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Systematic Review

3D Transesophageal Echocardiography in the Selection of Occluder Size for Left Atrial Appendage Occlusion: A Meta-Analysis

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Abstract

Background: Left atrial appendage occlusion (LAAO) can effectively reduce the risk of stroke in atrial fibrillation (AF) patients. However, the structure of left atrial appendage (LAA) varies greatly among individuals, and the size of the occluder influences the surgical success rate and prognosis. This study used a meta-analysis to investigate whether three dimensional-transesophageal echocardiography (3D-TEE) can prompt physicians to select the appropriate size of the occluder, thereby improving prognosis in patients with LAAO. **Methods**: Studies on 3D-TEE-assisted selection of occluder sizes in the treatment of LAAO were searched in pubmed, cochrane, Web of Science, CNKI, Wanfang, and Weipu public databases from the inception of each database to June 10, 2024. The QUADAS-2 tool was used to assess the quality of the studies. **Results**: 10 studies published between 2016 and 2024 were finally included, with a total sample size of 552 cases. The maximum opening of the LAA obtained by 3D-TEE, coronary angiography (CAG) and video-assisted thoracic surgery (VATS) significantly correlated with the size of the occluder ($p < 0.05$). 3D-TEE was superior to 2D-TEE in measuring the maximum ($p = 0.04$) and minimum diameters ($p = 0.01$) of LAA openings, and to DSA in measuring depth ($p = 0.01$). **Conclusion**: 3D-TEE can be applied to obtain LAA opening data close to the size of the occluder with minimal side effects and to assist physicians in selecting the appropriate occluder.

Keywords

three dimensional-transesophageal echocardiography; left atrial appendage; meta-analysis; occluder

Introduction

Atrial fibrillation (AF), a prevalent tachyarrhythmia, poses a global public health challenge due to the increasing incidence and mortality every year [1]. A 25-year-long investigation showed that secondary stroke makes patients with AF more prone to death [1,2]. Therefore, the cornerstone of AF treatment lies in rhythm control, heart rate control and stroke prevention [3]. The cardiogenic embolism in AF patients has been confirmed as an independent risk factor for stroke, which is related to the function of the left atrial appendage (LAA) [2,4]. The LAA is located in the right anterior protrusion of the left atrium, the dysfunction of which can lead to thrombosis and increase the risk of cardiogenic embolic events [5]. Hence, effectively preventing cardiogenic embolism is of great significance to improve the prognosis of AF patients.

Oral anticoagulants can prevent stroke in AF patients, but long-term use may result in adverse reactions such as bleeding [6]. Left atrial appendage occlusion (LAAO), as an alternative to long-term use of anticoagulants, can effectively reduce the risk of stroke in AF patients [7–9]. Specifically, LAAO has favorable short- and long-term effects in preventing the development of stroke in AF patients and is suitable for patients with contraindications to anticoagulants [6,10]. However, the LAA structure is narrow and curved and exhibits considerable variability among individuals; meanwhile, the selection of occluder size that is not well-matched can compromise surgical success [11]. For example, an under-sized occluder may result in residual leakage around the device, and conversely an over-sized occluder could potentially cause perforation of the LAA. Currently, imaging testing tools are used preoperatively to assess the LAA structure of patients and to assist the physician in selecting the appropriate size of the occluder [12]. However, the choice of treatment modality is often limited at the discretion of the physician, or by local hospital conditions or the conditions of patients.

In this study, we analyzed the correlation between the maximum diameter of the LAA opening and the diameter of the occluder detected by three dimensional-transesophageal echocardiography (3D-TEE) to assess the potential of 3D-TEE as a pivotal instrument in helping physicians select appropriate occluders. TEE has the advantage of being user-friendly and avoiding the adverse effects of radiation and contrast agents on the patients compared to X-ray and contrast testing. 3D imaging provides a more comprehensive view of the structure of the LAA opening in plane and space than 2D imaging. The comparative studies on various types of testing tools to measure the maximum diameter of LAA openings may be subjected to bias due to a small sample size. Herein, a meta-analysis was conducted to delve deeply into the reference value of 3D-TEE for the selection of the occluder, and to promote the application of 3D-TEE in the treatment of AF and stroke prevention.

Methods

Search Strategy

According to the statement of PRISMA 2020 (**Supplementary Table 1**), the published articles both in Chinese and English were searched in pubmed, cochrane, Web of Science, CNKI, Wanfang, and Weipu public databases from the inception of each database to June 10, 2024, following the PICOS principle and utilizing MeSH combined with free words. MeSH included Echocardiography, Transesophageal, Three Dimensions, Left atrial appendage closure and Heart atria. Free words encompassed Three-dimensional transesophageal echocardiography, Left atrial structure, and Left atrial function. The search process involved three researchers, with the third researcher making the final decision when two researchers disagreed on the inclusion of a particular article. In addition, our meta-analysis has been registered on the PROSPERO platform with the registration number of CRD42024655390.

Inclusion and Exclusion Criteria

The inclusion criteria were as follows: (1) study subjects undergoing LAA occluder placement and having relevant indices measured using 3D-TEE; (2) study subjects not restricted by age, gender, or race; (3) observational clinical studies using 3D-TEE in the selection of LAA occluder size; (4) studies with the most recent reporting time or the most complete data; (5) having at least one primary outcome metric or secondary outcome metric. Given the specific analysis on the application value of 3D-TEE in selecting the size of LAA occluder in this study, we excluded studies in a review format or in a technical report format, studies involving animal or cellular subjects, and studies with complete data unavailable from published results for objective assessment. 10 studies published from 2016 to 2024 were finally included, with a total sample size of 552 cases.

Risk of Bias and Applicability Judgments

After screening based on the inclusion and exclusion criteria, we evaluated the quality of the studies using the QUADAS-2 tool. The details of assessment are shown in Table 1, and to visualize the quality assessment of the study, the data were plotted using Review Manager Software (version 5.3, Cochrane Collaboration, Oxford, UK). Three researchers were involved in the quality assessment, with two researchers simultaneously determining the final inclusion of the study, and the third researcher determining the results in case of disagreement over the assessment.

Data Extractions

The researcher read the full text and extracted data from the finally included articles, incorporating basic information (e.g., first author, year of publication, and sample size), baseline information (e.g., sex, age, CHADS2 and HAS-BLED scores), and underlying conditions (e.g., hypertension, diabetes mellitus, coronary heart disease, history, and LAA thrombosis), as well as the test tools used to evaluate the maximum diameter of the LAA opening. The final information covered the occluder diameter, the maximum diameter, the minimum diameter and depth of the LAA opening, and the correlation coefficient with the maximum diameter of the occluder measured by 3D-TEE, 2D-TEE, X-Ray Radiography (DSA), coronary angiography (CAG), CT angiography (CTA), and video-assisted thoracic surgery (VATS). Three researchers participated in data extraction, with two researchers extracting data simultaneously and the third researcher making the final decisions for whether the data information could be included, or when there were differences in the extraction of data information for picture types.

Statistical Analyses

The extracted data were transformed as follows and then meta-analyzed using Review Manager (version 5.3, Cochrane Collaboration, Oxford, UK) and Stata Software (Stata Corporation, College Station, TX, USA). The conversion formula was as follows:

$$\textit{Fisher's Z} = 0.5 \times \ln \frac{1+r}{1-r} \tag{1}$$

$$Vz = \frac{1}{n-3} \tag{2}$$

$$S_E = \sqrt{Vz} \tag{3}$$

$$\text{Summary } r = \frac{e^{2z}-1}{e^{2z}+1} \tag{4}$$

For data that were scale-type and had a correlation coefficient *r* value for the outcome variable, the *fisher's Z* value was converted using the above formula, and then entered into the Review Manager software with standard error

Table 1. Essential elements of the QUADAS-2 tool for evaluating research quality.

Domain	Patient selection	Index test	Reference standard	Flow and timing
Description	Describe methods of patient selection: Describe included patients (prior testing, presentation, intended use of index test and setting)	Describe the index test and how it was conducted and interpreted	Describe the reference standard and how it was conducted and interpreted	Describe any patients who did not receive the index test(s) and/or reference standard or who were excluded from the 2 × 2 table (refer to flow diagram): Describe the time interval and any interventions between index test(s) and reference standard
Signaling questions (yes/no/unclear)	Was a consecutive or random sample of patients enrolled? Was a case-control design avoided? Did the study avoid inappropriate exclusions?	Were the index test results interpreted without knowledge of the results of the reference standard? If a threshold was used, was it pre-specified?	Is the reference standard likely to correctly classify the target condition? Were the reference standard results interpreted without knowledge of the results of the index test?	Was there an appropriate interval between index test(s) and reference standard? Did all patients receive a reference standard? Did all patients receive the same reference standard? Were all patients included in the analysis?
Risk of bias: High/low/unclear	Could the selection of patients have introduced bias?	Could the conduct or interpretation of the index test have introduced bias?	Could the reference standard, its conduct, or its interpretation have introduced bias?	Could the patient flow have introduced bias?
Concerns regarding applicability: High/low/unclear	Are there concerns that the included patients do not match the review question?	Are there concerns that the index test, its conduct, or interpretation differs from the review question?	Are there concerns that the target condition as defined by the reference standard does not match the review question?	

Table 2. The general characteristics of the included literature.

Study	Year	Sample size	Age (y)	Gender (male/female)	CHADS2 (score)	HAS-BLED (score)	Hypertensive	Diabetes	Coronary heart disease	History of stroke	History of left auricular thrombus	Diagnostic methods
Yosefy *et al.* [13]	2016	30	64.30 ± 11.80 (NA)	16/14	NA	NA	NA	NA	NA	NA	NA	2D/3D
Al-Kassou *et al.* [14]	2017	46	75.00 ± 7.00 (NA)	32/14	4.30 ± 1.80	4.40 ± 1.00	43	13	19	NA	NA	2D/3D/CAG
Li *et al.* [21]	2019	62	68.30 ± 8.60 (55~79)	39/23	NA	≥2	NA	NA	NA	NA	NA	2D/3D/CAG
Jin *et al.* [22]	2019	47	68.47 ± 9.07 (NA)	26/21	3.77 ± 1.20	2.67 ± 0.96	29	7	15	28	NA	2D/3D/DSA
Zhang *et al.* [17]	2019	32	65.80 ± 10.50 (NA)	22/10	4.30 ± 1.20	3.20 ± 0.60	23	10	NA	28	NA	2D/3D
Peng *et al.* [19]	2023	42	68.24 ± 8.59 (47~78)	22/20	3~7	3~7	NA	10	NA	NA	NA	3D/CT/DSA
Sun *et al.* [18]	2022	37	61.20 ± 9.98 (NA)	19/18	3.20 ± 1.32	2.17 ± 0.92	25	12	5	4	NA	2D/3D/CTA
Bai *et al.* [15]	2017	189	59.4 ± 11.8 (NA)	118/71	NA	NA	72	14	NA	6	NA	3D/CT
Zhou *et al.* [16]	2017	28	66.64 ± 8.52 (NA)	15/13	3.86 ± 1.33	NA	24	4	NA	NA	NA	2D/3D/CT/X-ray
Duan *et al.* [20]	2024	41	59.3 ± 9.0 (NA)	31/10	NA	NA	23	7	6	10	NA	2D/3D/VATS

2D, Two Dimensional-Transesophageal Echocardiography; 3D, Three Dimensional-Transesophageal Echocardiography; DSA, X-Ray Radiography; CAG, coronary angiography; CTA, CT angiography; CT, computed tomography; VATS, video-assisted thoracic surgery.

(S_E) to derive the summary r value using the inverse variance method. Heterogeneity was analyzed based on the chi-square test results, and either a random-effects model ($p < 0.1$, $I^2 > 50\%$) or a fixed-effects model ($p \geq 0.1$, $I^2 \leq 50\%$) was chosen for the analysis. In addition, outcomes with high heterogeneity were analyzed using meta-regression to rank possible sources of heterogeneity, and a sensitivity analysis was performed by comparing *fisher's Z* value for the fixed-effects model and the random-effects model. Besides, outcomes with included studies greater than 5 were dissected for publication bias. Finally, summary *r* value was employed to evaluate the correlation coefficient between the occluder diameter and the maximum diameter of the LAA opening measured by each detection tool. Normally, their correlation was judged by the absolute value of the correlation coefficient *r* with the absolute value closer to 1 indicating stronger correlation.

Table 3. Correlation between maximum diameter of LAA opening detected by each measurement tool and occluder size.

		Occluder size	
	r	95% CI lower limit	95% CI upper limit
2D-TEE	0.725897	0.604367777	0.817754
3D-TEE	0.824272	0.753065905	0.874053
CT	0.807569	0.66959026	0.893698
DSA	0.769867	0.272905081	0.942503
CAG	0.864275	0.604367777	0.958733
VATS	0.861723	0.757362324	0.924624

LAA, left atrial appendage; 2D-TEE, two dimensional-transesophageal echocardiography; 3D-TEE, three dimensional-transesophageal echocardiography; DSA, X-Ray radiography; CAG, coronary angiography; CT, computed tomography; VATS, video-assisted thoracic surgery; CI, confidence interval.

Results

Search Results

Initially 347 studies were identified based on the search strategy. After ineligible and duplicate studies were removed as per the inclusion and exclusion criteria, 10 studies were finally included [13–22]. Fig. 1 indicates the selection process.

General Characterization and Quality Assessment of Included Studies

The included 10 studies were published from 2016 to 2024, with a total sample size of 552 cases. Table 2 (Ref. [13–22]) provides an overview of the general characteristics of the included studies. All included studies were not case-control trials, and all included cases were enrolled continuously with high clinical appropriateness. The inclusion and exclusion criteria for case screening were relatively complete. Fig. 2 presents the quality assessment of all included studies, revealing that the studies included had moderate quality.

Correlation Assessment of the Maximum LAA Opening Obtained by Each Measurement Tool with the Occluder Diameter

The maximum diameters of the LAA openings obtained by each measurement tool were compared to the diameter of occlude, and it was found that the maximum LAA opening was related to the size of the occluder, especially the 2D-TEE and 3D-TEE (Fig. 3). *Fisher's Z* value was converted to *r* value (Table 3). The largest *r* values were found in CAG (r = 0.864275) and VATS (r = 0.861723), followed by 3D-TEE (r = 0.824272), hinting that the most appropriate measurement tools for assisting the physician in selecting the occluder size were CAG and VATS, and that the 3D-TEE was a slightly inferior choice. Due to $p < 0.1$ and $I^2 > 50\%$, there was significant heterogeneity among the studies in Fig. 3A (p = 0.002 and I^2 = 71%), Fig. 3B (p = 0.009 and I^2 = 63%), Fig. 3C (p = 0.002 and I^2 = 90%), and Fig. 3E (p = 0.0007 and I^2 = 91%). Fig. 3D,F included only one study and do not need to analyze heterogeneity.

Comparative Summary of 2D-TEE and 3D-TEE

The maximum diameter of LAA openings measured by 2D-TEE and 3D-TEE was counted in 6 of the included studies, with mean difference value of 1.26 (95% CI: 0.04, 2.48; p = 0.04; I^2 = 85%) (Fig. 4A). The minimum diameter was counted in 3 studies with mean difference value of 0.93 (95% CI: 0.21, 1.65; p = 0.01; I^2 = 0%; Fig. 4B). The depth of LAA opening was calculated in 2 studies with mean difference value of 0.39 (95% CI: –0.55, 1.33; p = 0.41; I^2 = 0%; Fig. 4C). According to p and I^2 values in Fig. 4, there was evident heterogeneity among the studies in Fig. 4A (p < 0.00001 and I^2 = 85%), but no heterogeneity among the studies in Fig. 4B (p = 0.82 and I^2 = 0%) and Fig. 4C (p = 0.38 and I^2 = 0%). Collectively, this meta-analysis demonstrated that 3D-TEE outperformed 2D-TEE in measuring maximum and minimum diameters of LAA opening.

Comparative Summary of CT and 3D-TEE

The maximum diameter of LAA openings measured by CT and 3D-TEE was analyzed in 3 of the included studies, with mean difference value of 0.20 (95% CI: –1.21, 1.60; p = 0.78; I^2 = 64%) (Fig. 5A). The minimum diameter was counted in only 1 study with mean difference value of –0.75 (95% CI: –2.05, 0.55; p = 0.26; Fig. 5B). Besides, the depth of LAA opening was detected in 2 studies with mean difference value of –1.75 (95% CI: –3.07, –0.44; p = 0.009; I^2 = 42%; Fig. 5C). In light of p and I^2 values in

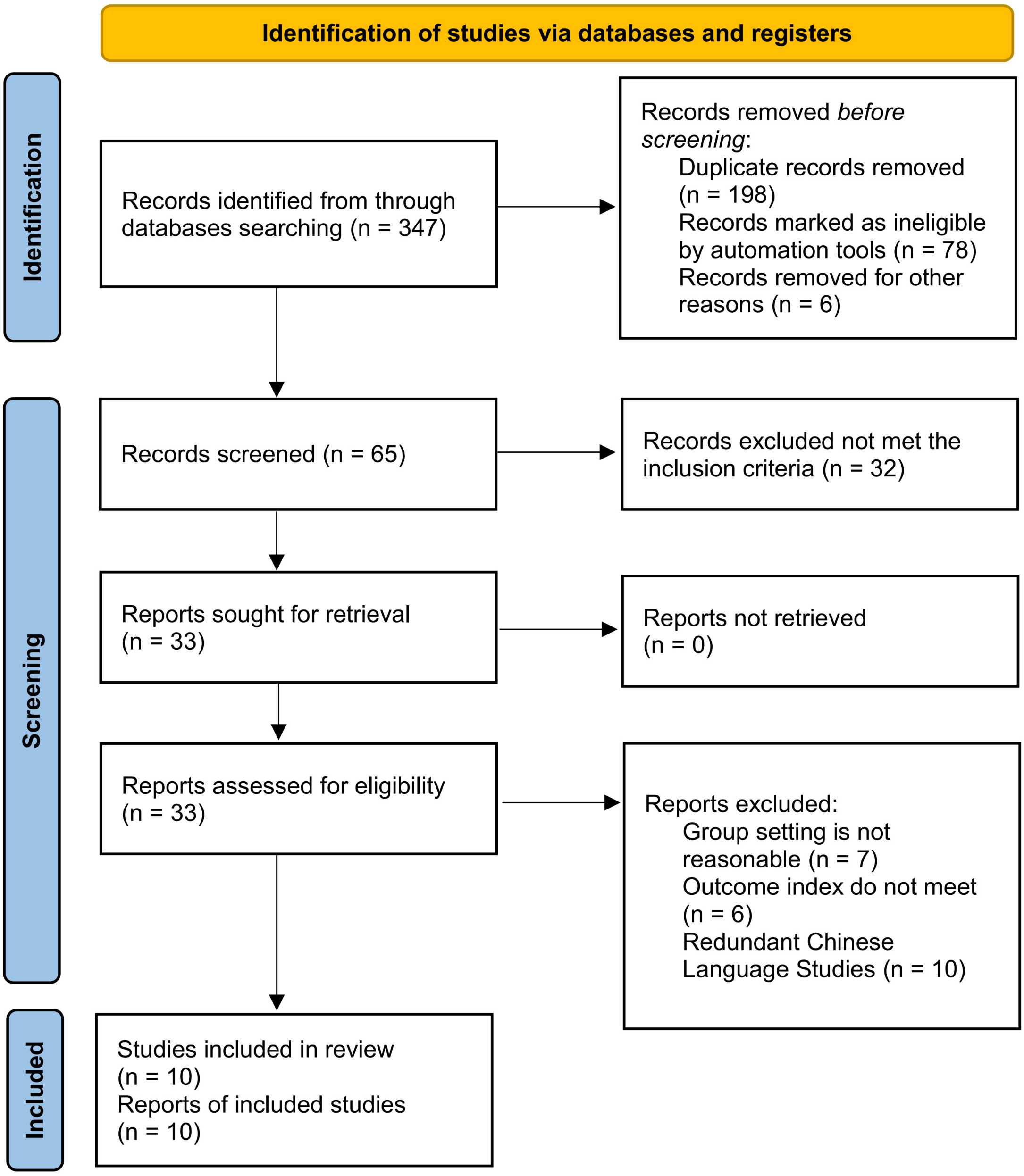

Fig. 1. Flowchart of the study search.

Fig. 5, studies in Fig. 5A exhibited apparent heterogeneity ($p = 0.06$ and $I^2 = 64\%$), while the heterogeneity cannot be ruled out among studies in Fig. 5C ($p = 0.19$ and $I^2 = 42\%$). In conclusion, this meta-analysis revealed that 3D-TEE was inferior to CT in measuring the depth of LAA opening.

Comparative Summary of DSA and 3D-TEE

The maximum diameter of LAA openings measured by DSA and 3D-TEE was assessed in 2 of the included studies, with mean difference value of 0.01 (95% CI: –0.87, 0.90; $p = 0.97$; $I^2 = 0\%$) (Fig. 6A), while the minimum diameter was counted in only 1 study with mean difference value of –0.50 (95% CI: –1.84, 0.84; $p = 0.47$; Fig. 6B). The depth of LAA opening was measured in 1 study with mean difference value of 2.11 (95% CI: 0.49, 3.73; $p = 0.01$; Fig. 6C). In line with p and I^2 values in Fig. 6, no heterogeneity was detected among the studies in Fig. 6A ($p = 0.98$ and $I^2 = 0\%$). In short, this meta-analysis verified that 3D-TEE was superior to DSA in measuring the depth of LAA opening.

Comparative Summaries of VATS and 3D-TEE

The maximum diameter of LAA openings measured by VATS and 3D-TEE was dissected in only 1 study of the included studies, with mean difference value of –1.36 (95% CI: –1.59, –1.13; $p < 0.001$; Fig. 7), suggesting that 3D-TEE was inferior to VATS in determining maximum diameters of LAA openings.

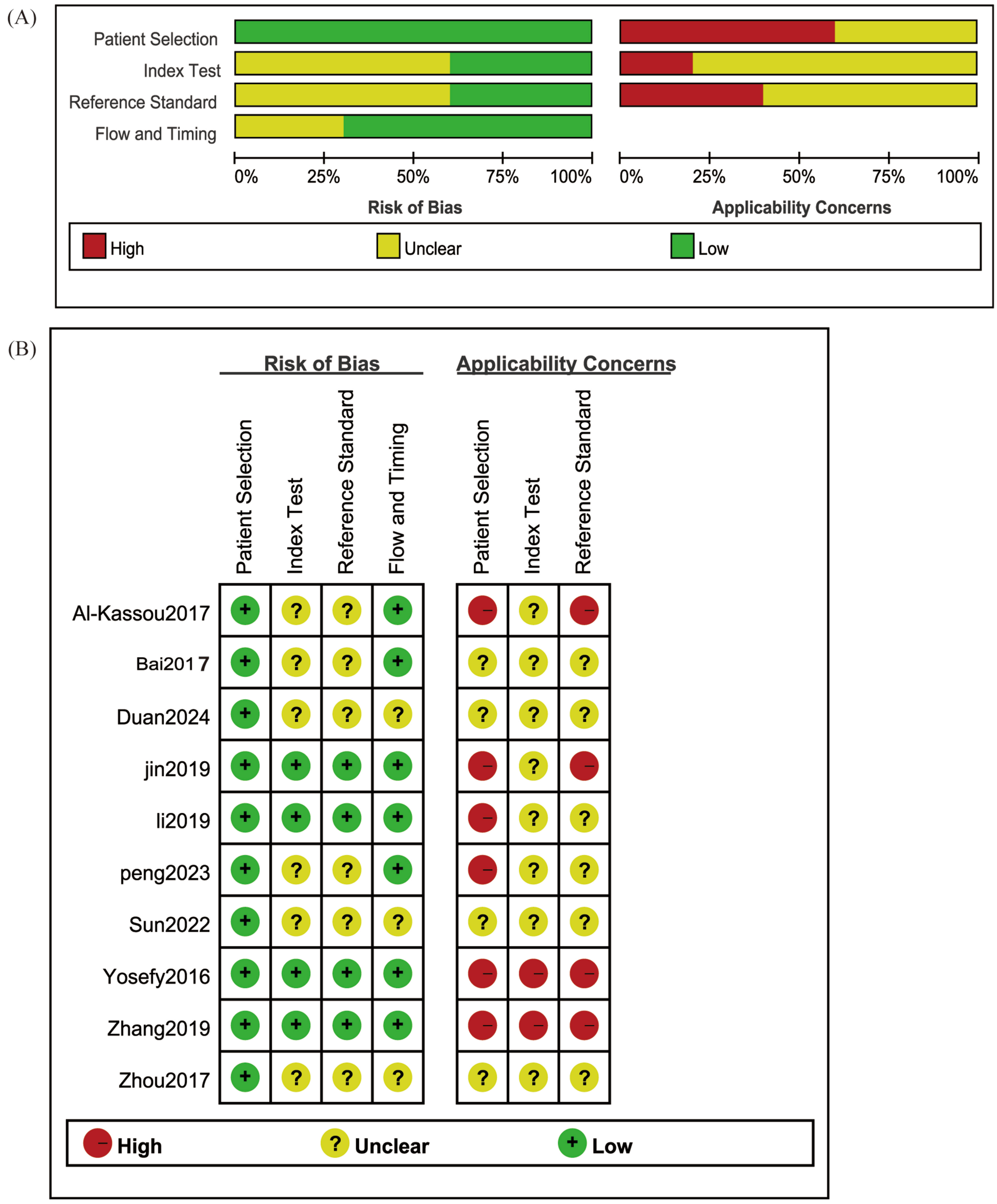

Fig. 2. Quality assessment. (A) Risk of bias and applicability concerns graph. (B) Risk of bias and applicability concerns summary.

Heterogeneity Analysis

Outcomes with high heterogeneity were analyzed using meta-regression to rank possible sources of heterogeneity. Each measurement tool and the occluder size were highly correlated as revealed by the statistical results, irrespective of the presence of heterogeneity (Fig. 3). When comparing the maximum diameter of the LAA opening obtained from 2D-TEE and 3D-TEE, Duan *et al*. [20] used the Atriclip effective length as a control. We hypothesized that the difference in calculation methods may be the source of heterogeneity. After dividing Duan's literature and the other one into two subgroups, Cochran's Q statistic analysis revealed that within-group heterogeneity disappeared (Fig. 8), a result supported by regression analysis ($t = 0.64$, $p = 0.555$). For outcomes that included fewer than 5 papers, the limited data made it challenging to determine the source of heterogeneity, which therefore were not further discussed.

Sensitivity Analysis

To fathom the correlation between the maximum diameter of LAA opening obtained by each measurement tool and the size of the occluder, a sensitivity analysis was performed by comparing *fisher's Z* value for the fixed-effects

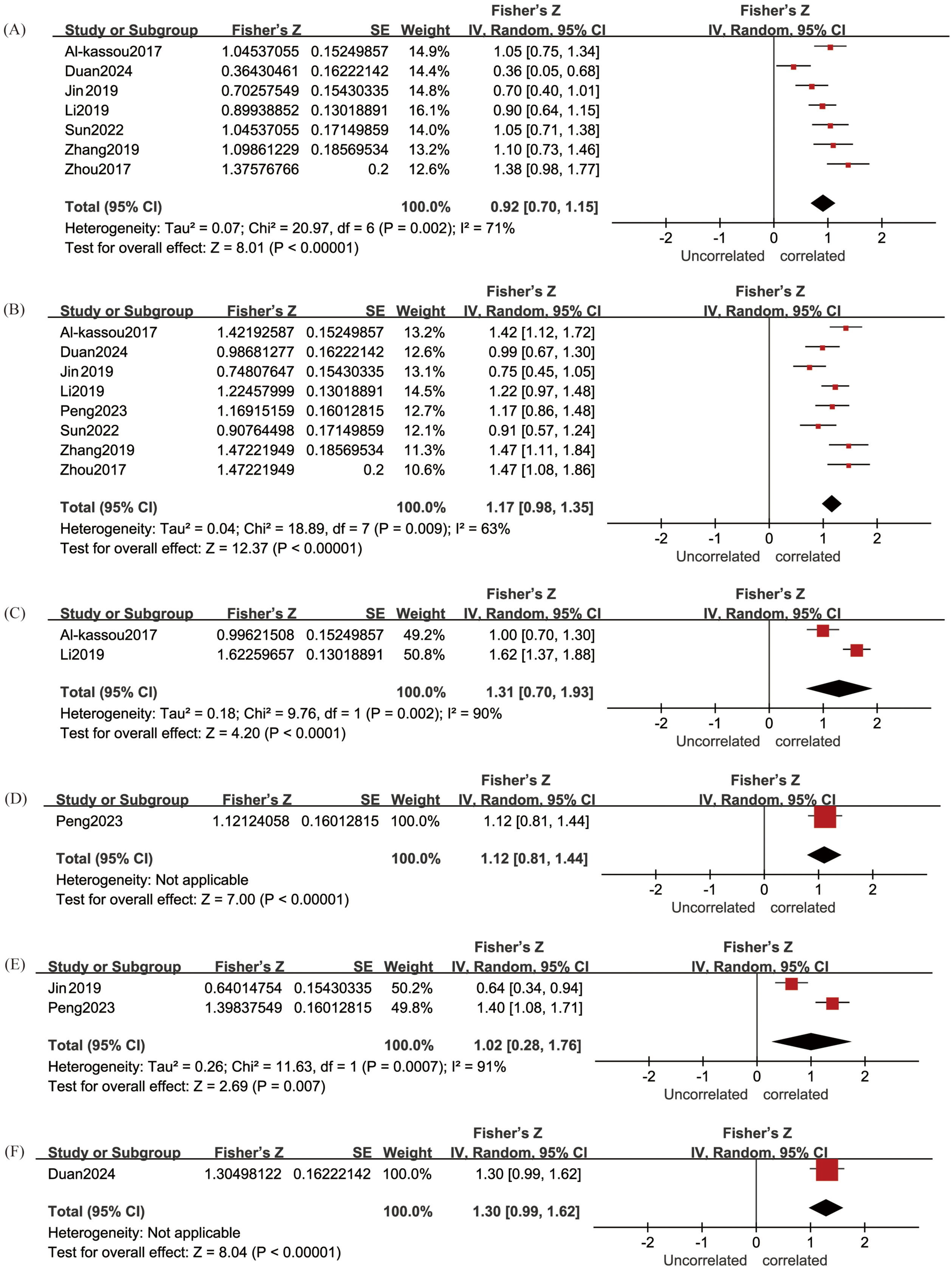

Fig. 3. Forest plot of correlation between maximum LAA opening detected by each measurement tool and diameter of occluder. (A) 2 dimensional-transesophageal echocardiography. (B) 3 dimensional-transesophageal echocardiography. (C) Coronary angiography. (D) CT angiography. (E) X-Ray radiography. (F) Video-assisted thoracic surgery. LAA, left atrial appendage.

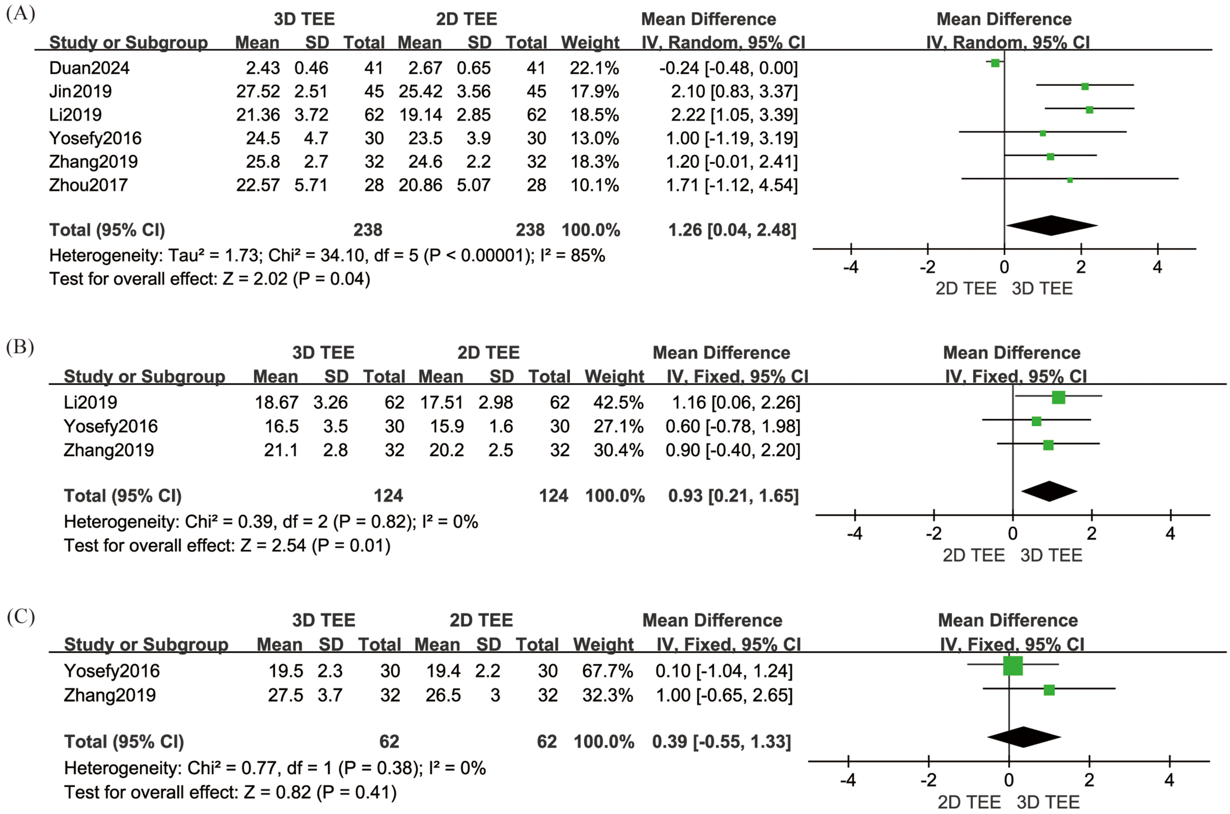

Fig. 4. Comparative summaries of 2D-TEE and 3D-TEE. (A) Comparison of maximum diameter of LAA openings measured by 2D-TEE and 3D-TEE. (B) Comparison of minimum diameter of LAA openings measured by 2D-TEE and 3D-TEE. (C) Comparison of the depth of LAA openings measured by 2D-TEE and 3D-TEE. 2D-TEE, 2 dimensional-transesophageal echocardiography; 3D-TEE, 3 dimensional-transesophageal echocardiography; LAA, left atrial appendage.

Table 4. Sensitivity analysis results for the correlation between the maximum LAA opening detected by each measurement tool and the size of the occluder.

	Random effects	Fix effects
	Fisher's Z (95% CI)	*Fisher's Z* (95% CI)
2D-TEE	0.92 (0.70, 1.15)	0.90 (0.78, 1.02)
3D-TEE	1.17 (0.98, 1.35)	1.16 (1.05, 1.27)
CT	1.31 (0.70, 1.93)	1.36 (1.16, 1.55)
CTA	1.12 (0.81, 1.44)	1.12 (0.81, 1.44)
DSA	1.02 (0.28, 1.76)	1.01 (0.79, 1.22)
VATS	1.30 (0.99, 1.62)	1.30 (0.99, 1.62)

model and the random-effects model. The combined effect values were found to be relatively similar, indicating that the analysis was robust and reliable, and the results of the sensitivity analysis are detailed in Table 4.

Publication Bias

Outcomes with included studies greater than 5 were analyzed for publication bias. A funnel plot of the correlation between the maximum diameter of LAA opening obtained by each measurement tool and the size of the occluder was plotted, and the absence of missing corners in the plot signified no publication bias (Fig. 9). In addition, the scatter points were more evenly distributed on both sides of the null line and lay outside the confidence intervals, indicating the presence of heterogeneity, which was consistent with previous results. Funnel plots were drawn for comparing the maximum diameters of LAA obtained by 2D-TEE and 3D-TEE, where no missing corners were observed; however, there were scatters that lay outside the confidence intervals, denoting a publication bias (Fig. 10A). After excluding the study by Duan *et al.* [20], all scatter points were within the confidence interval and were distributed on both sides of the null line (Fig. 10B). This suggested that the difference in calculation methods has contributed to discrepancy.

Discussion

The 10 included studies have been confirmed to have moderate to relatively high quality by means of QUADAS-2 tool [23], enhancing the reliability of our findings. The sample size varied with some studies including up to 189 cases, and others as few as 28. It is generally accepted that

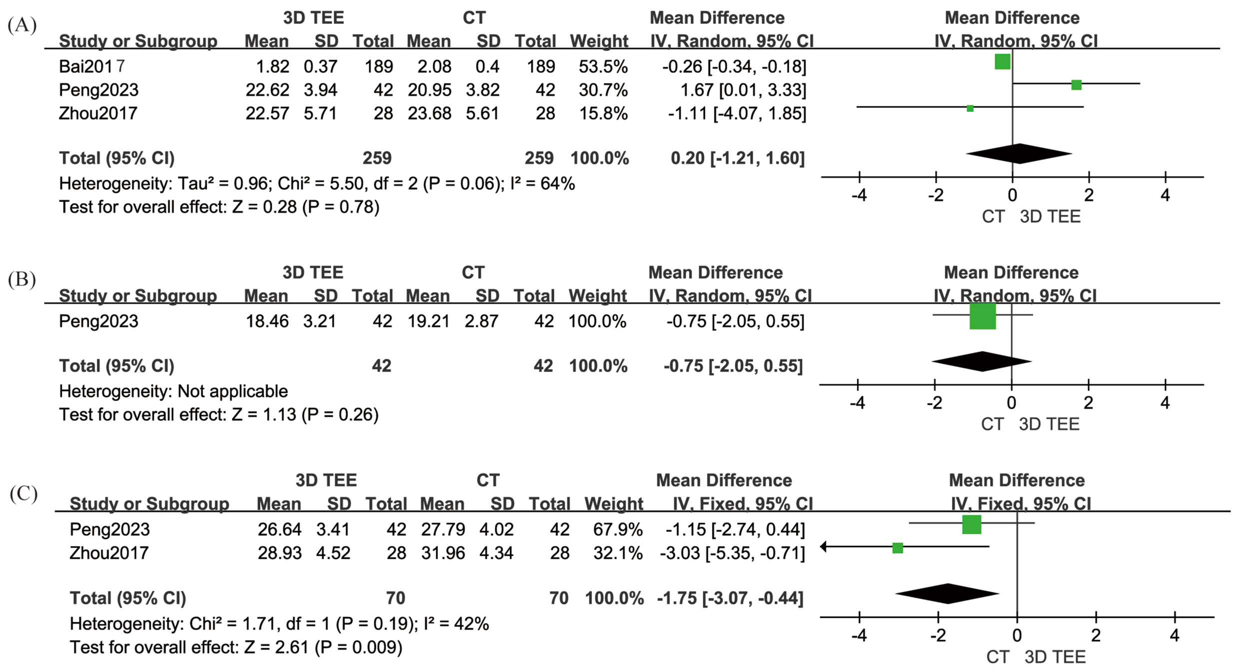

Fig. 5. Comparative summaries of CT and 3D-TEE. (A) Comparison of the maximum diameter of LAA openings measured by CT and 3D-TEE. (B) Comparison of the minimum diameter of LAA openings measured by CT and 3D-TEE. (C) Comparison of the depth of LAA openings measured by CT and 3D-TEE. CT, CT angiography; 3D-TEE, 3 dimensional-transesophageal echocardiography; LAA, left atrial appendage.

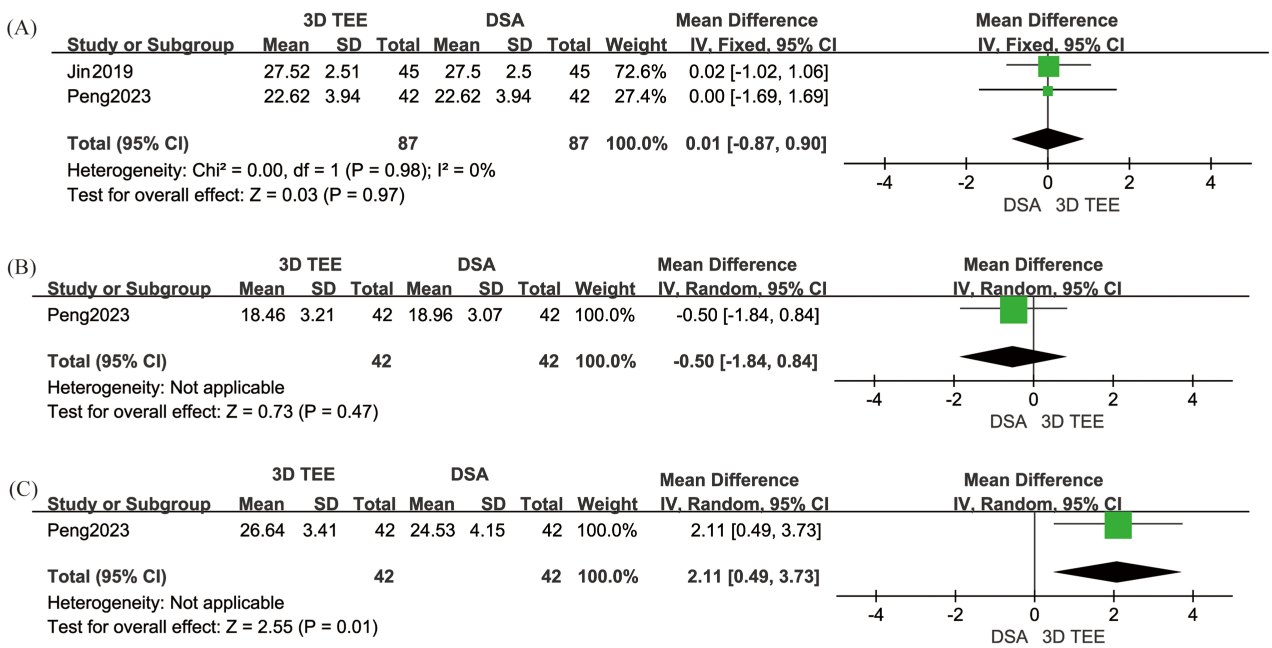

Fig. 6. Comparative summaries of DSA and 3D-TEE. (A) Comparison of the maximum diameter of LAA openings measured by DSA and 3D-TEE. (B) Comparison of the minimum diameter of LAA openings measured by DSA and 3D-TEE. (C) Comparison of the depth of LAA openings measured by DSA and 3D-TEE. DSA, X-Ray radiography; 3D-TEE, 3 dimensional-transesophageal echocardiography; LAA, left atrial appendage.

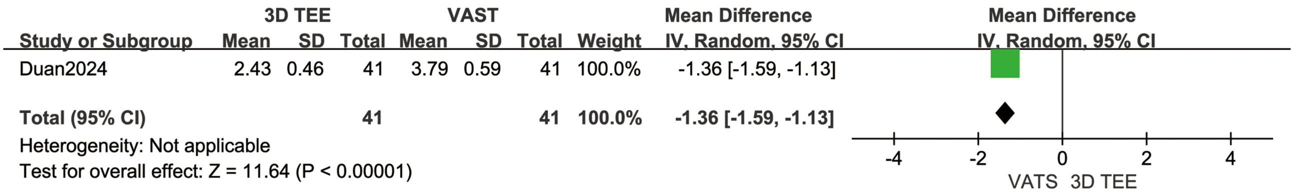

Fig. 7. Comparison of maximum diameters of LAA openings measured by 3D-TEE and VATS. LAA, left atrial appendage; 3D-TEE, 3 dimensional-transesophageal echocardiography; VATS, video-assisted thoracic surgery.

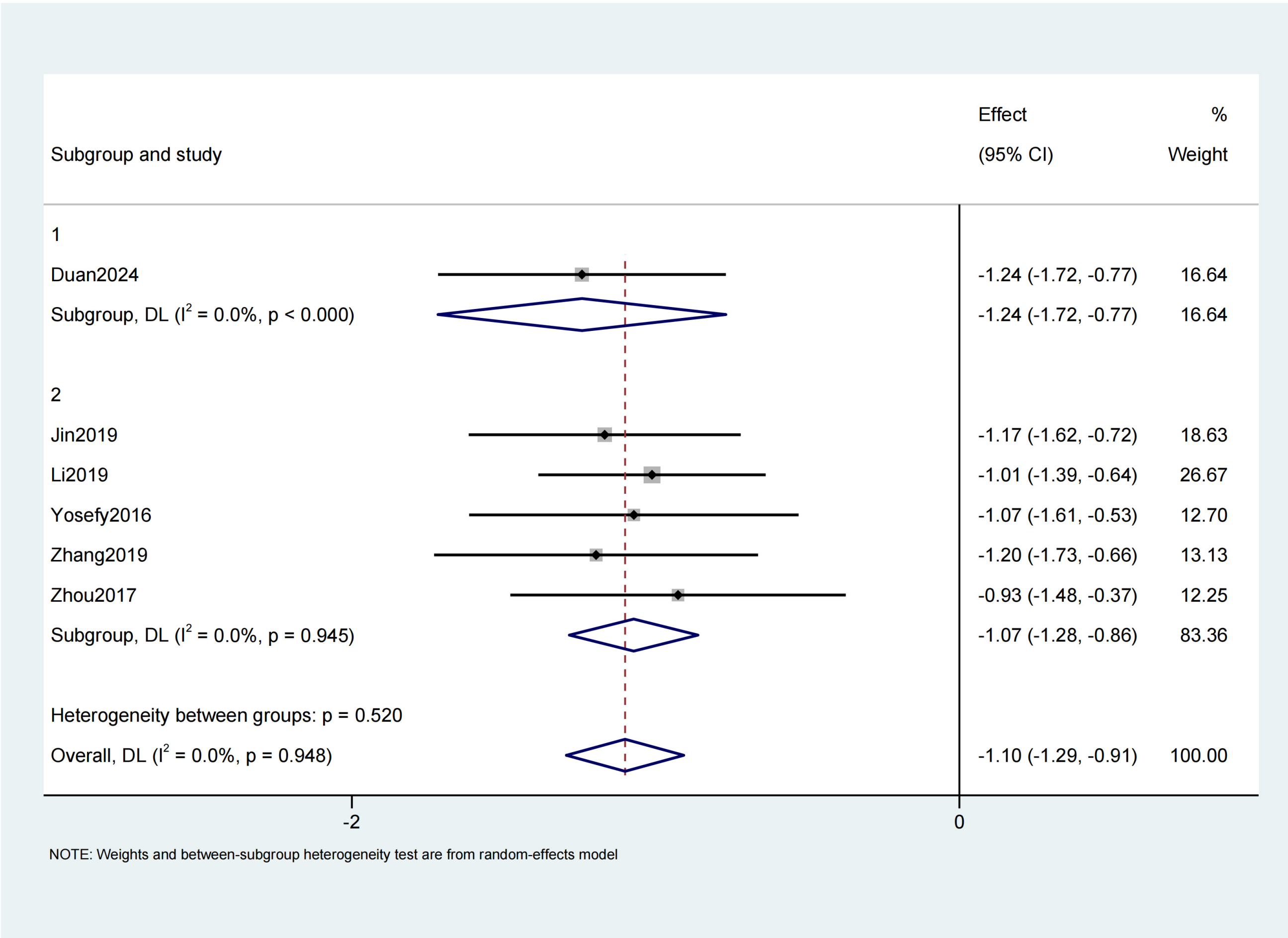

Fig. 8. Analysis of heterogeneity in comparing the maximum diameter of LAA opening measured by 2D-TEE and 3D-TEE.

conclusions drawn from larger sample sizes may be more reliable; however, small and accurate studies may yield more interesting insights [24]. Meanwhile, the basic characteristics of the patients selected in different studies, such as medical history, may also introduce bias into the conclusions. In addition to sample size and patient selection, the index test, reference standard, and flow and timing may have biases in our study, which possibly led to the deviation of the results. In this review, we compared the maximum diameter, the minimum diameter and depth of LAA openings obtained by tools including 3D-TEE. We found that when comparing the *r* values of the maximum diameters, CAG and VATS were proved to be better measurement tools than 3D-TEE; however, CAG may negatively impact the angiography, and only 1 article included VATS, which may have biased the results. Further, for CAG, VATS and 3D-TEE, additional clinical trials can be performed to deeply investigate their advantages for LAAO.

Several studies have demonstrated that LAAO is an effective modality for stroke prevention in patients with AF [25–27]. In LAAO, clearer visualization of the morphology and size of LAA opening and the appropriate size of the occluder are critical for the success of the procedure [28]. Currently, DSA combined with 2D-TEE is the routine tool to select the size of the occluder, which however was questioned gradually [29,30], and prompted the evaluation and observation of the new technique 3D-TEE [31]. Theoretically, 3D-TEE can unveil spatial and 3D morphology of

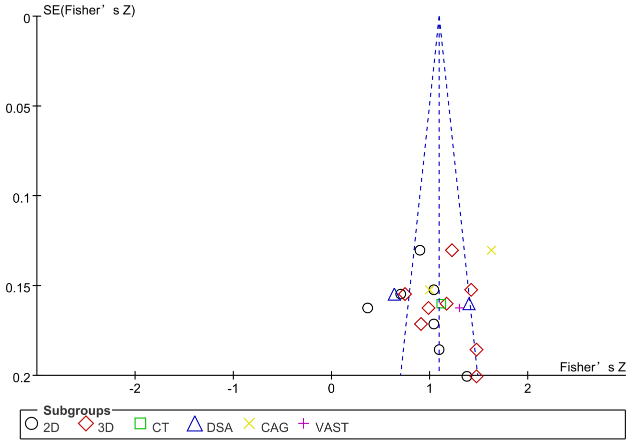

Fig. 9. Funnel plot of correlation between the maximum diameter of LAA opening detected by each measuring tool and the size of the occluder.

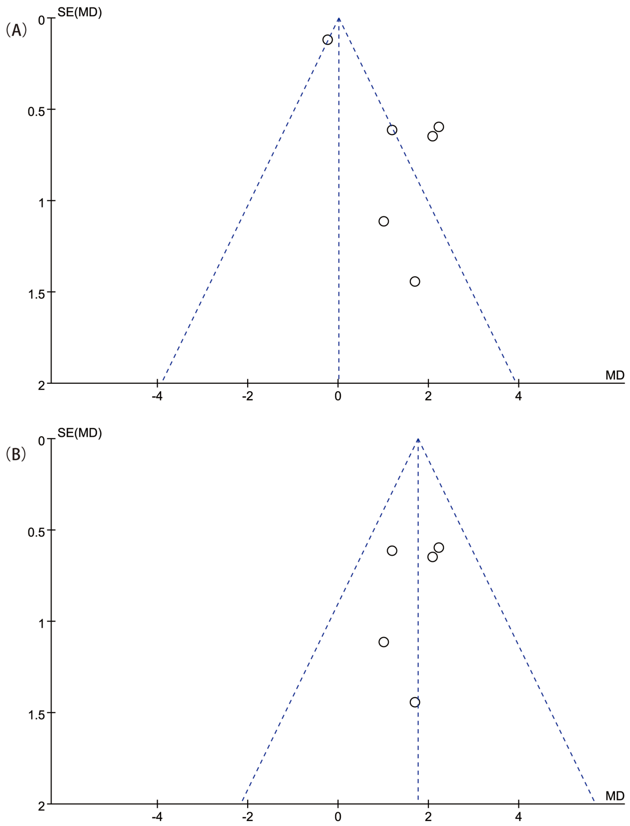

Fig. 10. Funnel plot for comparison between 2D-TEE and 3D-TEE. (A) Funnel plot for comparison between 2D-TEE and 3D-TEE. (B) After excluding the study by Duan *et al.* [20], funnel plot for comparison between 2D-TEE and 3D-TEE.

LAA from multiple angles and can be a more effective detection tool, which requires further support from substantial high-quality factual evidence. Of note, this review pooled several high-quality relevant studies to validate 3D-TEE as an assisted detection tool in the selection of an appropriate occluder for patients through a comprehensive and comparative meta-analysis. Analogous to previous studies [14,19,21], this review identified that 3D-TEE had significant advantages over other tools, such as 2D-TEE and DSA, in choosing the optimal device size for LAAO.

Some limitations exist in this review and more evidence is needed to bolster up our results. Since only one study used X-ray for detection and the majority used the DSA method, we did not discuss X-ray-related results in the specific calculations. Differences in brands of occluders have not been considered, and besides the familiar Watchman device, products from other companies that may be equally effective for LAAO have been approved and came into the market [32]. When evaluating the detection tools, we directly compared the r value of the correlation between the measured maximum LAA opening and the occluder size, and also compared the depth of the occluder and the minimum diameter of the LAA opening obtained with 3D-TEE and other tools. However, because of the small number of included studies, the network-meta could not be tested for consistency and ring inconsistency. We look forward to further development in this field together with more high-quality articles on 3D-TEE-assisted LAAO, which in turn will allow us to evaluate the advantages of 3D-TEE more comprehensively.

Conclusion

In summary, this meta-analysis shows that 3D-TEE can more effectively measure LAA opening closer to occluder size and is less harmful than other measurement tools. More specifically, 3D-TEE is superior to 2D-TEE in measuring the maximum ($p = 0.04$) and minimum diameters ($p = 0.01$) of LAA openings, and to DSA in measuring the depth of LAA openings ($p = 0.01$). This suggests that 3D-TEE can be applied more frequently to detect relevant parameters, including the maximum diameter of LAA opening, when selecting the size of the occluder prior to LAAO surgery. Therefore, 3D-TEE serves as an effective tool for assisting physicians in selecting the appropriate size of the occluder, contributive to improving surgical outcomes and efficiency. In the future, we will expand the sample size and continue to evaluate the application advantages of 3D-TEE in LAAO surgery.

Availability of Data and Materials

The analyzed data sets generated during the study are available from the corresponding author on reasonable request.

Author Contributions

Substantial contributions to conception and design: ZZ. Data acquisition, data analysis and interpretation: JD, YY, YX, KX, ND, ML. Drafting the article or critically revising it for important intellectual content: All authors. Final approval of the version to be published: All authors. Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of the work are appropriately investigated and resolved: All authors.

Ethics Approval and Consent to Participate

Not applicable.

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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.7735.

References

[1] Lip GYH, Proietti M, Potpara T, Mansour M, Savelieva I, Tse HF, *et al*. Atrial fibrillation and stroke prevention: 25 years of research at EP Europace journal. Europace. 2023; 25: euad226.

[2] Holmes DR, Jr, Korsholm K, Rodés-Cabau J, Saw J, Berti S, Alkhouli MA. Left atrial appendage occlusion. EuroIntervention. 2023; 18: e1038–e1065.

[3] Li J, Gao M, Zhang M, Liu D, Li Z, Du J, *et al*. Treatment of atrial fibrillation: a comprehensive review and practice guide. Cardiovascular Journal of Africa. 2020; 31: 153–158.

[4] Diegolli H, Oliveira RENDN, Silva CFD, Silva GFD, Souza FFD, Machado FRA, *et al*. Incidence of cardioembolic stroke related to atrial fibrillation in Joinville, Brazil. Arquivos De Neuro-Psiquiatria. 2023; 81: 329–333.

[5] Karim N, Ho SY, Nicol E, Li W, Zemrak F, Markides V, *et al*. The left atrial appendage in humans: structure, physiology, and pathogenesis. Europace. 2020; 22: 5–18.

[6] Cruz-González I, Trejo-Velasco B. Percutaneous left atrial appendage occlusion in the current practice. Kardiologia Polska. 2021; 79: 255–268.

[7] Sylvester CB, Patel V, Ghanta RK, Loor G. Considerations for Left Atrial Appendage Occlusion During Cardiac Surgery. Cardiovascular Drugs and Therapy. 2023; 37: 1011–1019.

[8] Tsai YC, Phan K, Munkholm-Larsen S, Tian DH, La Meir M, Yan TD. Surgical left atrial appendage occlusion during cardiac surgery for patients with atrial fibrillation: a meta-analysis. European Journal of Cardio-Thoracic Surgery. 2015; 47: 847–854.

[9] Mesnier J, Cepas-Guillén P, Freixa X, Flores-Umanzor E, Hoang Trinh K, O'Hara G, *et al*. Antithrombotic Management After Left Atrial Appendage Closure: Current Evidence and Future Perspectives. Circulation. Cardiovascular Interventions. 2023; 16: e012812.

[10] Sahiner L, Coteli C, Kaya EB, Ates A, Kilic GS, Yorgun H, *et al*. Left Atrial Appendage Occlusion in Patients With Thrombus in Left Atrial Appendage. The Journal of Invasive Cardiology. 2020; 32: 222–227.

[11] Li W, Zhao J, Ruan Z, Zhu L, Ren Y, Zhang B. Using the Perimeter-Derived Diameter and Ellipticity Index of the Left Atrial Appendage Landing Zone to Predict Watchman Occluder Size. Alternative Therapies in Health and Medicine. 2023; 29: 726–732.

[12] Zhang K, Zhou J, Zhang T, Zhang Z, Jin S, He Q, *et al*. Comparison of multiple imaging modalities for measuring orifice diameter and selecting occluder size in patients undergoing left atrial appendage closure. Clinical Cardiology. 2022; 45: 864–872.

[13] Yosefy C, Laish-Farkash A, Azhibekov Y, Khalameizer V, Brodkin B, Katz A. A New Method for Direct Three-Dimensional Measurement of Left Atrial Appendage Dimensions during Transesophageal Echocardiography. Echocardiography. 2016; 33: 69–76.

[14] Al-Kassou B, Tzikas A, Stock F, Neikes F, Völz A, Omran H. A comparison of two-dimensional and real-time 3D transoesophageal echocardiography and angiography for assessing the left atrial appendage anatomy for sizing a left atrial appendage occlusion system: impact of volume loading. EuroIntervention. 2017; 12: 2083–2091.

[15] Bai W, Chen Z, Tang H, Wang H, Cheng W, Rao L. Assessment of the left atrial appendage structure and morphology: comparison of real-time three-dimensional transesophageal echocardiography and computed tomography. The International Journal of Cardiovascular Imaging. 2017; 33: 623–633.

[16] Zhou Q, Song H, Zhang L, Deng Q, Chen J, Hu B, *et al*. Roles of real-time three-dimensional transesophageal echocardiography in peri-operation of transcatheter left atrial appendage closure. Medicine. 2017; 96: e5637.

[17] Zhang L, Cong T, Liu A. Percutaneous closure of the left atrial appendage: The value of real time 3D transesophageal echocardiography and the intraoperative change in the size of the left atrial appendage. Echocardiography. 2019; 36: 537–545.

[18] Sun A, Ren S, Xiao Y, Chen Y, Wang N, Li C, *et al*. Real-time 3D echocardiographic transilluminated imaging combined with artificially intelligent left atrial appendage measurement for atrial fibrillation interventional procedures. Frontiers in Physiology. 2022; 13: 1043551.

[19] Peng XW, Wu QB, Zhao L, Jiang N. Application value of real-time three-dimensional transesophageal echocardiography

in left atrial appendage occlusion and its prognostic evaluation. Journal of Clinical Ultrasound Medicine. 2023; 25: 183–187. (In Chinese)
[20] Duan F, Li H, Zhou C, Li H, Tao J, Kang W, *et al*. Novel sizing role of 3D transesophageal echocardiography in a novel left atrial appendage clip device for patients undergoing video-assisted atrial fibrillation ablation: a cohort study. Quantitative Imaging in Medicine and Surgery. 2024; 14: 1335–1347.
[21] Li J, Ma XJ, Cheng G. Application value of real-time three-dimensional transesophageal echocardiography in percutaneous left atrial appendage occlusion in patients with non-valvular atrial fibrillation. Chinese Journal Medical Imaging Technology. 2019; 35: 1295–1299. (In Chinese)
[22] Jin QC, Zhang XC, Kong DH, Pan WZ, Zhang L, Chen SS, *et al*. Quantitative assessment of ostium perimeter in left auricle appendage (LAA) occlusion through three-dimensional transesophageal echocardiogram. Fudan University Journal of Medical Sciences. 2019; 46: 769–775. (In Chinese)
[23] Huang QX, Huang XW. QUADAS-2 tool for quality assessment in diagnostic meta-analysis. Annals of Palliative Medicine. 2022; 11: 1844–1845.
[24] Speich B. Adequate reporting of the sample size calculation in surgical randomized controlled trials. Surgery. 2020; 167: 812–814.
[25] Carvalho PEP, Gewehr DM, Miyawaki IA, Nogueira A, Felix N, Garot P, *et al*. Network Meta-Analysis of Initial Antithrombotic Regimens After Left Atrial Appendage Occlusion. Journal of the American College of Cardiology. 2023; 82: 1765–1773.
[26] Jiang X, Zeng J, Zhong L, Zhu W, Li J. Preliminary Study on the Safety and Efficacy of One-Stop Treatment of Percutaneous LAAO Combined with Coronary Intervention for Higher Risk of Bleeding in Patients with AF Complicated with CHD. The Heart Surgery Forum. 2021; 24: E474–E478.
[27] Mills MT, Calvert P, Velavan P, Lip GYH, Gupta D. Concurrent percutaneous left atrial appendage occlusion and catheter ablation for atrial fibrillation: State-of-the-art review. Trends in Cardiovascular Medicine. 2023. (online ahead of print)
[28] Kim WD, Cho I, Kim YD, Cha MJ, Kim SW, Choi Y, *et al*. Improving Left Atrial Appendage Occlusion Device Size Determination by Three-Dimensional Printing-Based Preprocedural Simulation. Frontiers in Cardiovascular Medicine. 2022; 9: 830062.
[29] Kapoor PM, Muralidhar K, Nanda NC, Mehta Y, Shastry N, Irpachi K, *et al*. An update on transesophageal echocardiography views 2016: 2D versus 3D tee views. Annals of Cardiac Anaesthesia. 2016; 19: S56–S72.
[30] Wunderlich NC, Beigel R, Swaans MJ, Ho SY, Siegel RJ. Percutaneous interventions for left atrial appendage exclusion: options, assessment, and imaging using 2D and 3D echocardiography. JACC. Cardiovascular Imaging. 2015; 8: 472–488.
[31] Kiesgen S, Messinger JC, Chintala NK, Tano Z, Adusumilli PS. Comparative analysis of assays to measure CAR T-cell-mediated cytotoxicity. Nature Protocols. 2021; 16: 1331–1342.
[32] Lakkireddy D, Thaler D, Ellis CR, Swarup V, Sondergaard L, Carroll J, *et al*. Amplatzer Amulet Left Atrial Appendage Occluder Versus Watchman Device for Stroke Prophylaxis (Amulet IDE): A Randomized, Controlled Trial. Circulation. 2021; 144: 1543–1552.