Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

The Tango formula as a simplified Doppler-only alternative for aortic valve area estimation: a single-centre pilot and proof-of-concept study with intra- and inter-observer reproducibility analysis

Ernesto J. Rocha-Reyes
Hospital Universitario del Valle ESE
Stephany Barbosa-Balaguera
sb.balaguera@hotmail.com
Hospital Universitario del Valle ESE
Sebastián Ayala-Zapata
Hospital Universitario del Valle ESE
Oswaldo E. Aguilar-Molina
Hospital Universitario del Valle ESE
Álvaro A. Herrera-Escandón
Cardiovascular Surgery Research Group, Department of Cardiology, Clínica Colsanitas S.A., Clínica Sebastián de Belalcázar

Research Article

Keywords: aortic stenosis, aortic valve area, continuity equation, Tango formula, echocardiography, Bland–Altman analysis, concordance correlation coefficient, reproducibility, pilot study

Posted Date: May 4th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-9407098/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

Abstract

Background.

Accurate aortic valve area (AVA) estimation is central to aortic stenosis (AS) severity grading. The continuity equation (CE) is the reference echocardiographic method but is vulnerable to squared-error propagation from left ventricular outflow tract (LVOT) diameter measurement. The Tango formula (TF) estimates AVA from three continuous-wave Doppler parameters obtained from a single window, eliminating LVOT measurement. As a simplified Doppler-only index, TF has not been adequately validated outside its original description. We designed this pilot and proof-of-concept study to generate preliminary agreement and reproducibility data that can inform the design of future adequately-powered multicentre validation work.

Methods.

Single-centre retrospective pilot study. Echocardiographic reports from January 2022 to December 2023 were reviewed. Adults (≥ 18 years) with moderate (AVA > 1.0 cm²) or severe (AVA ≤ 1.0 cm²) AS confirmed by CE were included. Method-agreement was assessed with Lin's concordance correlation coefficient (CCC) and Bland–Altman analysis, with pre-specified subgroup analyses by AS severity. A reproducibility sub-study was performed in 15 randomly selected cases, in which TF measurements were repeated by the same observer (intra-observer) and by a second independent level-3 echocardiographer (inter-observer) blinded to prior values.

Results.

Of 3,433 studies reviewed, 54 patients (median age 74 years, IQR 67–79; 50% women; 22 moderate, 32 severe AS) met inclusion criteria. Overall CE–TF agreement was excellent for absolute AVA (CCC = 0.94; 95% CI 0.89–0.98) and indexed AVA (CCC = 0.95; 95% CI 0.91–0.98); Bland–Altman bias was negligible (mean difference 0.001 cm²; 95% limits of agreement [LoA] − 0.22 to 0.21 cm²). In severe AS, agreement was excellent (CCC = 0.87; 95% CI 0.75–0.93); in moderate AS, agreement was more limited (CCC = 0.46; 95% CI − 0.04 to 0.88). Reproducibility of TF was good: intra-observer CCC = 0.87 (95% CI 0.66–0.95) and inter-observer CCC = 0.82 (95% CI 0.56–0.93). Four of 54 patients (7.4%) were reclassified between methods, all within the moderate AS group; no reclassification occurred in severe AS.

Conclusions.

This pilot and proof-of-concept study provides the first single-centre agreement and reproducibility data for the Tango formula. TF shows excellent agreement with CE in severe AS and good intra- and inter-observer reproducibility (CCC 0.87 and 0.82, respectively), supporting further evaluation as a

complementary Doppler-only tool when LVOT measurement is technically unreliable. The wider confidence intervals in moderate AS and the modest sample size underline that these findings should be interpreted as hypothesis-generating. A prospective, adequately-powered multicentre study with anatomical validation is warranted.

What is known about the topic?

The continuity equation is the reference echocardiographic method for AVA calculation in AS, but requires three measurements from different acoustic windows, and LVOT diameter error is squared in area computation. Simplified Doppler-only indices have been proposed as complements, but published clinical validation of the Tango formula—including its reproducibility—has been scarce.

What does this pilot study add?

This pilot and proof-of-concept study provides the first single-centre agreement and reproducibility data for the Tango formula in moderate-to-severe AS. Agreement between TF and CE is excellent in severe AS (CCC=0.87) and more limited in moderate AS (CCC=0.46). Intra- and inter-observer reproducibility of TF are good (CCC=0.87 and 0.82, respectively). These preliminary data support designing a prospective, adequately-powered multicentre validation study with anatomical reference.

Background

Aortic stenosis (AS) is the most prevalent acquired valvular disease in developed countries, affecting approximately 1–2% of adults over 65 years of age and rising to 3.4% in those over 75.[1,2]

Clinical management of AS relies on accurate assessment of aortic valve area (AVA). According to the 2021 ESC/EACTS guidelines on valvular heart disease and their 2025 update, AS is classified as mild (AVA >1.5 cm²), moderate (AVA 1.0–1.5 cm²), or severe (AVA ≤1.0 cm²).[3,4] The continuity equation (CE) is the reference echocardiographic method for AVA calculation, but it requires three measurements: LVOT diameter, LVOT velocity–time integral (VTI) by pulsed-wave Doppler, and aortic valve VTI by continuous-wave Doppler.[5,6] A critical limitation is that any error in LVOT diameter measurement is squared during area computation, propagating substantial inaccuracy into AVA estimates, particularly in patients with extensive annular calcification, LVOT ellipticity, or suboptimal acoustic windows.[7,8]

The Tango formula (TF) was proposed as a simplified Doppler-only alternative: AVA_{TF} = Ejection Time (ms) / [Peak Aortic Velocity (m/s) × Acceleration Time (ms)]. All three variables are obtained from a single continuous-wave Doppler interrogation of the aortic valve, eliminating LVOT measurement and the two additional windows required by CE.[9] The TF-derived value was originally described as an aortic valve area index, and its precise physical interpretation has not been fully established. The most formal

published account of the formula currently available is a 2023 report in a regional point-of-care ultrasound journal,[9] a limitation that is acknowledged throughout this work.

Rationale for a pilot and proof-of-concept design. Before a simplified echocardiographic index can be recommended for routine use, two essential questions must be answered: (i) does the index agree numerically with the established reference method in clinical practice, and (ii) is the index reproducible between and within observers? No published data adequately address either question for the Tango formula. A formal multicentre validation trial would be premature without preliminary agreement and reproducibility estimates to inform sample-size calculation and refine the research question. The present work was therefore designed as a single-centre pilot and proof-of-concept study to generate these preliminary estimates. Our findings are explicitly intended to be hypothesis-generating rather than confirmatory, and to inform the protocol of a future prospective multicentre study with anatomical validation.

Methods

Study design and rationale

We conducted a single-centre retrospective pilot and proof-of-concept study comprising two linked components: (i) a cross-sectional method-agreement analysis comparing TF and CE for AVA estimation in a consecutive clinical cohort, and (ii) a reproducibility sub-study in a random subsample to estimate intra- and inter-observer variability of TF measurements. The study was conducted and reported in accordance with the Guidelines for Reporting Reliability and Agreement Studies (GRRAS)[17] where applicable to the available retrospective dataset.

Setting and population

Echocardiographic reports from January 2022 to December 2023 at a tertiary cardiology centre in Cali, Colombia, were systematically reviewed twice weekly. Patients were eligible if they were ≥18 years of age with a diagnosis of moderate or severe AS confirmed by the continuity equation. Exclusion criteria were prosthetic heart valves, concomitant moderate-to-severe aortic or mitral regurgitation (which can affect TF accuracy), heart rate >100 bpm at the time of examination, and isolated mild AS.

All echocardiograms were performed by cardiologists with level 3 training in echocardiography using commercially available ultrasound systems, following the 2017 EACVI/ASE recommendations for the echocardiographic assessment of aortic valve stenosis.[6] Parameters required for CE and TF calculation were obtained during standard clinical examinations and extracted from validated echocardiographic reports for secondary analysis.

Reproducibility sub-study

To quantify measurement variability of TF—a central question for any simplified Doppler index—a reproducibility sub-study was pre-specified. From the final cohort, 15 cases were selected by computer-generated random sampling, with stratification to ensure representation of moderate and severe AS phenotypes. Digital images from these studies were retrieved from the laboratory archive. Intra-observer reproducibility was assessed by having the original observer re-measure the three TF components (ejection time, peak aortic velocity, and acceleration time) from the archived Doppler envelopes after an interval of ≥4 weeks, blinded to the original values. Inter-observer reproducibility was assessed by having a second level-3 echocardiographer—independent of the study team and blinded to previous measurements and to clinical data—perform the same measurements on the same archived envelopes. Agreement between paired measurements was quantified with Lin's concordance correlation coefficient (CCC) and Bland–Altman analysis.

Sample-size considerations

As a pilot study, the primary analysis was descriptive and no a priori power calculation was performed; sample size was determined by the number of eligible cases identified during the study window. The reproducibility sub-study sample size (n=15) is consistent with published recommendations for pilot reproducibility studies of continuous echocardiographic measurements,[17,18] and is intended to provide a preliminary estimate to inform the sample-size calculation of a future definitive study.

Statistical analysis

Categorical variables are expressed as absolute and relative frequencies; continuous variables as median and interquartile range (IQR), given their non-normal distribution assessed by the Shapiro–Wilk test. Between-group comparisons used the chi-square or Fisher's exact test for categorical variables and the Mann–Whitney U test for continuous variables ($p<0.05$ considered statistically significant).

Method-agreement between CE-derived and TF-derived AVA was assessed using Lin's concordance correlation coefficient (CCC), which simultaneously measures precision (correlation) and accuracy (deviation from the line of perfect agreement). Agreement was interpreted according to the benchmarks proposed by McBride: CCC ≥0.90 excellent, 0.71–0.90 good, 0.51–0.70 moderate, and ≤0.50 poor.[12] Bland–Altman analysis was used to quantify systematic bias (mean difference, MD) and random variability (95% limits of agreement, LoA). The CE was used as the reference method, consistent with guideline recommendations.[3,4] Pre-specified subgroup analyses were performed by AS severity (moderate vs. severe), and a sensitivity analysis of severity reclassification across the 1.0 cm^2 boundary was performed. Intra- and inter-observer reproducibility of TF were quantified using the same CCC framework. All analyses were conducted in R version 4.3; the study is descriptive and exploratory, and no correction for multiple comparisons was applied—in line with the pilot nature of the work.

Ethics

The study was approved by the Research Committee of the Universidad del Valle and the Ethics Committee of the Hospital Universitario del Valle – Evaristo García (approval reference withheld for double-blind peer review and available on request). The requirement for individual informed consent was waived in accordance with institutional policy for fully anonymised, retrospective echocardiographic data. All procedures were conducted in accordance with the Declaration of Helsinki.

Results

Study population

A total of 3,433 echocardiographic reports were reviewed; 116 (3.4%) had AS. Of these, 62 (53.4%) were excluded: 27 (43.5%) had mild AS and 35 (56.4%) had concomitant moderate-to-severe aortic or mitral regurgitation. The final sample comprised 54 patients (Figure 1): 22 (40.7%) with moderate AS and 32 (59.3%) with severe AS.

The median age was 74 years (IQR 67–79), and 50% were women. Hypertension was the most common comorbidity (66.7%), followed by dyslipidaemia (24.7%), type 2 diabetes mellitus (22.2%), and heart failure (22.2%). No significant differences in baseline characteristics were observed between moderate and severe AS groups (Table 1).

Table 1. Baseline clinical characteristics stratified by aortic stenosis severity.

Variable	All, n=54 (%)	Moderate, n=22 (%)	Severe, n=32 (%)	p-value
Age, years, median (IQR)	74 (67–79)	71 (67–79)	75.5 (66.5–79.5)	0.470
Sex				
Male	27 (50.0)	13 (59.1)	14 (43.7)	0.268
Female	27 (50.0)	9 (40.9)	18 (56.3)	0.268
Comorbidities				
Hypertension	36 (66.7)	12 (54.6)	24 (75.0)	0.141
Dyslipidaemia	13 (24.7)	8 (36.4)	5 (15.6)	0.109
Type 2 diabetes	12 (22.2)	4 (18.8)	8 (25.0)	0.742
Heart failure	12 (22.2)	4 (18.2)	8 (25.0)	0.742
Ischaemic heart disease	11 (20.4)	6 (27.3)	5 (15.6)	0.324
Chronic kidney disease	9 (16.7)	4 (18.8)	5 (15.6)	>0.999
Other*	38 (70.4)	17 (77.3)	21 (65.6)	0.545

*IQR, interquartile range. *Other comorbidities: hypothyroidism, atrial fibrillation, stroke, prostate cancer, other malignancies, prostatic hyperplasia, atrioventricular block, and others.*

Echocardiographic findings

Patients with severe AS showed significantly higher peak aortic velocity (median 3.8 vs. 2.9 m/s; p<0.001) and mean transaortic gradient (32 vs. 16 mmHg; p<0.001), and lower DVI (0.24 vs. 0.42; p<0.001) compared with moderate AS. AVA by CE was 0.72 cm² (IQR 0.53–0.85) in severe AS and 1.24 cm² (IQR 1.20–1.42) in moderate AS. AVA by TF was numerically comparable: 0.73 cm² (IQR 0.59–0.85) and 1.24 cm² (IQR 1.17–1.40), respectively (Table 2).

Table 2. Anthropometric and echocardiographic characteristics stratified by aortic stenosis severity.

Variable	All, n=54	Moderate, n=22	Severe, n=32	p-value
Anthropometric data, median (IQR)				
Weight (kg)	61.5 (54.0–73.0)	60.5 (53.0–70.0)	63.5 (55.0–76.5)	0.256
Height (m)	1.60 (1.50–1.67)	1.60 (1.55–1.66)	1.57 (1.50–1.69)	0.951
BSA (m²)	1.63 (1.55–1.75)	1.61 (1.55–1.70)	1.67 (1.53–1.77)	0.316
BMI (kg/m²)	23.75 (22.2–27.5)	23.95 (21.0–25.9)	22.20 (22.2–28.9)	0.597
Echocardiographic data, median (IQR) unless otherwise stated				
Heart rate (bpm)	71.5 (64–81)	71.5 (64–81)	71.5 (64–81)	0.252
Valve morphology, n (%)				
Bicuspid	12 (22.2)	2 (9.1)	10 (31.2)	0.095
Tricuspid	42 (77.8)	20 (90.9)	22 (68.8)	0.095
LVOT diameter (mm)	20 (19–21)	20 (19–21)	20 (19–21)	0.786
LVEF (%)	58 (55–65)	63 (57–65)	56.5 (54–64)	0.099
Peak aortic velocity (m/s)	3.4 (2.9–3.9)	2.9 (2.3–3.2)	3.8 (3.3–4.9)	<0.001
Mean gradient (mmHg)	26 (19–37)	16 (12–22)	32 (26–57)	<0.001
SVI (mL/m²)	39.2 (33.7–49.4)	40.0 (33.7–54.6)	38.4 (33.0–46.0)	0.333
DVI	0.27 (0.23–0.38)	0.42 (0.37–0.44)	0.24 (0.18–0.27)	<0.001
AVA by CE (cm²)	0.86 (0.69–1.22)	1.24 (1.20–1.42)	0.72 (0.53–0.85)	<0.001
AVA by TF (cm²)	0.88 (0.69–1.22)	1.24 (1.17–1.40)	0.73 (0.59–0.85)	<0.001

BMI, body mass index; BSA, body surface area; CE, continuity equation; DVI, Doppler velocity index; IQR, interquartile range; LVEF, left ventricular ejection fraction; LVOT, left ventricular outflow tract; SVI, stroke volume index; TF, Tango formula. Values are median (IQR) unless stated otherwise.

Severe aortic stenosis patterns

Among the 32 patients with severe AS, 13 (40.6%) had high-gradient AS (mean gradient ≥40 mmHg). The remaining 19 (59.4%) had low-gradient, low-flow AS: 4 (21%) classic low-flow/low-gradient (LVEF <50%) and 15 (79%) paradoxical low-flow/low-gradient with preserved LVEF (≥50%), as classified per current guidelines[3,4] (Figure 2). Most patients in this subgroup had DVI >0.25. Specific subgroup analysis of TF

performance within low-gradient, low-flow AS was not feasible given the small subgroup sizes (n=4 classic, n=15 paradoxical); this remains a key question for future powered studies.

Method-agreement between the Tango formula and the continuity equation

Overall agreement between TF and CE was excellent for absolute AVA (CCC=0.94; 95% CI 0.89–0.98) and indexed AVA (CCC=0.95; 95% CI 0.91–0.98). Bland–Altman analysis showed negligible mean bias (MD=0.001 cm²; 95% LoA −0.22 to 0.21 cm²).

In the severe AS subgroup, agreement remained excellent: CCC=0.87 (95% CI 0.75–0.93) for absolute AVA and CCC=0.90 (95% CI 0.82–0.95) for indexed AVA; Bland–Altman bias was MD=−0.010 cm² (95% LoA −0.171 to 0.151 cm²). In moderate AS, agreement was moderate for absolute AVA (CCC=0.46; 95% CI −0.04 to 0.88) and moderate-to-good for indexed AVA (CCC=0.71; 95% CI 0.29–0.94), with wider limits of agreement (MD=0.01 cm²; 95% LoA −0.27 to 0.29 cm²). Detailed agreement statistics are summarised in Table 3 and illustrated in Figure 3. The wider confidence interval observed in the moderate AS subgroup is consistent with the pilot sample size and with range-restriction effects on CCC within a narrow AVA band.

Severity reclassification sensitivity analysis. Four of 54 patients (7.4%) were classified differently by the two methods using the 1.0 cm² AVA threshold: all 4 reclassifications occurred in the moderate AS group (4 of 22 patients, 18.2%), in whom TF yielded a value ≤1.0 cm² whereas CE yielded a value >1.0 cm². No reclassification events occurred in the severe AS group (0 of 32 patients, 0%). These exploratory findings suggest that TF is most reliable for confirming severe AS classification, whereas caution is warranted when applying it to patients whose CE-derived values cluster near the 1.0 cm² threshold.

Table 3. Method-agreement between the Tango formula and the continuity equation.

Group / measure	CCC (95% CI)	Interpretation	MD, cm² (95% LoA)	Bias direction
Overall — Absolute AVA	0.94 (0.89–0.98)	Excellent	0.001 (−0.22 to 0.21)	Negligible
Overall — Indexed AVA	0.95 (0.91–0.98)	Excellent	—	—
Moderate AS — Absolute AVA	0.46 (−0.04 to 0.88)	Moderate	0.01 (−0.27 to 0.29)	Negligible
Moderate AS — Indexed AVA	0.71 (0.29–0.94)	Moderate–good	—	—
Severe AS — Absolute AVA	0.87 (0.75–0.93)	Excellent	−0.010 (−0.171 to 0.151)	Negligible
Severe AS — Indexed AVA	0.90 (0.82–0.95)	Excellent	—	—

AS, aortic stenosis; AVA, aortic valve area; CCC, Lin's concordance correlation coefficient; CI, confidence interval; LoA, limits of agreement; MD, mean difference. CCC interpretation thresholds: ≥0.90 excellent, 0.71–0.90 good, 0.51–0.70 moderate, ≤0.50 poor.

Intra- and inter-observer reproducibility of the Tango formula

Fifteen cases (27.8% of the cohort) were included in the reproducibility sub-study, selected by random stratified sampling to maintain representation of both moderate (n=6) and severe (n=9) AS phenotypes. Intra-observer reproducibility of TF-derived AVA was good, with CCC=0.87 (95% CI 0.66–0.95) and a negligible mean bias between paired measurements. Inter-observer reproducibility was also good, with CCC=0.82 (95% CI 0.56–0.93), slightly lower than the intra-observer estimate—an expected pattern given the additional variance contributed by a second independent operator—but still within the "good agreement" band. Detailed reproducibility statistics are reported in Table 4.

These preliminary reproducibility estimates are central to the proof-of-concept nature of the present work: they demonstrate that the three Doppler components of TF (ejection time, peak aortic velocity, and acceleration time) can be measured with acceptable consistency from archived continuous-wave envelopes, both by the same observer over time and across independent level-3 echocardiographers. The 95% CIs are appropriately wide for a pilot sample of n=15, and should be refined in a larger prospective study.

Table 4. Intra- and inter-observer reproducibility of Tango formula-derived aortic valve area in the pilot reproducibility sub-study.

Comparison	n	CCC (95% CI)	Interpretation
Intra-observer (TF, ≥4-week interval)	15	0.87 (0.66–0.95)	Good
Inter-observer (TF, two level-3 readers)	15	0.82 (0.56–0.93)	Good

CCC, Lin's concordance correlation coefficient; CI, confidence interval; TF, Tango formula. CCC interpretation thresholds: ≥0.90 excellent, 0.71–0.90 good, 0.51–0.70 moderate, ≤0.50 poor. Measurements were performed on the same archived continuous-wave Doppler envelopes by the same observer (intra-observer, with a washout interval ≥4 weeks) and by a second independent level-3 echocardiographer blinded to previous measurements (inter-observer).

Discussion

Principal findings. This single-centre pilot and proof-of-concept study generated three preliminary observations that we consider relevant for the design of a future definitive study of the Tango formula. First, overall agreement between TF and CE for AVA estimation is excellent, with negligible bias; agreement is particularly strong in severe AS (CCC=0.87) and more limited in moderate AS (CCC=0.46). Second, no reclassification events between methods occurred in the severe AS subgroup, whereas 18.2% of moderate AS patients were reclassified—an exploratory signal consistent with the expected range-restriction behaviour of CCC near a classification threshold. Third, and importantly, the Tango formula demonstrated good intra-observer (CCC=0.87) and inter-observer (CCC=0.82) reproducibility, supporting the feasibility of its use by independent operators. Taken together, these findings are hypothesis-generating and support advancing to a prospective, adequately-powered multicentre validation.

These results align with those of Gamaza-Chulián et al.,[11] who reported that the Doppler time indices underlying TF—acceleration time and ejection time—are tightly associated with AS severity, and with the general recognition that haemodynamic Doppler parameters become more reproducible as stenosis becomes haemodynamically significant.[13]

Reproducibility as a proof of concept. The reproducibility sub-study is the most novel component of this work. For a simplified Doppler-only index to be clinically useful, it must be demonstrably reproducible across operators and over time. Our observed intra-observer CCC of 0.87 and inter-observer CCC of 0.82 both meet the threshold for "good" agreement according to established benchmarks[12] and are numerically similar to published inter-observer reproducibility estimates for conventional CE-derived AVA, which range between 0.78 and 0.90 in comparable retrospective datasets.[11,18] The slightly lower inter-observer than intra-observer CCC is the expected pattern and reflects the additional variance introduced by a second independent operator. Because TF eliminates the single-most error-prone measurement of CE—the LVOT diameter—we hypothesise that in a prospective setting its reproducibility may approach or exceed that of CE; this is a primary question for future study.

Conceptual framing. We are careful to position the continuity equation as the comparator method—consistent with its guideline status as the reference standard for AVA estimation[3,4]—rather than as an absolute anatomical truth. The TF-derived value is an approximation whose precise physical meaning has not been fully elucidated, and CE itself is subject to measurement error, particularly through LVOT diameter assessment. The present work therefore evaluates agreement between two practical clinical methods and does not claim anatomical validation. A definitive study should compare both methods against a gold standard such as cardiac computed tomography–derived planimetry or cardiac catheterisation.

Interpretation of the moderate AS subgroup. The more limited agreement observed in moderate AS—wider LoA (−0.27 to 0.29 cm²) and lower CCC (0.46)—reflects at least two effects. First, a statistical range-restriction phenomenon: in moderate AS, AVA values cluster within a narrow band (~1.0–1.5 cm²), so even small absolute differences have a disproportionate relative impact on CCC. Second, pathophysiologically, less severe stenoses are characterised by lower transvalvular velocities and less well-defined Doppler spectra, increasing measurement variability. These observations suggest that the clinical utility of TF is likely greatest in the haemodynamically significant severe phenotype. Crucially, in the overall sample the 95% LoA (−0.22 to 0.21 cm²) span the clinically relevant 1.0 cm² boundary—meaning that at the individual-patient level near this threshold, classification by TF alone is not advisable. TF should be used as a complementary cross-validation tool rather than a standalone primary method, especially near the moderate/severe boundary.[14]

Clinical implications. Where LVOT measurement is technically unreliable—due to heavy valve or annular calcification, suboptimal parasternal window, obesity, or LVOT ellipticity—TF offers a single-window, single-measurement approach that eliminates the squared-error propagation inherent to LVOT-based AVA computation.[7,8] In such scenarios, the present pilot data suggest that TF can provide a useful independent estimate, particularly when CE-derived values fall within the severe range. We do not propose TF as a replacement for CE; we propose it as a Doppler-only complementary tool warranting prospective validation.

Low-gradient, low-flow AS. The cohort included a high proportion (59.4%) of low-gradient, low-flow AS—predominantly the paradoxical phenotype with preserved LVEF (79% of the low-flow group). Although sample size precluded dedicated subgroup analysis, the overall excellent agreement within severe AS provides an initial signal that TF performs adequately in these haemodynamically challenging patients. Targeted evaluation in this subgroup should be a priority for the definitive study.

Strengths and limitations

Strengths. To our knowledge, this is the first published evaluation of the Tango formula to include a formal intra- and inter-observer reproducibility sub-study. The cohort includes a representative distribution of AS severities and a high proportion of low-gradient, low-flow phenotypes that are

particularly relevant to contemporary practice. Statistical methods were pre-specified and follow published recommendations for agreement studies.[12,17]

Limitations. This work has important limitations that define its interpretation as a pilot and proof-of-concept study. First, the retrospective single-centre design limits causal inference and external generalisability. Second, the overall sample size (n=54) and the reproducibility sub-study size (n=15) are modest—by design—and yield appropriately wide confidence intervals; these are not definitive estimates. Third, CE was used as the reference comparator rather than an independent anatomical gold standard such as CT planimetry or catheterisation. Fourth, a limited number of patients had bicuspid aortic valves (22.2%), and TF performance in this subgroup could not be evaluated separately. Fifth, high-gradient versus low-gradient AS subtypes could not be separately powered for agreement analysis. Sixth, the original description of the Tango formula has not been published in a peer-reviewed indexed journal with a DOI; the most formal written account currently available is the 2023 publication cited here,[9] which limits external verification of the formula's theoretical derivation. Finally, the reproducibility analysis was performed on archived Doppler envelopes; prospective acquisition-level reproducibility (two independent acquisitions on the same patient) remains to be assessed.

Conclusion

In this single-centre pilot and proof-of-concept study, the Tango formula demonstrated excellent agreement with the continuity equation for aortic valve area estimation in severe AS and good intra- and inter-observer reproducibility (CCC 0.87 and 0.82, respectively). Preliminary findings suggest that TF is most reliable in the haemodynamically significant phenotype and should be used with caution near the moderate/severe classification boundary. These hypothesis-generating data support the design and conduct of a prospective, adequately-powered multicentre study incorporating anatomical validation against CT planimetry or cardiac catheterisation and dedicated evaluation in low-gradient AS subtypes. Pending such validation, TF may be considered a complementary Doppler-only tool for cross-checking CE-derived AVA when LVOT measurement is technically unreliable.

Abbreviations

AS, aortic stenosis; AVA, aortic valve area; CCC, Lin's concordance correlation coefficient; CE, continuity equation; CSA, cross-sectional area; DVI, Doppler velocity index; ICC, intraclass correlation coefficient; LoA, limits of agreement; LVEF, left ventricular ejection fraction; LVOT, left ventricular outflow tract; MD, mean difference; SVI, stroke volume index; TF, Tango formula; VTI, velocity–time integral.

Declarations

Ethics approval and consent to participate

The study was approved by the Research Committee of the Universidad del Valle and the Ethics Committee of the Hospital Universitario del Valle – Evaristo García (approval reference withheld for double-blind peer review and available on request). The requirement for individual informed consent was waived by the same Ethics Committee given the retrospective, fully anonymised nature of the data. All procedures were conducted in accordance with the Declaration of Helsinki.

Consent for publication

Not applicable. The manuscript contains no individually identifiable patient data, images, or videos.

Availability of data and materials

The de-identified datasets generated and analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Authors’ contributions

EJRR and SBB conceived and designed the study and drafted the manuscript. EJRR and SAZ collected and curated the data. SBB and OEAM performed the statistical analyses, including the reproducibility sub-study. AAHE provided clinical supervision, served as the independent second reader for the inter-observer analysis, and critically revised the manuscript for important intellectual content. All authors read and approved the final manuscript.

Acknowledgements

The authors thank the echocardiography laboratory staff at the participating institutions for their collaboration in data retrieval.

Use of artificial intelligence

Artificial intelligence tools were used solely to assist with the preparation of the graphical abstract. All scientific content, analyses, interpretations, and conclusions were produced and reviewed by the authors. Large language models do not meet authorship criteria and are not listed as authors.

ORCID iDs

All authors will provide their ORCID iDs at submission via the journal's manuscript system.

References

1. Osnabrugge RLJ, Mylotte D, Head SJ, et al. Aortic stenosis in the elderly. J Am Coll Cardiol. 2013;62(11):1002–1012.
2. d'Arcy JL, Coffey S, Loudon MA, et al. Large-scale community echocardiographic screening reveals a major burden of undiagnosed valvular heart disease in older people: the OxVALVE population cohort study. Eur Heart J. 2016;37(47):3515–3522.
3. Vahanian A, Beyersdorf F, Praz F, et al. 2021 ESC/EACTS guidelines for the management of valvular heart disease. Eur Heart J. 2022;43(7):561–632.
4. Praz F, Borger MA, Lanz J, et al. 2025 ESC/EACTS guidelines for the management of valvular heart disease. Eur Heart J. 2025;ehaf194. doi:10.1093/eurheartj/ehaf194.
5. Lang RM, Badano LP, Mor-Avi V, et al. Recommendations for cardiac chamber quantification by echocardiography in adults: an update from the ASE and EACVI. J Am Soc Echocardiogr. 2015;28(1):1–39.e14.
6. Baumgartner H, Hung J, Bermejo J, et al. Recommendations on the echocardiographic assessment of aortic valve stenosis: a focused update from the EACVI and ASE. J Am Soc Echocardiogr. 2017;30(4):372–392.
7. Michelena HI, Margaryan E, Miller FA, et al. Inconsistent echocardiographic grading of aortic stenosis: is the left ventricular outflow tract important? Heart. 2013;99(13):921–931.
8. Utsunomiya H, Yamamoto H, Horiguchi J, et al. Underestimation of aortic valve area in calcified aortic valve disease: effects of LVOT ellipticity. Int J Cardiol. 2012;157(3):347–353.
9. Merlo M, Cuneo C, Nolly M, et al. Fórmula Tango para estimación del área valvular aórtica mediante ecocardiografía. Revista POCUS. 2023;(6):8–14.
10. Otto CM, Bonow RO. Valvular heart disease: a companion to Braunwald's heart disease. 4th ed. Philadelphia: Elsevier; 2014.
11. Gamaza-Chulián S, Díaz-Retamino E, Camacho-Freire S, et al. Acceleration time and ratio of acceleration time to ejection time in aortic stenosis. J Am Soc Echocardiogr. 2017;30(10):947–955.

12. McBride GB. A proposal for strength-of-agreement criteria for Lin's concordance correlation coefficient. NIWA Client Report HAM2005-062. Hamilton: National Institute of Water and Atmospheric Research; 2005.
13. Baumgartner H, Otto CM. Aortic stenosis severity: do we need a new concept? J Am Coll Cardiol. 2009;54(11):1012–1013.
14. Coffey S, Cairns BJ, Iung B. The modern epidemiology of heart valve disease. Heart. 2016;102(1):75–85.
15. Siontis GCM, Overtchouk P, Cahill TJ, et al. Transcatheter aortic-valve implantation vs. surgical aortic-valve replacement: updated meta-analysis. Eur Heart J. 2019;40(38):3143–3153.
16. Manzo R, Ilardi F, Nappa D, et al. Echocardiographic evaluation of aortic stenosis: a comprehensive review. Diagnostics. 2023;13(15):2527.
17. Kottner J, Audigé L, Brorson S, et al. Guidelines for Reporting Reliability and Agreement Studies (GRRAS) were proposed. J Clin Epidemiol. 2011;64(1):96–106.
18. Thavendiranathan P, Liu S, Verhaert D, et al. Feasibility, accuracy, and reproducibility of real-time full-volume 3D transthoracic echocardiography to measure LV volumes and systolic function: a fully automated endocardial contouring algorithm in sinus rhythm and atrial fibrillation. JACC Cardiovasc Imaging. 2012;5(3):239–251.

Figures

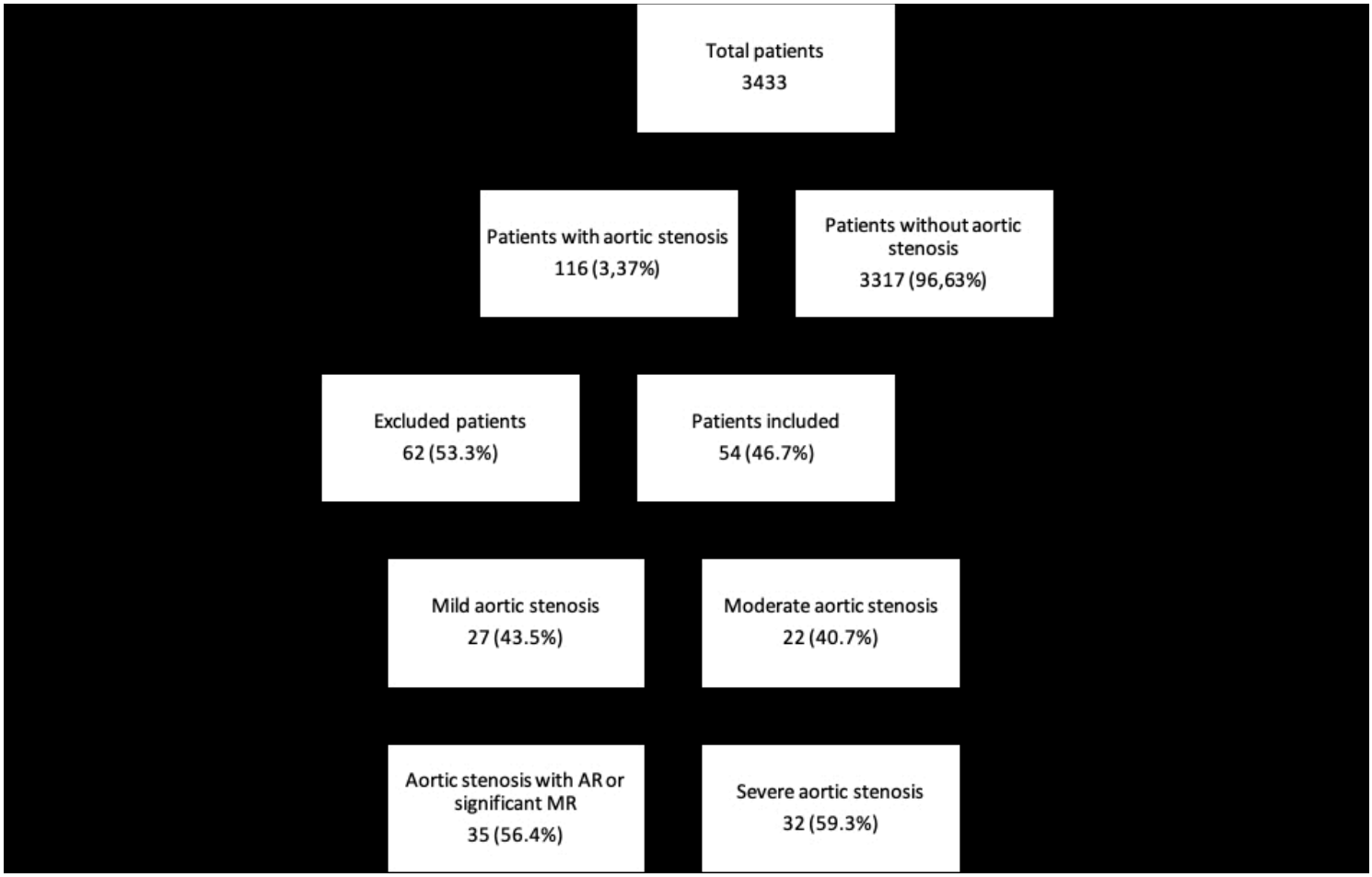


Figure 1

Patient selection flowchart. Of 3,433 echocardiographic studies reviewed, 116 had aortic stenosis (3.4%). Sixty-two patients (53.4%) were excluded: 27 for mild AS and 35 for concomitant moderate-to-severe aortic or mitral regurgitation. The final cohort comprised 54 patients (22 moderate, 32 severe). A random stratified subsample of 15 patients was selected for the intra- and inter-observer reproducibility sub-study. AR, aortic regurgitation; MR, mitral regurgitation.

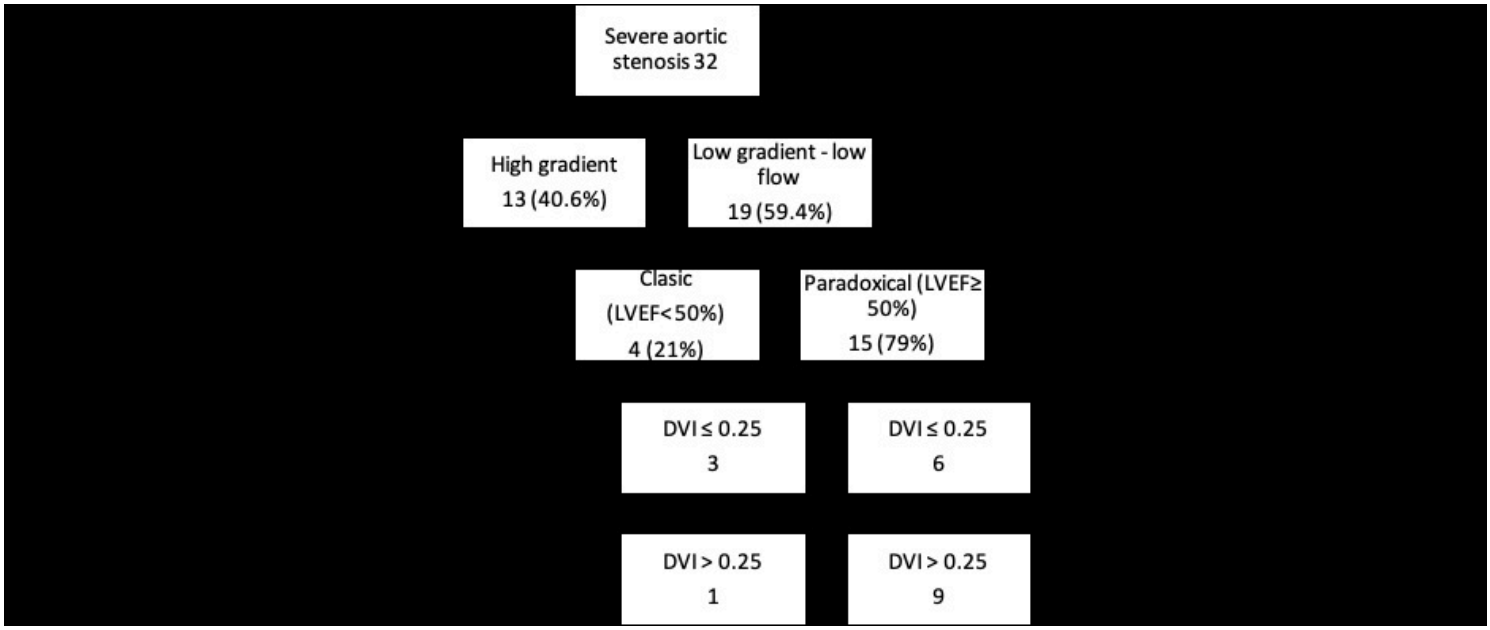


Figure 2

Classification of severe aortic stenosis according to mean transaortic gradient, stroke volume index (SVI), and left ventricular ejection fraction (LVEF), following the 2021 ESC/EACTS guidelines and the 2025 update. Among 32 patients with severe AS, 13 (40.6%) had high-gradient AS. Of the remaining 19 with low-gradient, low-flow AS, 4 (21%) had classic low-flow/low-gradient AS (LVEF <50%) and 15 (79%) had paradoxical low-flow/low-gradient AS (LVEF ≥50%). DVI, Doppler velocity index; LVEF, left ventricular ejection fraction.

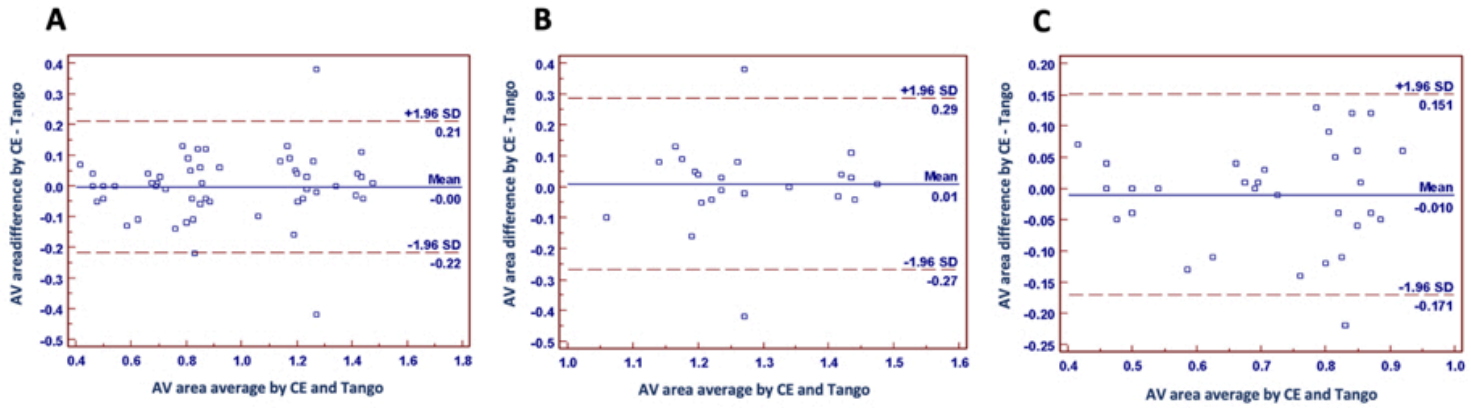


Figure 3

Bland–Altman plots of the difference versus the mean of aortic valve area (AVA) measured by the continuity equation (CE) and the Tango formula (TF). (A) Overall sample (n=54): MD=0.001 cm²; 95% LoA −0.22 to 0.21 cm². (B) Moderate aortic stenosis subgroup (n=22): MD=0.01 cm²; 95% LoA −0.27 to 0.29 cm². (C) Severe aortic stenosis subgroup (n=32): MD=−0.010 cm²; 95% LoA −0.171 to 0.151 cm². Solid line, mean difference; dashed lines, 95% limits of agreement. MD, mean difference; LoA, limits of agreement.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Graphicabstract.png