Original Article

# Comparative Analysis of Pre-Operative Transthoracic and Intraoperative Transesophageal Echocardiography for Grading Aortic Stenosis in Adults Undergoing Elective Aortic Valve Replacement: A Single-Center Experience

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## Abstract

**Background:** Severe aortic stenosis necessitates precise preoperative evaluation to inform surgical decisions and ensure favourable patient outcomes. This study investigates the diagnostic discordance between pre-anaesthesia transthoracic echocardiography (TTE) and intraoperative transesophageal echocardiography (TEE) in patients undergoing elective aortic valve replacement (AVR) surgery. **Material and Methods:** A prospective randomized study enrolled 100 patients scheduled for AVR surgery due to aortic stenosis between January 2020 and December 2021. Pre-induction TTE and post-induction TEE examinations were compared. The study evaluated multiple parameters, including mean pressure gradient (PGm), peak jet velocity, aortic valve area (AVA) via continuity equation and planimetry, and dimensionless index (DI), across both TTE and TEE cohorts. **Results:** There were some apparent differences between measurements of TTE and TEE: A statistically significant difference in mean gradient across the aortic valve was noted while comparing TTE (57.16 ± 5.72mm Hg) with TEE (39.59 ± 5.97 mm Hg), which may have been a result of anesthetic effects. Similarly, the peak jet velocity in TTE was 506.06 ± 19.41 cm/s, whereas it was 386.72 ± 23.38 cm/s ($P < 0.0001$) for TEE. This shift saw 76% of the patients initially diagnosed with severe AS in TTE reassessed with moderate AS in TEE, showing that intraoperative situations played a big role. Using the continuity equation technique, the mean AVA for TTE and TEE were 0.84 cm² and 0.83 cm², respectively. PLANIMETRY AVA 0.88 ± 0.046 cm², in TTE, and 0.87 ± 0.055 cm², in TEE. Even if the valve area was decreased by 0.01 cm² with both approaches, there was no statistical significance ($P = 0.15$). In TTE and TEE, the DI mean was 0.20 ($P = 0.62$). Continuity equation, planimetry, and DI techniques were used; all patients had significant AS in TTE and TEE. **Conclusion:** Intraoperative TEE measurements often demonstrated reduced peak aortic jet velocities and mean pressure gradients compared to preoperative TTE assessments in patients with severe aortic stenosis, leading to potential underestimation of stenosis severity.AVA measurement by planimetry, continuity equation, and DI methods demonstrated more reliability.

**Keywords:** Aortic stenosis, continuity equation, dimension less index, planimetry.

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## Introduction

Severe aortic stenosis necessitates precise preoperative evaluation to inform surgical decisions and ensure optimal patient outcomes. Echocardiography, utilizing transthoracic and transesophageal methods, is vital in assessing stenosis severity. Standardization is crucial to maintaining accuracy and consistency in echocardiography.[1]

Numerous important factors lead to aortic stenosis, a common valvular heart disease, which affects 7.3% of people.[2] The dominant cause in older individuals is degenerative calcification, whereas in younger patients, the cause may be a congenital bicuspid aortic valve that leads to stenosis.[3] In some groups, rheumatic heart disease is still a big contributor, although it is less prevalent in wealthier countries.[4] Causes occurring rarely are abnormal metabolism disorders and radiation-induced stenosis.[5]

In cardiac surgery and catheterization labs, intraoperative TEE has emerged as a vital tool, aligning with recommendations from the American Society of Anesthesiologists and the Society of Cardiovascular Anesthesiologists Task Force.[6]

However, discrepancies in grading severity between

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transthoracic echocardiography (TTE) and TEE imaging have been observed.[7] This disparity may stem from the original definition of AS grading in spontaneously breathing patients.

Studies have shown that pre-cardiopulmonary bypass TEE often underestimates AS severity compared to preoperative TTE.[8] Research involving 1011 patients revealed abnormal intraoperative TEE findings in 11.4% of cases, influencing surgical decisions in 5.8%.[9] Another study demonstrated multiplane TEE's high accuracy in detecting severe aortic stenosis (valve orifice area <0.75 cm2), with 96% sensitivity and specificity.[10] These results indicate that 2D multiplane TEE accurately assesses aortic valve area in most patients with aortic stenosis, enhancing the diagnostic utility of transthoracic echocardiography. In most patients, the planimetry assessment technique utilized by transoesophageal echocardiography (TEE) allows for effective measurement of the aortic valve orifice area without lengthening examination time. The reliability of the approach is confirmed by its high correlation and concordance with the conventional invasive measurements, which verify its clinical use as a non-invasive, reliable substitute.

The present prospective observational study compares the relative effectiveness of pre-induction transthoracic echocardiography (TTE) and post-induction multiplane transoesophageal echocardiography (TEE) in determining the level of aortic stenosis in patients undergoing elective aortic valve replacement (AVR).

A spectral echocardiographic data (mean pressure gradient (PGm); peak aortic jet velocity) planimetric assessment of aortic valve area (AVA) obtained based on the planimetry technique and continuity equation, as well as the dimensionless index (DI), is used in the research to define the degree of aortic stenosis. For elective aortic valve replacement patients, these data present a conclusive literature comparison of pre-induction transthoracic echocardiography (TTE) and transesophageal echocardiography (TEE) after induction.[3] The characteristic severe aortic stenosis (AS) has been reported according to the echocardiographic criteria of the American Heart Association (AHA) and the American College of Cardiology (ACC).

1. PGm more than 40 mmHg.
2. AVA < 1 cm²
3. Peak speed more than 4 m/s
4. Dimensionless index <0.25 (also known as velocity ratio or DI) ACC/AHA Guidelines for the Management of Patients with Valvular Heart Disease, 2020 is the source.

## Materials and Methods

**Study Design:** A double-blinded, randomized controlled trial was conducted for a Comparative Analysis of Pre-Operative Transthoracic and Intraoperative Transesophageal Echocardiography.

**Study Setting:** This prospective randomized study enrolled 100 patients slated for aortic valve replacement (AVR) surgery due to aortic stenosis from U N Mehta Institute of Cardiology & Research Centre, Ahmedabad, Gujarat, India. Obtaining Institutional Ethics Committee approval (UNMICRC/C.ANESTHE/2019/31) and informed patient consent.

**Sample size:** It is a duration-based study from January 2020 to December 2021, and simple random sampling techniques were used.

**Inclusion criteria:**

Aortic stenosis (AS) with a high degree but not secondary to coronary artery disease (CAD)

Age range: twenty to seventy years

- For normal systolic function, the minimum value of LVEF should be at least 50%.
- The other valve of the heart does not show any significant structural or functional abnormalities.
- No aortic pathology requires coexistence treatment.

**Exclusion criteria:**

- Moderate to severe aortic regurgitation exists.
- Severe coronary artery disease (CAD), which required a combination treatment.
- Other valvular anomalies (tricuspid or mitral valve disease).
- Cardiogenic shock or low cardiac output syndrome; such types of hemodynamic instability.
- Poor transthoracic echocardiography (TTE) imaging window due to patient anatomical makeup.

Specific limitations for the installation of transesophageal echocardiography (TEE) probes include

- Varices, stricture of the esophagus, or cancer.
- History of moderate or severe dysphagia or perforation of the esophagus.
- Bleeding or recent upper gastrointestinal surgery

All patients underwent comprehensive preanesthetic evaluation, comprising:

- Detailed medical history
- Complete physical examination

Routine preoperative investigations included complete blood counts (CBC), renal function (blood urea, serum creatinine), and electrolyte evaluation. Blood glucose tests were used to monitor glucose levels. Imaging tests such as echocardiograms (ECHO) and chest X-rays (CXR) were performed to provide a comprehensive heart examination. Electrocardiography (ECG) was also used to carry out a baseline cardiac examination, and the patients were made ready for any possible blood transfusions (through this activity) through blood type and cross-matching.

An anxiolytic—alprazolam (0.5 mg)—was given preoperatively the night before surgery as part of the anesthetic plan. After surgical preparedness had been verified, patients went to the operating room, and their bodies lay on the surgical table. Standard intraoperative monitoring techniques were used to maintain ideal perioperative hemodynamic stability, such as electrocardiography (ECG), arterial oxygen saturation (SpO2), and noninvasive blood pressure estimation.

Baseline vital signs were documented.

Following transthoracic echocardiography, anesthesia was induced with a combination regimen:

1. Midazolam (0.1 mg/kg)
2. Fentanyl (5 µg/kg)
3. Vecuronium (0.2 mg/kg) for endotracheal intubation

Invasive monitoring lines (Right internal jugular vein (IJV) &Radial arterial line were secured:

Anesthesia maintenance consisted of Sevoflurane (1-2%) in a 1:1 oxygen-air mixture and Supplemental fentanyl and vecuronium as needed. Ventilator settings were optimized to deliver a tidal volume of 8 mL/kg, and the respiratory rate was adjusted to maintain arterial carbon dioxide levels ($PaCO_2$) within a target range of 30-35 mmHg.

Comparative Analysis of Pre-Induction Transthoracic Echo (TTE) and Post-Induction Transesophageal Echo (TEE)

Parameters assessed in both TTE & TEE:

- Mean pressure gradient (PGm) across the aortic valve
- Peak jet velocity
- Aortic valve area (AVA) via continuity equation
- Dimensionless index (DI)

Echocardiographic assessments were carried out on a GE Healthcare Vivid Iq cardiac ultrasound machine with the 5-MHz multi-plane phased array probe (GE Healthcare Vivid-I 6T-TS) for TEE and the phased array probe 3Sc (3 MHz) for TTE.[11] In the operating room, TTE imaging was performed pre-anesthetic induction, and TEE was performed by a single anesthesiologist following induction.[12] Standard views of TTE and TEE were obtained for the presentation of aortic stenosis. For the purpose of reducing errors, hemodynamic values such as heart rate (HR) and mean arterial pressure (MAP) were recorded and preserved within 20 % of the baseline value of all the nodes of TEE examinations.[13] Also reported for TTE and TEE across the aorta valve were AV Ada, peak jet velocity of the aorta, DI, and PGm.

Processing the CWD signal across the aortic valves derived a mean pressure gradient (PGm). The AVA was calculated using the continuity equation.

$$\text{AVA}(cm^2) = \frac{\text{LVOTCSA} \times \text{LVOTVTI}}{\text{Aortic Valve VTI}}$$

The LVOT CSA, which stands for left ventricular outflow tract cross-sectional area, is calculated using the following formula: 3.14 x (LVOT diameter, d, measured in the parasternal long-axis view), provided that the length is the intersection of the mouths of the two ventricles.

$$\text{CSA} = \pi(\frac{d^2}{2})$$

The integrals throughout the velocity time for pulsed-wave Doppler (PWD) and continuous-wave Doppler (CWD) are recorded in LVOT VTI and Aortic Valve VTI, respectively. The dimensionless index (DI) was calculated using the ratio of LVOT VTI to aortic valve VTI. Standard echocardiography textbooks contain a lot of information on the equations used to estimate parameters.

Optimal alignment was achieved using:

- Apical 5-chamber view
- Suprasternal view
- Right parasternal view

Sample volume was parallel to blood flow, ensuring a deviation of less than 15°."

1. Aortic Valve Area (AVA) Calculation Method:

The continuity equation was utilized to calculate AVA as follows:

AVA ($cm^2$) = Left Ventricular Outflow Tract (LVOT) Cross-Sectional Area (CSA) × (LVOT Velocity Time Integral (VTI) / Aortic Valve VTI)

LVOT Cross-Sectional Area Assessment:

1. LVOT diameter measured in parasternal long-axis view, 0.5-1.0 cm from valve orifice
2. CSA estimated using formula: CSA = $\pi (d/2)^2$, where d = LVOT diameter

Velocity Time Integrals Measurement:

1. LVOT VTI measured using pulsed-wave Doppler (PWD)
2. Aortic Valve VTI measured using continuous-wave Doppler (CWD)

2. Additional Parameters Assessed:

Aortic Stenosis (AS) Peak Jet Velocity: Direct measurement via continuous-wave Doppler (CWD) tracing across the aortic valve.

3. Dimensionless Index (DI): Calculated by dividing left ventricular outflow tract velocity time integral (LVOT VTI) by aortic valve velocity time integral (AV VTI)."

**Transesophageal Echocardiography (TEE) Protocol:** Following anesthesia induction, a single anesthesiologist performed TEE using a 5-MHz multi-plane phased array probe (GE Healthcare Vivid-I 6T-TS). The TEE Assessment was conducted with heart rate (HR) and mean arterial pressure (MAP) within 20% of baseline values. Systolic and pulse pressure variations were maintained within normal limits to minimize hemodynamic errors. Parameters were assessed: Mean pressure gradient (PGm) across the aortic valve, peak velocity, Aortic valve area (AVA) by continuity equation method, planimetry method, dimensionless index (DI).[14]

**Doppler Assessments:**

- Continuous-wave Doppler (CWD) and pulsed-wave Doppler (PWD) measurements were obtained across the aortic valve and left ventricular outflow tract (LVOT), respectively, using:
- Deep transgastric aortic valve long-axis view
- Transgastric long-axis view

**Echocardiographic Measurements:**

- Left ventricular outflow tract (LVOT) diameter: measured in mid-esophageal aortic valve long-axis view
- Aortic valve area (AVA) by planimetry: measured in mid-esophageal aortic valve short-axis view (Figure 2)

**Statistical Analysis:** For statistical analysis, IBM SPSS version 22.0 was used. Whereas quantitative data were presented as mean ± standard deviation (SD) or median with interquartile range (IQR) when appropriate, the qualitative data were presented in percentages. If the data passed the normality test, the unpaired t-test was applied to compare two subgroups of a qualitative variable.[15] As for proportions, the chi-square test was used. A p-value below 0.05 was considered statistically significant, thus enabling the complete statistical analysis of the research findings.

**Funding:** The study was self-funded, with resources allocated by the researchers. No external funding sources were involved.

**Conflict of Interest:** The researchers declare no conflicts of interest that could influence the study's conduct or interpretation of results, ensuring transparency and objectivity in the research process.

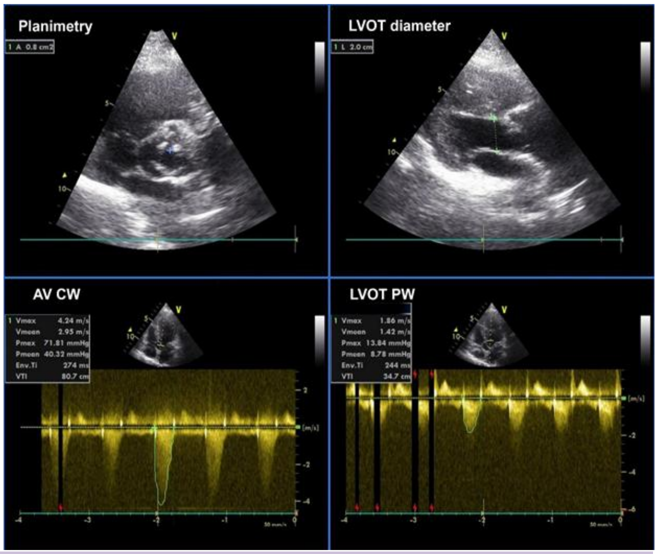


Figure 1: TTE Assessment

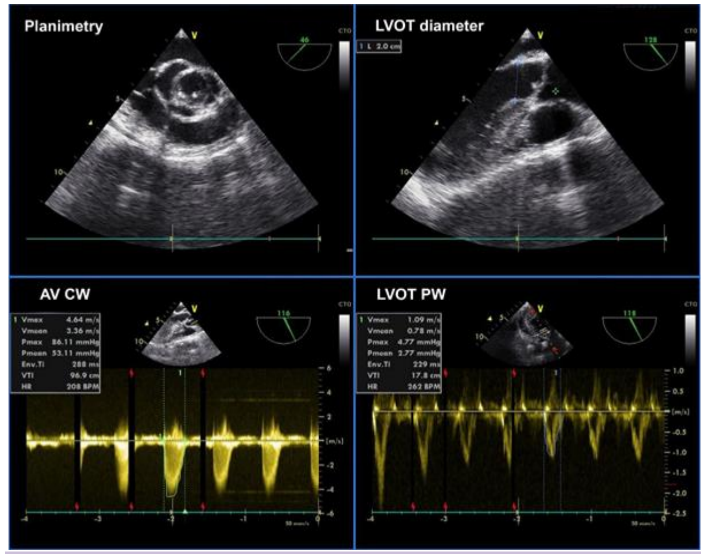


Figure 2: TEE Assessment

## Results

**Table 1: Distribution of various demographic characteristics**

| Demographic Parameters | No. of Patients (n=100) |
|---|---|
| Age (years) | 60.32 ± 7.25 |
| Gender | Male: 82 (82%) <br> Female: 18 (18%) |
| Body Surface Area (BSA) (m²) | 1.59 ± 0.06 |
| Etiology | Rheumatic Heart Disease (RHD): 1 (1%) <br> Bicuspid Aortic Valve (BAV): 21 (21%) <br> Degenerative Aortic Stenosis: 78 (78%) |

When comorbidities were assessed in the demographic studies, it was realized that 18% of the patients had a smoking history, 22% had diabetes mellitus, and 35% had a history of hypertension. As isolated aortic stenosis was the primary inclusion criterion, there were no patients with severe CAD necessitating intervention.

No contemporaneous coronary revascularization was performed during the procedure. Instead, every patient had a solo elective AVR. The fact that no severe CAD was available ensured that the study's sole focus was comparative echocardiographic vicarious evaluation of pre-induction transthoracic echocardiography (TTE) and post-induction transesophageal echocardiography (TEE) in AS grading.

Mean HR was 74.96 ± 5.58/min while performing TTE and 73.59 ± 5.97/min while performing TEE, which was statistically non-significant with a P value of 0.0952.

There was no statistically significant difference in the mean arterial blood pressure (MAP) during TTE and TEE, which were 94.95 ± 5.45 mmHg and 93.59 ± 5.84 mmHg, respectively (P = 0.0902).

Mean value of PGm was 57.16 ± 5.72 mmHg in TTE and 39.59 ± 5.97 mmHg in TEE. There is a statistically significant reduction in PGm. In TTE, 100 patients were graded with severe AS due to PGm being >40. In TEE, only 25 patients remained in severe AS due to PGm, and the rest were moderate. Thus, 75% of patients with severe AS were underestimated to have moderate AS in TEE based on PGm. This discordance, tested by the exact symmetry test, was statistically significant with a P value <0.0001.

Peak velocity of the aortic valve jet was 506.06 ± 19.41 cm/s. In TTE, compared to 386.72 ± 23.38cm/s in TEE. This reduction was statistically significant with a P value <0.0001. Of 100 patients with severe AS according to jet velocity by TTE, only 24 remained in the severe category in TEE. In 76% of patients, who were graded as severe in TTE, the grading of AS was reduced to moderate in TEE based on jet velocity. [Table 2]

**Table 2: Comparison of Echocardiographic Parameters Between TTE and TEE**

| Variables | Group TTE (n=100) | Group TEE (n=100) | P Value |
|---|---|---|---|
| Mean gradient (mmHg) | 57.16 ± 5.72 | 39.59 ± 5.97 | <0.0001 |
| Peak jet velocity (cm/s) | 506.06 ± 19.41 | 386.72 ± 23.38 | <0.0001 |
| Aortic Valve Area (AVA) by continuity equation method | 0.84 ± 0.046 | 0.83 ± 0.052 | 0.1513 |
| Aortic Valve Area (AVA) by planimetry method | 0.88 ± 0.046 | 0.87 ± 0.055 | 0.1647 |
| Dimensionless Index (DI) | 0.207 ± 0.015 | 0.206 ± 0.014 | 0.6265 |

A comparison of pulsatile echocardiographic characteristics between intraoperative transesophageal echocardiography (TEE) and preoperative transthoracic echocardiography (TTE) is demonstrated in Table 2. The data indicate that the TEE measurements created lower average gradient and peak jet velocity results, statistically significant from TTE to TEE ($P < 0.0001$). In particular, the peak jet velocity decreased from 506.06 ± 19.41 cm/s at TTE to 386.72 ± 23.38 cm/s at TEE, while the mean gradient decreased from 57.16 ± 5.72 mmHg at TTE to 39.59 ± 5.97 mmHg at TEE.

On the other hand, the dimensionless index (DI) and measurements using the aortic valve area (AVA) with both the continuity equation and the planimetric approaches did not have statistically significant differences between TTE and TEE. Planimetry demonstrated an AVA of 0.88 ± 0.046 cm² in TTE versus 0.87 ± 0.055 cm² in TEE ($P = 0.1647$), and a continuity equation (area) of 0.84 ± 0.046 cm² in TTE versus 0.83 ± 0.052 cm² in TEE ($P = 0.1513$). TTE and TEE had dimensionless indices of 0.207 ± 0.015 and 0.206 ± 0.014, respectively ($P=0.6265$).

## Discussion

Several studies have compared the accuracy of TTE and TEE in grading the severity of AS in adult patients undergoing AVR surgery. The diagnostic capacity of TTE to identify infective endocarditis (IE) findings observed on TEE was compiled into a meta-analysis reported in the American Journal of Echocardiography.[16] In a highly detailed meta-analysis from the American Journal of Echocardiography, 16 observational studies that reported on the likelihood of detecting the signs of infective endocarditis (IE), as existed in transthoracic echocardiography (TTE) vs transesophageal echocardiography (TEE) [17] were reviewed. Compared to TEE, the research demonstrated limitations of TTE in detecting valve perforations, abscess forms, and vegetations.[17,18]

Harmonic TTE, compared to TEE (the diagnostic gold standard of IE), which remains the gold standard for diagnosing IE, had a sensitivity of 61% and a specificity of 94% in detecting vegetations, with moderate but poor performance.[19] The meta-analysis showed efficient use of TEE in surgical planning and clinical decision-making in approximately 5.8% of patients, proving superior in diagnosing subtle valvular diseases.[20] These results underline the need to select the appropriate echocardiographic modality, specifically for patients whose valve study occurs before surgery. For detecting vegetation in all patients, harmonic TTE had a sensitivity of 61% and a specificity of 94%.[21] Our study comprised 100 patients with severe AS undergoing aortic valve replacement (AVR), with a mean age of 60.32 ± 7.25 years. The primary causes of AS were: degenerative (78%), bicuspid aortic valve (BAV) (21%), and rheumatic heart disease (RHD) (1%). These findings align with previous studies conducted in Indian populations. Nanditha et al. reported a mean age of 60 years and a similar distribution of AS causes: degenerative (50%) and BAV (36%). Similarly, CN Manjunath et al. found degenerative calcification to be the most common cause (65.0%), followed by BAV (33.9%) and RHD (1.1%). In contrast, Western population studies, such as GamazaChulián et al,[13] reported a higher mean age (75 ± 8 years) among 262 patients with severe AS. This suggests a disparity in the age of presentation between Indian and Western populations.

Pre-induction heart rate (HR: 74.96 ± 5.58/min) and mean arterial pressure (MAP: 94.95 ± 5.45 mmHg) remained comparable (within 20%) to post-induction values (HR: 73.59 ± 5.97/min, MAP: 93.59 ± 5.84 mmHg). To maintain hemodynamic stability during TTE and TEE, post-induction hypotension was managed with intravenous fluids and vasopressors. Transvalvular flow is influenced by preload, afterload, left ventricular diastolic compliance, and heart rate.

Hemodynamic fluctuations, positive pressure ventilation, general anesthesia, and surgical procedures may reduce the transvalvular flow, resulting in reduced mean pressure gradient (PGm) and jet velocity in TEE. These effects have been demonstrated in perioperative hemodynamic examinations, and they indicate that the anesthetic-induced circulatory changes alter echocardiographic readouts.[22]

The contrast mainly informs intraoperative decision-making in the management of aortic stenosis (AS) of data obtained through transthoracic echocardiography (TTE) and transesophageal echocardiography (TEE). Surgical planning may also have underestimated the gravity of AS, as the intra-op TEE is reported to measure a lower mean pressure gradient (PGm) and peak aortic jet velocity relative to the pre-op TTE.

Anesthetic effects, positive pressure breathing, and hemodynamic fluctuations can describe the possibilities for creating the differences in modality. These discrepancies may cause anesthesiologists and surgeons to rethink some of the targets for intraoperative hemodynamic targets (surgery time, as well as valve selection benchmarks). Further, a single echocardiographic modality may impact patient outcome, hence the need for a multimodal assessment of both modalities, carefully synthesizing TPP and TEE results in perioperative therapy. To increase the quality of surgical decision-making, subsequent research should focus on defining the thresholds of intraoperative TEE interpretation.

Consistent with our findings, Uda et al. analyzed data from 319 patients. They reported Intraoperative TEE peak velocity: 0.59 m/s lower ($P < 0.0001$), Intraoperative TEE mean gradient: 12.5 mmHg lower ($P < 0.0001$), TEE-estimated aortic stenosis severity (by peak velocity and mean gradient): at least one grade lower than TTE in 45.1% and 42.7% of patients, respectively.[4] These results corroborate our study's observations, highlighting the discrepancies between TTE and TEE measurements.

Whitener et al. noted that pre-cardiopulmonary bypass (CPB) transesophageal echocardiography (TEE) yields distinct mean pressure gradient (PGm) and aortic valve area (AVA) values compared to preoperative transthoracic echocardiography (TTE), potentially underestimating aortic stenosis (AS) severity.[5] They suggest standardizing or adjusting pre-CPB TEE PGm and AVA values to account for hemodynamic changes under anesthesia. In our study, AVA measurements by the planimetry method showed comparable results between TTE and TEE, with a non-significant decrease of 0.01 cm² in TEE ($P = 0.1647$).

Isabel João et al. conducted a study on 45 patients with calcified valvular aortic stenosis, demonstrating the reliability of aortic valve area (AVA) planimetry in assessing disease severity. Methodology: AVA assessment using planimetry and continuity equation, Invasive measurements via Gorlin formula in 25 patients (56%).[23] Key Findings: Planimetry-based AVA evaluation was feasible and efficient, without prolonging exam duration in most cases (89%), and exceptions occurred in 5 patients (11%). This study supports planimetry as a reliable method for AVA assessment in aortic stenosis.

Overall, TTE and TEE are important imaging techniques in diagnosing and grading aortic stenosis in adult patients undergoing aortic valve replacement surgery. Although TTE is typically the initial imaging modality used, TEE can provide more detailed information in case TTE is limited.

## Conclusion

In this research, due consideration was given to transthoracic echocardiogram (TTE) and transesophageal echocardiography (TEE) for assessment of the degree of aortic stenosis (AS) in patients having aortic valve replacement (AVR). The effect of anesthesia on intraoperative echocardiographic assessment was underscored by the observation that though TTE and TEE confirmed equal aortic valve area (AVA) values, TEE showed more constant low mean pressure gradient (PGm) and peak aortic jet velocity. The results emphasize the necessity of interpreting the degree of AS determined by TEE with anesthesia-induced hemodynamic changes in mind. Standardization of intraoperative echocardiogram measures may increase the accuracy of diagnosis & help clinicians make optimal treatment choices for patients undergoing AVR.

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Nil.

### Conflicts of interest

There are no conflicts of interest.

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