy Index

① The success rate of surgery.
② Surgery time.
③ Fluoroscopy time.
④ Total complication rate.
⑤ Long-axis measurement.

Quality Evaluation

Eligible literature was assessed for methodological quality using the Jadad scoring scale, scored on a scale of 1 to 7, by assessing random sequence generation, blinding, allocation concealment, and patient withdrawal or withdrawal. A Jadad score of 4–7 was considered high-quality literature, and that of 1–3 was considered low-quality literature.

Risk of Bias

(1) Random sequence generation.
(2) Allocation concealment.
(3) Blinding of participants and personnel.
(4) Blinding of outcome assessment.
(5) Incomplete outcome data.
(6) Selective reporting.

Statistical Method

All analyses were pooled using Review Manager 5.4 (RevMan, The CochraneCollaboration, Oxford, UK) statistical software, with weighted mean differences (WMDs) and 95% confidence intervals (CI) for continuous data and relative risk (RR) and 95% CI for dichotomous data. The heterogeneity index (I^2) was used to evaluate the heterogeneity of the treatment effect. When there was no significant heterogeneity among the studies ($I^2 < 50\%$), the fixed effect model was used; when there was significant heterogeneity among the studies ($I^2 \geq 50\%$), the random effects model was used. Sensitivity analysis was performed on factors that may cause heterogeneity, and literature with high sensitivity was excluded. A descriptive analysis was performed for those who could not perform a meta-analysis. $p < 0.05$ indicated that the data were significant and statistically significant. PRISMA was a supplementary material in this study (**Supplementary material**).

Results

Literature Search Results

We systematically retrieved the original literature on TTE, TEE, ASD, random, and children published in databases such as CNKI, Wanfang, VIP, EMBASE, Web of Science, and PubMed. We used subject headings combined with free words for systematic retrieval, and we manually retrieved 1047 studies. A total of 539+45+23 articles that were repeatedly published or only used one ultrasonic ECG were obtained, and 225 articles were obtained. After reading the full text, 67+98 articles that could not obtain the full text and had an incomplete experimental design were eliminated. Finally, six articles were obtained [12–17]. The literature screening process is shown in Fig. 1.

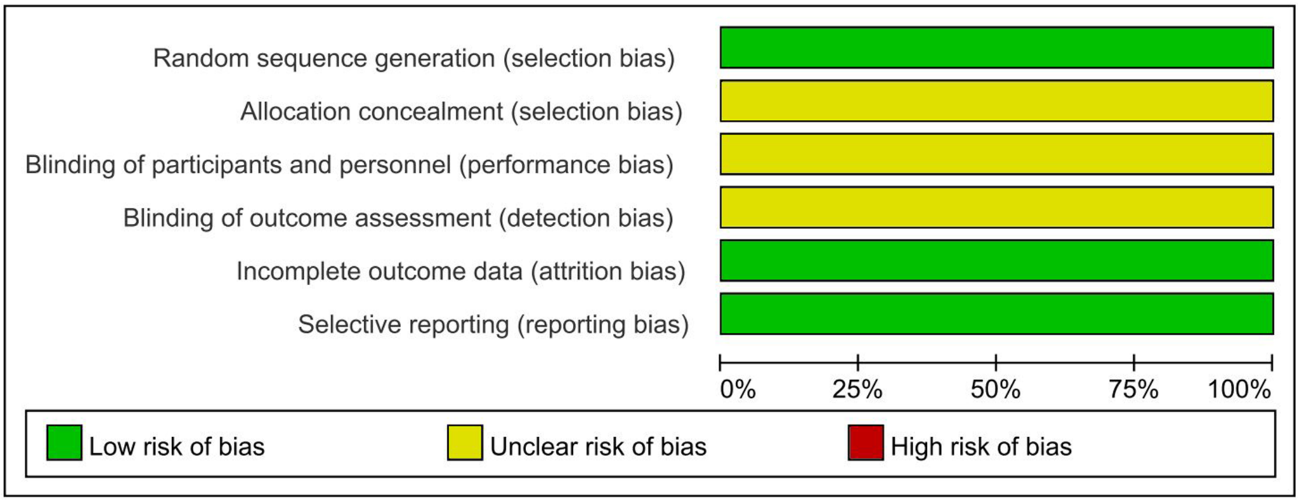

Fig. 2. Risk of bias bar plot.

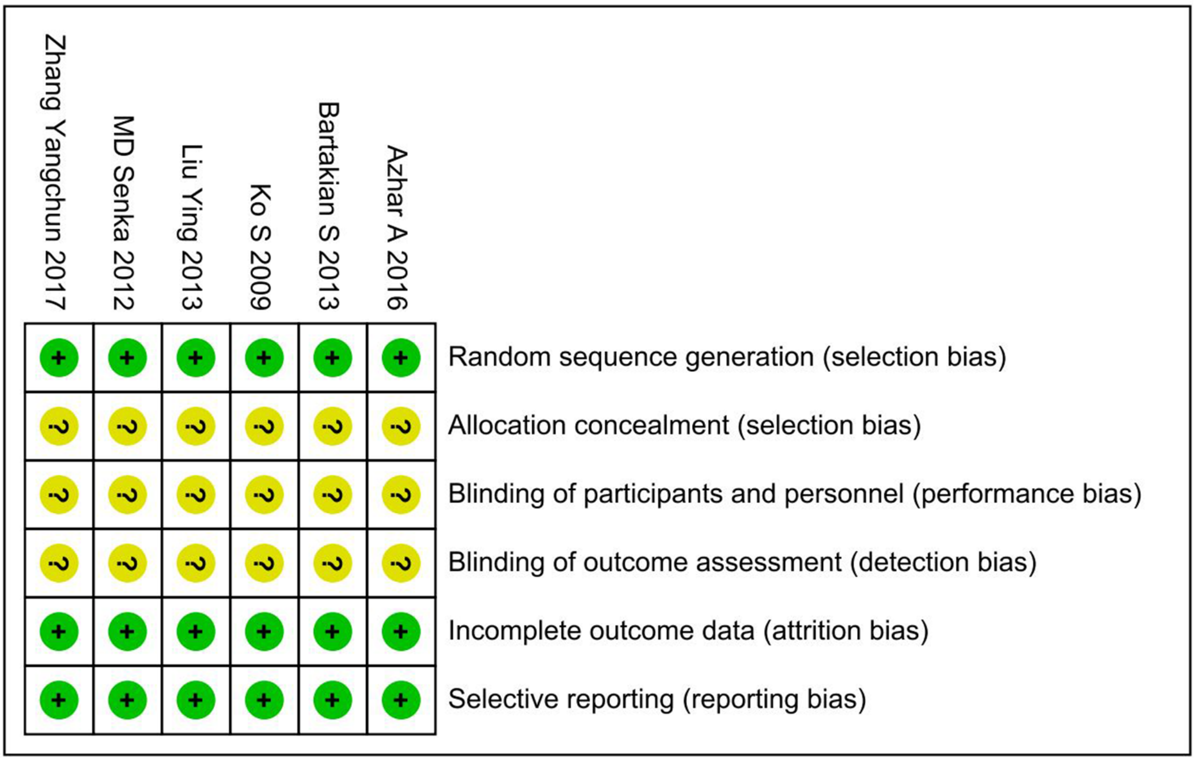

Fig. 3. Risk of bias summary.

Basic Characteristics and Quality Evaluation of Included Literature

The demographic and baseline characteristics of the patients are shown in Table 1 (Ref. [12–17]). In the included literature, patients were divided into different groups based on the various types of echocardiography of the studies.

The Jadad score of the included literature was 4 to 5, which indicated high-quality literature. None of the six included studies had withdrawn.

Risk of Bias Results

The analysis of the risk of bias (Figs. 2,3) showed that most of the studies included in this study correctly described the generation of random sequences. In terms of allocation concealment, implementer—participant double-blinding was not described comprehensively in every study.

Table 1. Basic characteristics and Jadad score of included studies.

Researcher	Number of cases (TTE group/TEE group)	Age (TTE group/TEE group)	Gender (male/female) (TTE group, TEE group)	Research design	Efficacy index	Follow-up time/month	Jadad score
Zhang Yangchun 2017 [12]	26/24	2–14/4–13	15/11, 13/11	Single-center RCT	①②④	6	5
Azhar A 2016 [13]	45/28	$8.18 \pm 5.85/17.68 \pm 14.88$	14/31, 10/18	Single-center RCT	①②③④	3–12	5
Liu Ying 2013 [14]	38/16	4–15/6–17	18/20, 8/5	Single-center RCT	①②④	3–6	4
Bartakian S 2013 [15]	19/19	$5.50 \pm 3.40/6.50 \pm 4.80$	12/7, 9/10	Single-center RCT	①②③④	1–12	5
MD Senka 2012 [16]	12/4	2–17/5–15	3/9, 2/2	Single-center RCT	⑤	12	4
Ko S 2009 [17]	14/8	$5.79 \pm 2.75/3.50 \pm 2.73$	3/11, 4/4	Single-center RCT	⑤	30	4

Note: ① The success rate of surgery. ② Surgery time. ③ Fluoroscopy time. ④ Total complication rate. ⑤ Long-axis measurement. TTE, transthoracic echocardiography; TEE, transesophageal echocardiography; RCT, randomized clinical trial.

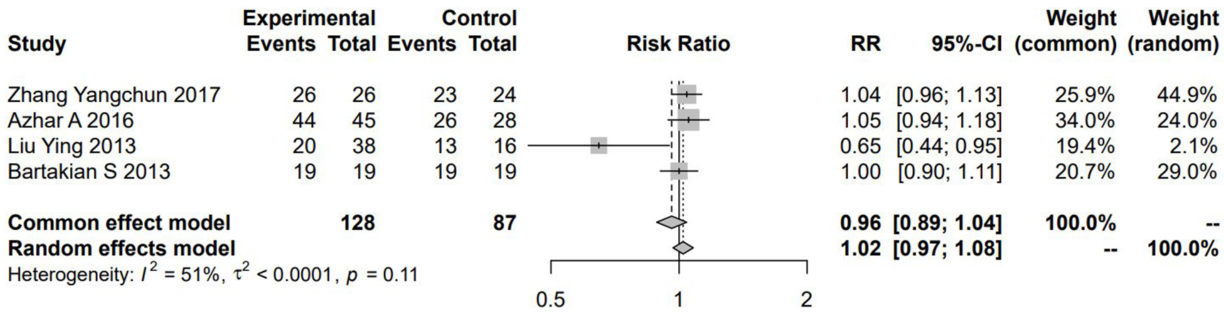

Fig. 4. Meta-analysis and forest plot of the success rate of surgery.

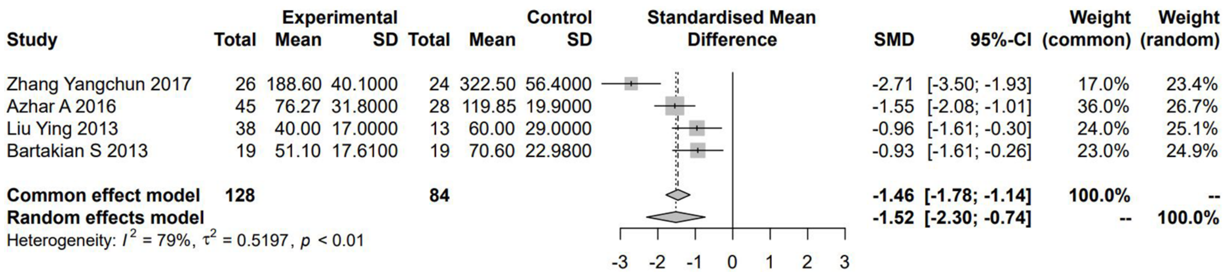

Fig. 5. Meta-analysis forest plot of the surgery time.

Efficacy Index Results

Success Rate of Surgery

Four studies [12–15] reported the success rate of surgery and included 212 research subjects. As shown in Fig. 4, in all the included studies, the results of the heterogeneity test showed I^2 = 51%, and the results of the meta-analysis using the random effect model showed that $p = 0.11$ (RR = 1.02, 95% CI: 0.97 to 1.08). The surgical success rate in each study was more than 90%, with no difference between TEE and TTE in this index. Subsequently, we conducted a sensitivity analysis by excluding the documents individually. After excluding the study of Liu *et al*. [14], the heterogeneity was 0%, indicating that this document was the source of heterogeneity.

Surgery Time

Four studies [12–15] reported the surgery time. As shown in Fig. 5, in all the included studies, the heterogeneity test results showed I^2 = 79%, and the meta-analysis results using the random effects model showed $p < 0.01$ (standard mean difference (SMD) = –1.52, 95% CI: –2.30 to –0.74, Fig. 5). These findings suggested that the surgery time of TTE was significantly shorter than that of TEE.

Therefore, we performed relevant subgroup analysis (Fig. 6). The results showed that the heterogeneity in subgroup allocation according to length of time I^2 = 0%, p = 0.75, HR (95% CI) = 0.61 (0.45, 0.83). This suggests that there is an interaction between the two surgeries and the grouping factor by length of time, and there is a subgroup effect.

Fluoroscopy Time

Only two studies reported fluoroscopy time. Among all the included studies, the heterogeneity test results showed I^2 = 0%, and the meta-analysis results using the fixed effects model showed $p < 0.01$ (SMD = –0.69, 95% CI: –1.08 to –0.30, Fig. 7). We also found that the fluoroscopy time of the TTE group was shorter than that of the TEE group.

Total Complication Rate

Four studies [12–15] specifically reported the occurrence of complications after related surgeries. Among all the included studies, the heterogeneity test results showed I^2 = 54%, and the meta-analysis results using the random effects model showed $p = 0.11$ (RR = 0.36, 95% CI: 0.09 to 1.39, Fig. 8). Thus, in some studies, TTE had fewer complications than TEE [12,14], whereas no significant difference in complications was reported in other studies [13,15].

Therefore, we performed a relevant subgroup analysis (Fig. 9). The results showed that the heterogeneity in subgroup allocation according to the method of operation was 49.3%, and $p = 0.12$. And the analysis provided a more detailed analysis based on surgical method and $p = 0.12$, there may be other factors that lead to no statistical difference in subgroup analysis. Therefore we performed a sensitivity analysis. Sensitivity analysis was performed by excluding the literature individually. After excluding the studies of Liu *et al*. [14], the heterogeneity was 0%, which indicated that the articles was sources of heterogeneity.

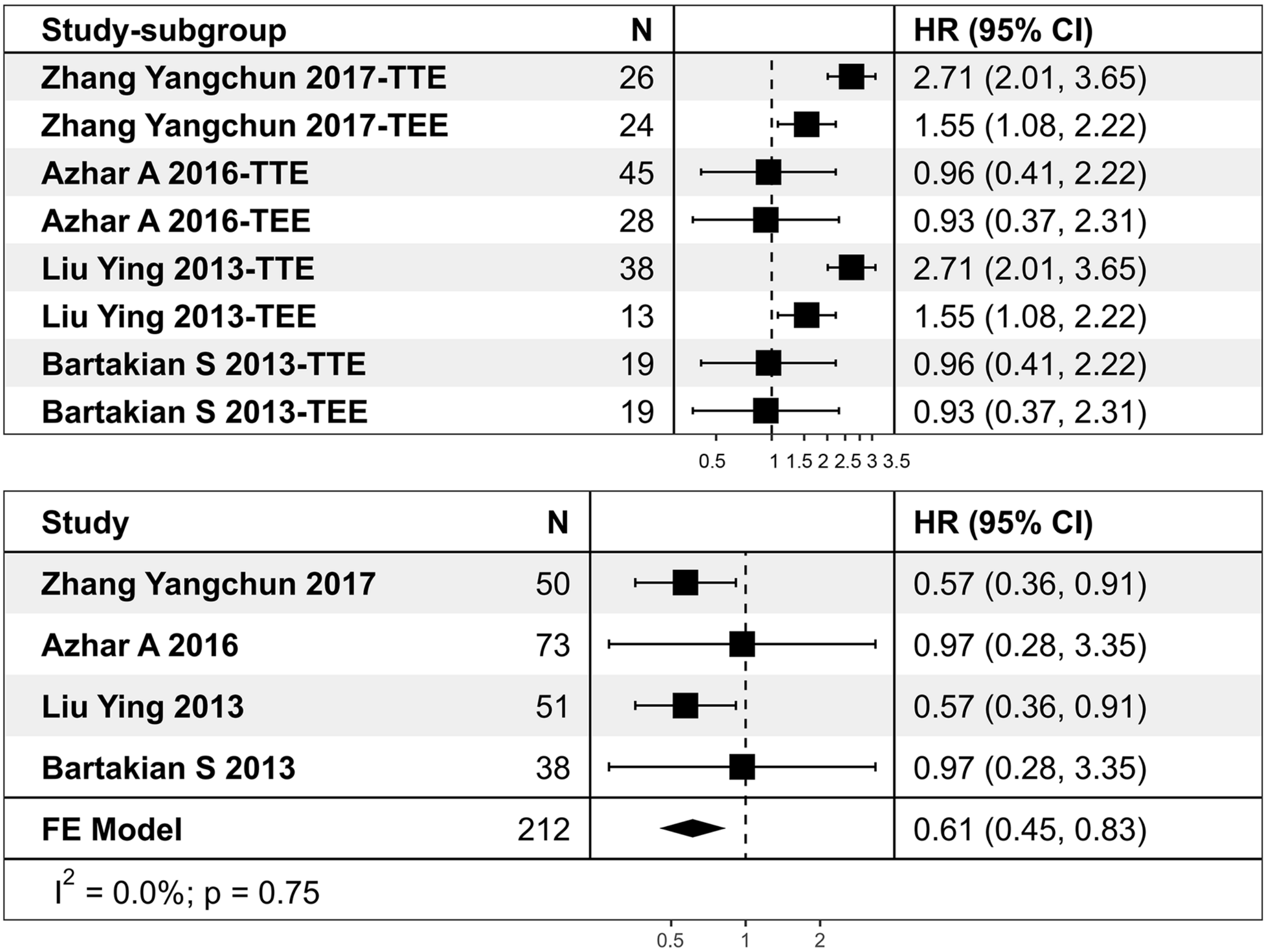

Fig. 6. Subgroup analysis result of the surgery time. HR, Hazard ratio; FE Model, fixed effects model; -TTE's subgroup refers to a short length of time, -TEE subgroup refers to a long length of time according to the comparison of each reference.

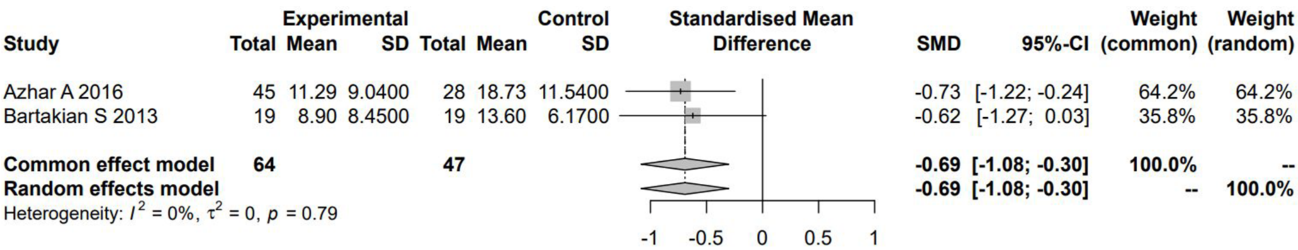

Fig. 7. Meta-analysis forest plot of incidence of fluoroscopy time.

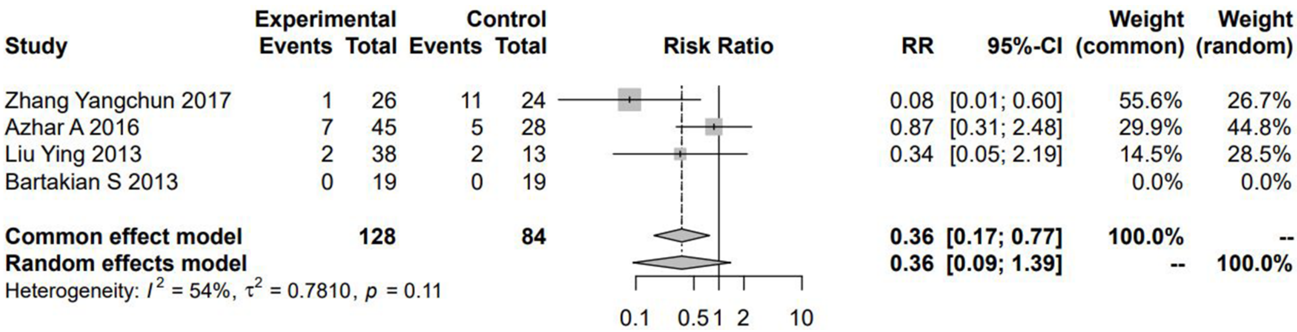

Fig. 8. Meta-analysis and forest plot of the occurrence of complications.

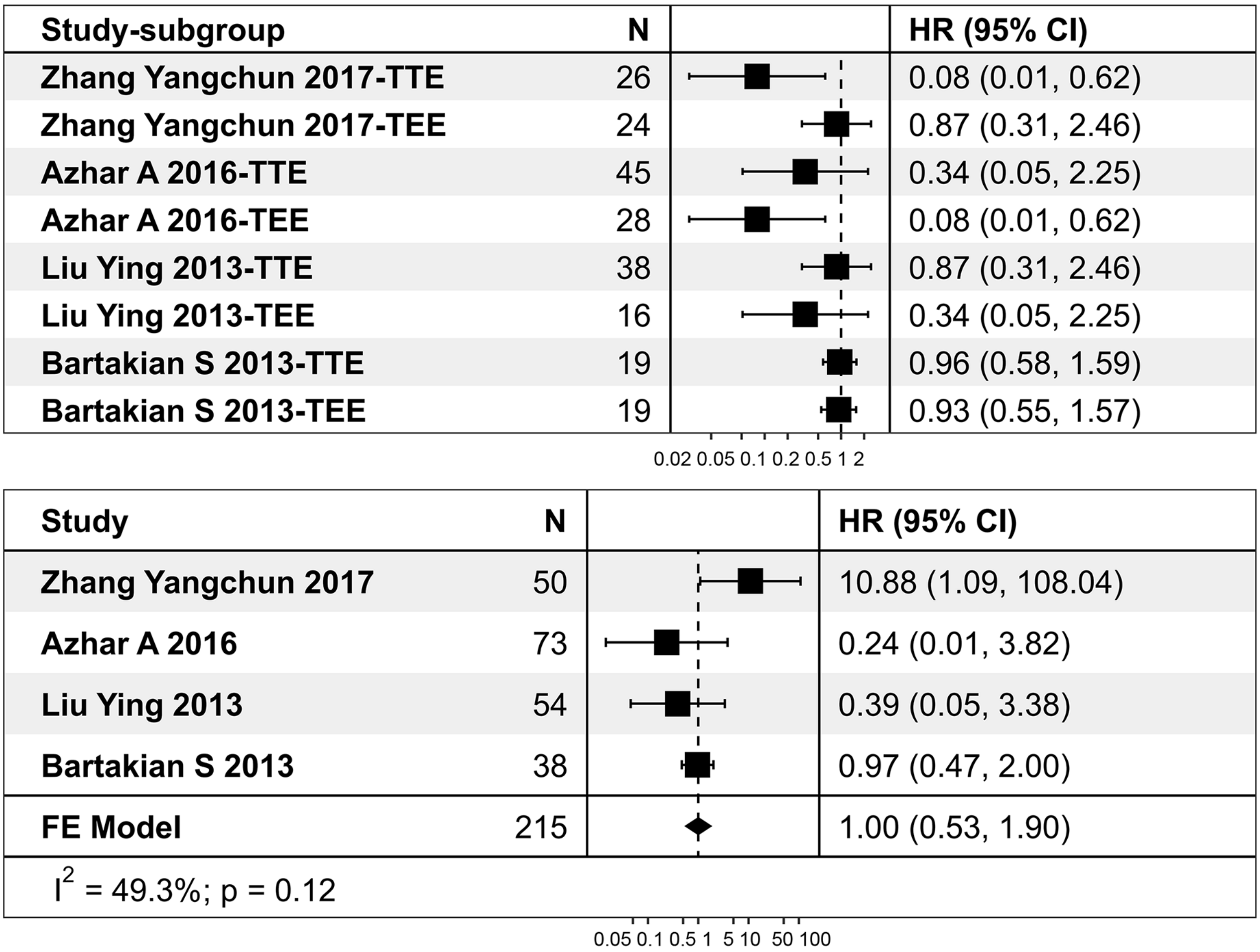

Fig. 9. Subgroup analysis result of the occurrence of complications. HR, Hazard ratio; FE Model, fixed effects model; TTE, transthoracic echocardiography; TEE, transesophageal echocardiography.

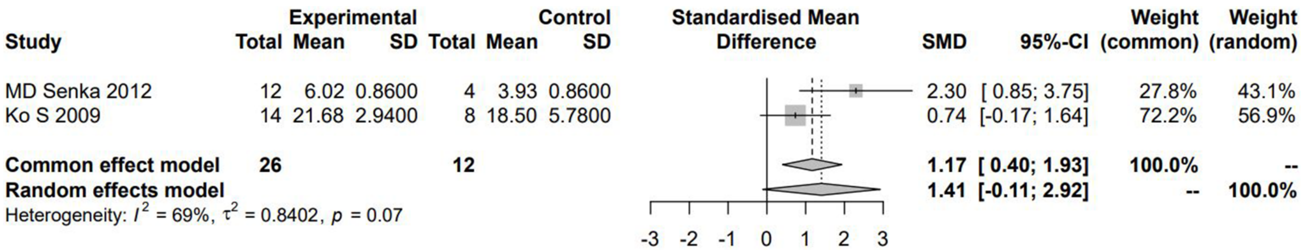

Fig. 10. Meta-analysis and forest plot of the long-axis measurement.

Long-Axis Measurement

Two studies [16,17] reported long-axis measurements. Among the included studies, heterogeneity was $I^2 = 69\%$, and the meta-analysis results using the random effects model showed $p = 0.07$ (SMD = 1.41, 95% CI: –0.11 to 2.92, Fig. 10). The results of 2 studies showed that there has obviously increase in long-axis measurements after surgery.

Bias Analysis

Bias analysis was performed on five results: the success rate of surgery, surgery time, fluoroscopy time, total complication rate, and long-axis measurement (Fig. 11). The results showed that the funnel plot was not completely symmetrical and had a certain publication bias. Ideally, studies should be evenly distributed on both sides. Publication bias may lead to overestimation of treatment effects. However, the studies included in this study were small sample trials, which may lead to publication bias due to insufficient analysis.

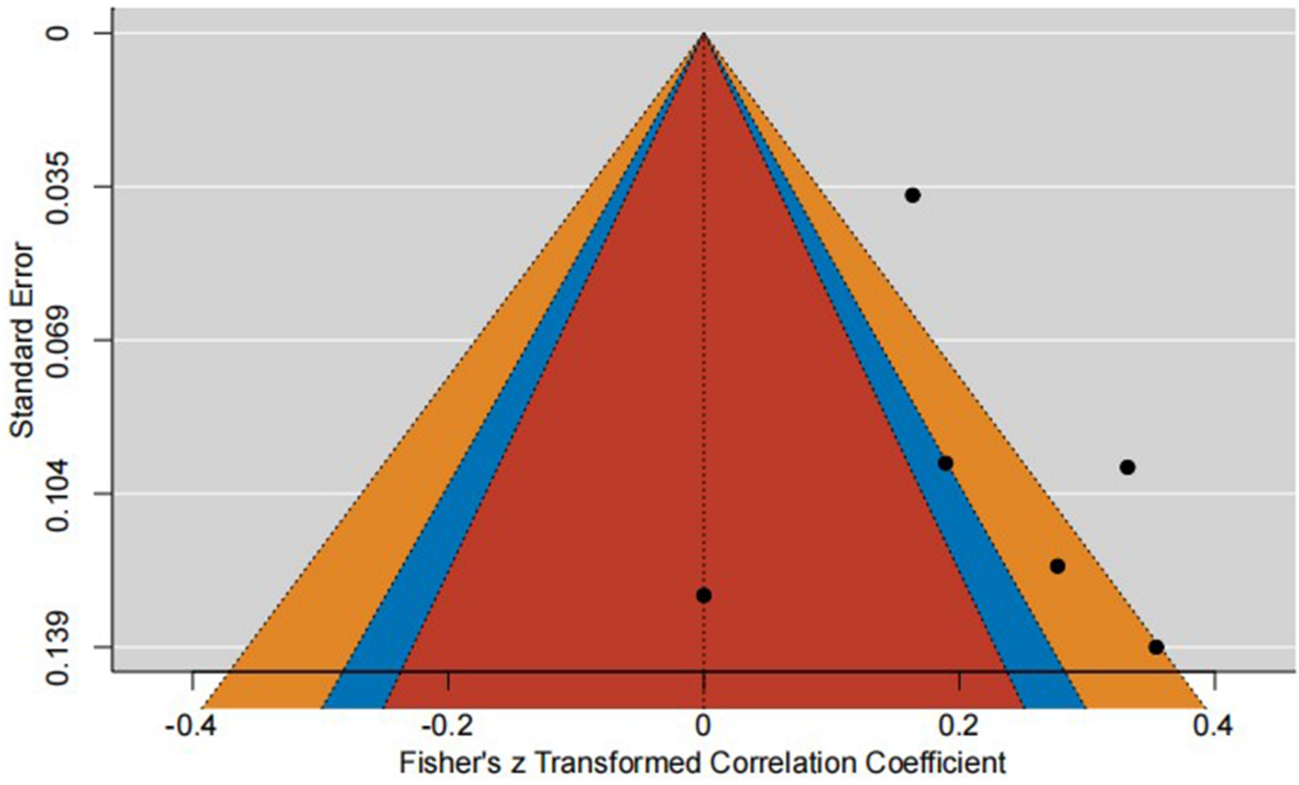

Fig. 11. Bias analysis was performed on five results.

Discussion

A comprehensive literature search yielded six articles that met the inclusion criteria, focusing on TTE and TEE in children with ASD. These studies demonstrated high-quality evidence with Jadad scores ranging from 4 to 5. Although most studies adequately described random sequence generation, there were limitations in reporting allocation concealment and blinding. An analysis of surgical success rates, involving 212 research subjects across four studies, revealed no significant difference between TTE and TEE. Both approaches exhibited success rates exceeding 90%, indicating comparable efficacy in guiding surgical interventions for ASD. Further research may explore the nuances of echocardiography techniques and their effect on surgical outcomes in pediatric populations.

Echocardiography plays a crucial role in screening for preoperative indications in interventional and minimally invasive surgical closure of ASD. Interventional closure and minimally invasive surgical closure of ASD require echocardiography to screen for preoperative indications [18,19]. Echocardiography can not only confirm the diagnosis and measure the defect size of ASD but also evaluate the length and thickness of the stump of each interatrial septum [20,21]. The most widely used methods in China are ordinary 2 dimensional (2D) TTE and TEE. TTE examination is convenient, safe, painless, and widely used [22]. It is not restricted by age, but it is easily affected by lung gas, intestinal gas, obesity, and chest wall deformity. TEE examination involves the direct insertion of the probe into the esophagus for scanning, which is not interfered by the chest wall and lung air and displays clear images.

The study analyzed surgical success rates and found no significant difference in the one-time closure success rate between TTE and TEE-guided procedures. Recent studies have shown that both guided occlusions are very good [23,24]. TTE is easy to operate and non-invasive, and the examination cost has obvious advantages compared with computed tomography (CT) and magnetic resonance imaging (MR). The patients do not need to make special preparations in advance. Moreover, the diagnostic sensitivity for ASD in the foramen primum and secundum exceeds 90%, making it the preferred method for routine screening of congenital heart disease.

The comparison of surgery time and fluoroscopy time between TEE and TTE in the surgical repair of ASD highlights the significant advantage of a shorter duration in TTE than in TEE; this difference was due to factors such as the need for general anesthesia in young patients during TEE and the relative clarity of TEE images requiring additional time for observation. Although the success rate of surgical repair of ASD is high, the incidence of postoperative syndromes and prolonged hospitalization such as sternotomy and cardiopulmonary bypass is also high [25,26]. An interesting difference is the surgery time. The results of this study showed that the surgery time of TTE was significantly shorter than that of TEE [13,15]. As mentioned above, young patients require general anesthesia when performing TEE, whereas TTE does not. Moreover, the TEE images are relatively clear and show more details than the TTE images, so doctors need more time to identify and observe the findings [27]. In terms of the fluoroscopy time, the results of this study showed that the fluoroscopy time of TTE was relatively short compared with that of TEE. The operation time and fluoroscopy time play a crucial role in decision-making in clinical practice. Doctors need to select the appropriate ultrasound after evaluating the patient's various conditions. Some patients require additional time for diagnosis. At this time, the choice of ultrasound is critical. Therefore, the discussion of these two indicators in this study aims to provide reference value for future clinicians and researchers.

Accurate assessment of the location and size of ASD is crucial for determining the suitability of Amplatzer septal occluder implantation or surgical repair, and it relies on the effective utilization of TTE and TEE [28–30]. However, challenges arise in the vertical assessment of the interatrial septum, potentially leading to false-positive ASD diagnoses due to signal loss. This study found no significant disparity between TTE and TEE in long-axis measurement accuracy, suggesting the need for further large-scale validation to confirm this observation. TTE and TEE are highly effective tools for detecting ASD. However, given that the interatrial septum cannot be assessed vertically, signal loss may lead to a false-positive diagnosis of ASD [31]. For example, in TTE, it is difficult to find the optimal vertical axis of ASD with various landmarks, which may lead to insufficient assessment of surrounding edges [31]. Therefore, the long axis of ASD must be assessed. The results of this study showed no significant difference between TEE and TTE in the measurement of the long axis. We believe that a large sample survey is needed to verify this result.

This study highlighted the essential collaboration between TTE and TEE in cardiac surgeries, playing a crucial role in surgical success. While differing in procedural and observation times, they showed no significant variance in long-axis measurements. TTE guides cardiac interventions without the need for odds ratio (OR) entry, offering simplicity and swift postoperative recovery, whereas TEE serves as a vital adjunct and alternative for smaller incision methods, particularly in large defects and short margins. Both approaches demonstrate favorable clinical outcomes and safety, allowing for tailored selection and application based on patient-specific clinical contexts.

Despite advancements made in evaluating the methodology and outcomes of TTE and TEE in pediatric patients with ASDs, several limitations persist. First, our study encompassed a restricted scope of literature, comprising only six articles that met the inclusion criteria. This limited sample size may compromise the generalizability and reproducibility of our findings. Second, most studies provided comprehensive descriptions of randomized sequence generation, but deficiencies were noted in reporting allocation concealment and blinding, potentially affecting the internal validity and reliability of the findings. Moreover, our study may be susceptible to publication bias, as studies yielding positive or significant results are preferentially published, whereas those with negative or non-significant findings may be overlooked. This bias could skew the presentation of results in the literature, influencing the objective assessment of TTE and TEE effectiveness in guiding ASD surgical interventions. Thus, these limitations and the potential influence of publication bias must be acknowledged when interpreting our study's findings. Future investigations should aim to expand the sample size, enhance the methodological rigor, and explore the capabilities and constraints of cardiac ultrasound technology in managing pediatric cardiac diseases.

Conclusion

In general, the combination of TTE and TEE is a treatment method that is reliable and effective. It plays an important role in the success rate of surgery, and postoperative complications are relatively minimal. The combined use of the two methods could also be another option for treating room separation based on the good clinical effects and safety. In the future, doctors can choose the appropriate method according to the clinical conditions of patients, allowing children to benefit from minimal trauma and few complications.

Availability of Data and Materials

The original contributions presented in the study are included in the article/supplementary material. Further inquiries can be directed to the corresponding authors.

Author Contributions

HL: Conception, Design, Materials, Data Collection, Analysis, Literature Review, and Writing. JW: Design, Materials, Analysis, Literature Review, and Writing. LZ: Supervision, Materials, Data Collection, Analysis, and Writing. LL: Materials, Data Collection, Analysis, Writing, and Critical Review. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

Not applicable.

Acknowledgment

Not applicable.

Funding

This research received no external funding.

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.7353.

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