Original Investigation Reports

Mitral annular plane systolic excursion in moderate-severe aortic stenosis, low flow and preserved systolic function

Adrián Carlessi[1 2 3], Juan Morbidoni[2], Evangelina Garello[1 2], Bruno Strada[1], Leonel Perello[1 2].

1 Sanatorio San Gerónimo. 2 Hospital JM Cullen. 3 Diagnostico por imágenes Junín. Santa Fe Capital.

ARTICLE INFORMATION

Received on November 5, 2024.
Accepted after review on January 31, 2025.
www.revistafac.org.ar

There are no conflicts of interest to disclose.

Keywords:
Aortic stenosis,
low flow,
ejection fraction,
longitudinal strain,
MAPSE.

ABSTRACT

Background: low flow (LF) (stroke volume index (SVi) <35 ml/m²) serves as a prognostic marker of aortic stenosis (AS). Longitudinal strain assessed by speckle tracking is a determinant of LF. However, this method requires an adequate ultrasound window. Mitral annular plane systolic excursion (MAPSE) functions as an alternative for longitudinal strain.

Objectives: to investigate the relationship between MAPSE and LF in patients with moderate AS (MAS) or severe AS (SAS).

Methods: patients with MAS (valve area <1.50 cm²) or SAS (valve area <1 cm²) and an ejection fraction ≥ 50% were evaluated. The average MAPSE was calculated utilizing the lateral and medial MAPSE. All parameters related to LF (not involved in its calculation) were analyzed, and a logistic regression model was performed.

Results: a total of 222 patients were evaluated, 59.5% presented with SAS. The prevalence of LF in the general population was 16.7%. The median MAPSE was 1.34 cm (1.2-1.46) in patients with normal flow and 0.99 cm (0.90-1.06) in those with LF (p<0.001). MAPSE demonstrated an area under the curve of 0.89 for the prediction of LF. Multivariate analysis was conducted with the significant variables from the univariate analysis, with age (p=0.011), body surface area (p=0.003), heart rate (p=0.03), and MAPSE (p<0.001) remaining significant.

Conclusion: patients with MAS, SAS, and LF had lower MAPSE than those with normal flow. MAPSE is an excellent predictor of LF, and it was the only echocardiographic parameter associated with LF in a multivariate analysis.

INTRODUCTION

Aortic valve stenosis is a growing health issue with a considerable financial impact. Currently, aortic valve replacement is indicated in patients with severe aortic stenosis (SAS) that develop symptoms. The management of asymptomatic patients with AS is still being debated. In recent years, class I indication for aortic valve replacement is only for patients who present ejection fraction (EF) drop below 50%.[1] Patients with EF ≥50% and low transvalvular flow (LF) (stroke volume index (SVi) <35 ml/m²), present a worse prognosis than patients with SVi >35 ml/m².[2,3,4] LF is due, among multiple causes, to a greater peripheral vascular resistance, decrease of systemic arterial compliance, as well as a higher level of valvulo-arterial impedance (Zva).[5,6,7] On the other hand, patients with LF present lower values of global longitudinal strain (GLS) than those with preserved flow, caused by early compromise of subendocardial fibers of the left ventricle, which may lead to a drop in SVi[3,8]. The speckle technique is the one most used by GLS measurement, but it is not available in all echocardiography laboratories, the presence of inappropriate ultrasound window may generate variability between results, and in spite of differences between brands having diminished, some still persist, both in methods used and in established cutoff points.[9] Mitral annular plane systolic excursion (MAPSE) is an alternative to GLS. Regardless of the method used for measuring, left ventricular systolic longitudinal strain is the longitudinal shift in relation to its initial length in diastole, measured in apical views: (telediastolic length – telesystolic length) / telediastolic length. The difference between telediastolic length and telesystolic length is given by MAPSE, then: MAPSE/telediastolic length is an alternative for longitudinal function measurement. Stoylen et al. advise to not carry out MAPSE normalization by telediastolic length, as it increases dependence on body surface and gender in the parameter.[10]

The aim of this study, therefore, is to assess the LF-MAPSE relationship in patients with moderate aortic stenosis (MAS) and SAS, with EF ≥50% and the predictive capacity of LF that MAPSE may present.

Corresponding author's address: **Dr. Adrián Carlessi.** Carrera 8 #95-60. Bogotá, Cundinamarca. Colombia. Código Postal: 110221 Autopista Santa Fe Rosario Barrio privado Las Almenas lote 78. CP 3016. Santo Tome. Santa Fe. Argentina. *e-mail:* adriancarlessi@gmail.com

MATERIALS AND METHODS

Patients with SAS (valve area <1 cm2) and MAS (valve area <1.50 cm2) were included prospectively, who had been referred to Doppler echocardiogram as outpatients, since August 2022 until September 2024. The following patients were excluded: with EF <50%; another left valve disease, from major to mild; severe mitral annulus calcification; and prosthesis in mitral position.

Complete transthoracic echocardiography was carried out in all patients. All echocardiographic measurements were made following the current recommendations.[11] Left ventricular stroke volume was estimated in the following manner: left ventricular outflow tract x velocity-time integral of the left ventricular outflow tract measured by pulsed-wave Doppler. Furthermore, multiple transducer positions were applied to record the peak velocities of the aortic jet. The highest transaortic velocity was used for the continuity equation.

Systemic blood pressure was measured manually, with a sphygmomanometer cuff (in the arm), of the aneroid type, while Doppler measurement was carried out on the left ventricular outflow tract stroke volume. As a measure of the global load of the left ventricle, we estimated an Zva = (SBP x TPG)/SVi, where SBP is systolic blood pressure and TPG is the net transvalvular pressure gradient. Therefore, Zva represents the valvular and arterial factors opposing ventricular ejection when absorbing the mechanical energy developed by the LV. Patients presenting Zva ≥4.5 mmHg.ml-1.m2 were considered to have a high Zva.

MAPSE was obtained by M mode from the apical,

TABLE 1.
Clinical and echocardiographic variables.

VARIABLE	GENERAL	NORMAL FLOW	LOW FLOW	p
n	222	185	37	
AGE (mean (SD))	72,95 (10,67)	72,05 (10,90)	77,46 (8,17)	0,005
Male gender (%)	128 (57.7)	101 (54.6)	27 (73)	0.06
BS (m²)	1.89 (0.21)	1.87 (0.21)	1.97 (0.21)	0.009
DIABETES n (%)	68 (30.6)	54 (29.2)	14 (37.8)	0.397
HTN n (%)	173 (77.9)	144 (77.8)	29 (78.4)	1
DYSLIPIDEMIA n (%)	110 (49.5)	89 (48.1)	21 (56.8)	0.435
OBESITY n (%)	86 (38.7)	70 (37.8)	16 (43.2)	0.666
AMI n (%)	12 (5.4)	9 (4.9)	3 (8.1)	0.69
CAD n (%)	50 (22.5)	38 (20.5)	12 (32.4)	0.172
SBP (mmHg) – IQR	140 [121- 150]	140 [125 -150]	134 [120-150]	0.371
DBP (mmHg) – IQR	80 [70- 85]	80 [70- 85]	80[70-90]	0.762
HR (bpm) – SD	71.1 (10.24)	70.2(9.67)	75.2 (12.02)	0.007
LVDD (mm) – SD	47.4 (4.71)	47.2 (4.58)	48.6 (5.23)	0.084
LVSD (mm) – SD	28.35 (4.25)	28.05 (4.24)	29.89 (3.98)	0.016
EFS (% average) - SD	40.27 (6.34)	40.63 (6.37)	38.47 (5.97)	0.06
LVEDDI (ml/m²) - SD	48.8 [38-58]	49 [38.6- 58.2]	45.4 [37.9- 55]	0.358
LVESDI (ml/m2) – IQR	16.7 [12.7- 21.5]	16.7 [12.9-21.2]	16.39 [11.7-21.9]	0.943
EF (% average - SD)	65.1(6.1)	65.4 (5.9,)	63.4 (6.8,)	0.08
RWT - IQR	0.41 [0.365-0.4]	0.40 [0.36-0.44]	0.42 [0.38- 0.52]	0.026
LVMI (g/m2) – IQR	126.9 [107.6-153.2]	124 [106.3-147.7]	150.1 [118.1-170.3]	<0.001
Ee – IQR	10.2 [7.6-14]	9.9 [7.5- 13]	12.16 [10.3- 18.7]	<0.001
TRV (m/sec) – IQR	2.60 [2.42, 2.91]	2.57 [2.42, 2.85]	2.78 [2.43, 3.01]	0.15
LAV (ml/m²) – IQR	44 [38-52]	44[38- 51]	49 [38- 56]	0.098
LVOTD (cm) – IQR	2.08 [2- 2.18]	2.08 [1.99-2.17]	2.10 [2- 2.20]	0.541
SVi (ml/m²) – SD	43.2 (8.31)	45.6 (6.74)	31.08 (3.16)	<0.001
APV (m/sec) – IQR	4.06 [3.3 –4.48]	4.06 [3.25-4.48]	4.12 [3.35-4.47]	0.779
MPG (mmHg) – IQR	38 [25- 48.7]	38 [24- 48]	40[27- 49]	0.856
AVA (cm²) – IQR	0.94 [0.76, 1.16]	0.98 [0.80, 1.19]	0.73 [0.60, 0.88]	<0.001
PVR (mmHg·min/l) - IQR	1170.6 [972.7-1505]	1109.5 [950.2- 1456.9]	1447 [1170- 1750.6]	<0.001
Zva (mmHg.ml-1.m2)-IQR	3.19 [2.72- 3.77]	3.01 [2.63-3.48]	4.24 [3.83-4.73]	<0.001
MAPSE (cm) – IQR	1.31 [1.09-1.44]	1.34 [1.20-1.46]	0.99 [0.90-1.09]	<0.001

HTN: hypertension; **AMI:** acute myocardial infarction; **CAD:** coronary artery disease; **SBP:** systolic blood pressure; **DBP:** diastolic blood pressure; **HR:** heart rate; **LVDD:** left ventricular diastolic diameter; **LVSD:** left ventricular systolic diameter; **EFS:** endocardial fractional shortening; **LVEDDi:** left ventricular end-diastolic diameter index; **LVESDi:** left ventricular end-systolic diameter index; **EF:** ejection fraction; **RWT:** relative wall thickness; **LVMI:** left ventricular mass index; **Ee:** mitral Ee ratio; **TRV:** tricuspid regurgitation velocity; **LAV:** left atrial volume; **LVOTD:** left ventricular outflow tract diameter; **SVi:** stroke volume index; **APV:** aortic peak velocity; **MPG:** mean pressure gradient; **AVA:** aortic valve area; **PVR:** peripheral vascular resistance; **Zva:** valvulo-arterial impedance; **MAPSE:** mitral annular plane systolic excursion; **SD:** standard deviation; **IQR:** interquartile range.

4-chamber view at the lateral and medial mitral annulus level. The M mode cursor was aligned parallel to the left ventricular walls. MAPSE was measured from the lowest point at the end of diastole to the peak point measured at the end of T wave in ECG. Two measurements were made on both sides, and they were averaged.

STATISTICAL ANALYSIS

Quantitative variables of normal distribution are presented as mean±standard deviation; those with nonparametric distribution are described by median and interquartile range; and qualitative variables are presented as percentages. A t test was conducted for the evaluation of normal distribution variables and Mann-Whitney test for those not presenting normal distribution. Chi-square test or Fisher's exact test were implemented (when necessary) to compare categorical variables. Sensitivity and specificity were estimated using standard definition; receiver operating characteristic curves were built and area under the curve was estimated to predict SVi <35 ml/m². P values <0.05 were considered statistically significant. The analysis was made by Rstudio, version 4.3.2.

RESULTS

There were 222 patients evaluated, with mean age of 72.9 years (66-80), of whom 57.7% were males *(Table 1).* Patients presented SAS in 59.5%. Global prevalence of LF was 16.7%. In the group of patients with SAS, the prevalence of LF was 23.6% and in those with MAS it was 6.7% (p =< 0.001).

The MAPSE median was 1.34 cm (1.20-1.46) in patients with NF and 0.99 cm (0.90-1.06) in those with LF (p =< 0.001) *(Figure 1A).* No significant differences were found in EF or in endocardial fractional shortening (EFS) in the two groups *(Table 1).* Patients with MAS and NF presented a MAPSE median of 1.37 cm (1.14-1.47); while those with LF 1.05 cm (0.94-1.09) (p =< 0.001) *(Figure 1B).* In those with SAS and NF, MAPSE was 1.31 cm (1.14-1.46) and in those with LF 0.98 cm (0.89-1.06) (p =< 0.001) *(Figure 1C).*

On the other hand, there were no significant differences in terms of EF or EFS in regard to stenosis severity; patients with SAS had a mean EF of 65% (±5.83) and those with MAS 65.4% (±6.44) (p=0.71); EFS was 41% (±6.22) and 40.3% (±6.58) in patients with MAS and SAS respectively (p=0.39); instead, there were significant differences in terms of MAPSE, with the MAPSE median in patients with MAS being 1.38 cm (1.21-1.46) and with SAS 1.26 cm (1.00-1.40) (p =< 0.001) (Figure 1D). Patients with a high Zva presented less MAPSE than those with normal Zva, 1.02 cm (0.88-1.09) and 1.32 cm (1.11-1.45), respectively (p =< 0.001).

The predictive capacity of MAPSE to determine the presence of LF presented an area under the ROC curve of 0.89; a cutoff point of 1.16 cm presented 91% sensitivity and 77% specificity *(Figure 2).*

The variables significantly associated with LF in univariate analysis, and that were not part of the stroke volume estimation, were evaluated in a logistic regression model, with age (p = 0.011), body surface (p = 0.003), heart rate (p = 0.03) and MAPSE (p =< 0.001) *(Table 2).*

DISCUSSION

This study showed an association between the presence of LF and MAPSE. The patients with LF presented less MAPSE than those with NF. This association was observed both in patients with SAS and MAS, and it remained significant after multivariate analysis. This was not reflected in other parameters of systolic function evaluated, such as EF and EFS. MAPSE showed an excellent prediction for the

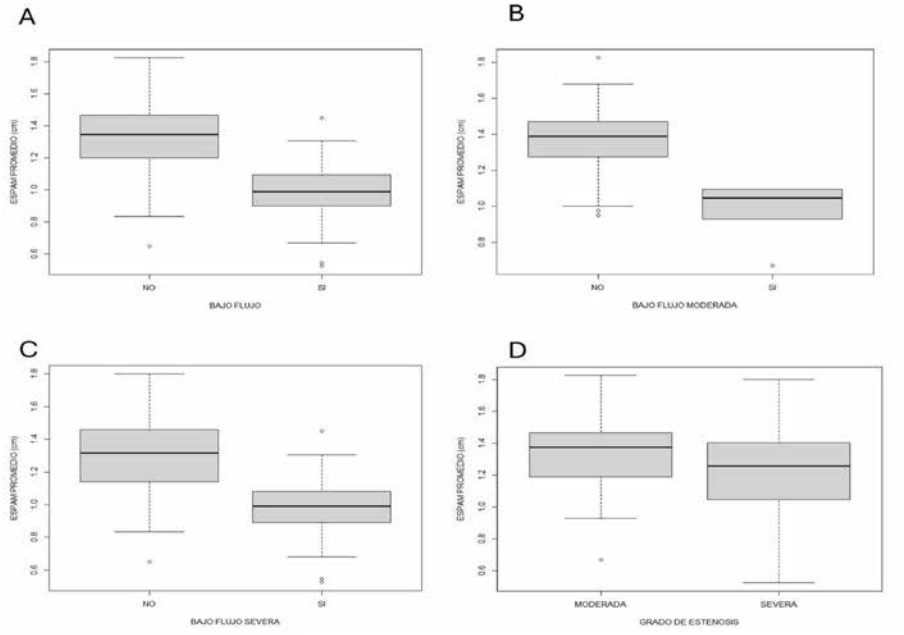


FIGURE 1.
MAPSE median according to the presence of LF in the general population (A). MAPSE according to the presence of low flow in patients with MAS (B) and SAS (C). MAPSE and AS severity relationship (D)

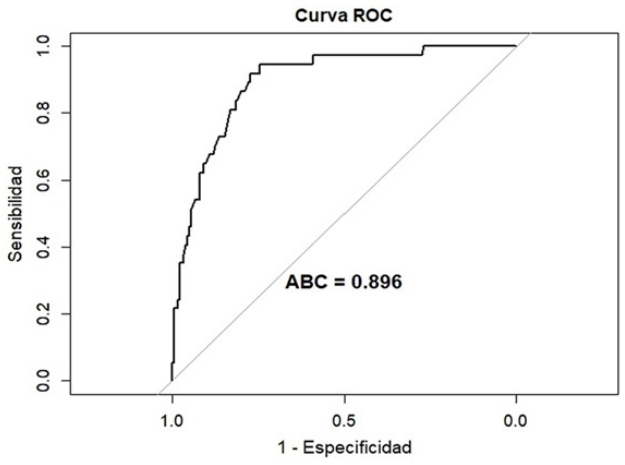


FIGURE 2.
Curva ROC que muestra el área bajo la curva (ABC) del ESPAM promedio para la predicción de BF.

TABLE 2.
Multivariate logistic regression analysis

Predictor	Estimator	EE	Z	p
Constant	-11.23588	6.23610	-1.802	0.072
AGE	0.08839	0.03480	2.540	0.011
MALE GENDER	0.46392	0.71429	0.649	0.516
BS	5.02726	1.68361	2.986	0.003
HR	0.05840	0.02697	2.166	0.030
LVSD	-0.02631	0.08441	-0.312	0.755
LVMI	-0.00428	0.00998	-0.429	0.668
RWT	2.27642	3.82240	0.596	0.551
Ee	-0.01334	0.05544	-0.241	0.810
MAPSE	-9.31400	1.80876	-5.149	< .001

BS: body surface; **HR:** heart rate; **LVSD:** left ventricular systolic diameter; **LVMI:** left ventricular mass index; **RWT;** relative wall thickness; **Ee**: mitral Ee ratio; **MAPSE:** mitral annular plane systolic excursion

presence of LF, presenting an area under the curve of 0.89, with high sensitivity (91%) and proper specificity (71%).

LF is a condition presenting in up to 35% of patients with severe aortic stenosis, and the association of LF and low gradient (medium gradient < 40 mmHg) in patients with SAS presents in 10-25% of patients.[4,12] In this study, we observed a global prevalence of 16.7% of LF, with patients with SAS being 23.6% and 6.7% in those with MAS. The latter, in previous studies, showed an LF prevalence of 7%, similar to that observed in our study.[13]

Patients with SAS, LF and EF ≥50% present less survival after valve replacement; particularly those with low mean gradient (<40 mmHg).[13,14,15] Beyond this, in patients with mid-to-high gradient (>40 mmHg) and EF ≥50%, those presenting LF, showed a worse prognosis in a mean follow-up of 48 months, thus reflecting the prognostic impact of LD per se, beyond the mean gradient.[16]

On the other hand, MAS is an entity that entails a risk of major events, and the presence of GLS deterioration, measured by speckle tracking, is a prognostic factor in the evolution of these patients, even in patients presenting EF deterioration.[17,18,19,20] In this study, patients with MAS and low flow presented less MAPSE than those with NF *(Figure 1C).*

Parameters evaluating afterload beyond the one imposed by valve stenosis, such as PVR, SAC and Zva, affect cardiac mechanics and may have an impact on the evolution of patients after valve replacement.[21,22] In this study, association between Zva and MAPSE association was observed, reflecting the sensitivity of the latter to the changes of the former.

Subendocardial fibers, responsible for longitudinal shortening, are affected early by different conditions, such as the overload imposed by AS. GLS, by speckle tracking, evaluates the function of said fibers. It was observed that patients with LF present less values than those with preserved transvalvular flow, so longitudinal function deterioration may lead, among other factors, to a drop in SVi.[23,24] And beyond LF, the longitudinal function is an independent prognostic marker in patients with SAS, establishing as a marker of early compromise in the disease.[25,26] However, the speckle tracking technique is not available in all laboratories, requiring a certain learning curve and a proper ultrasound window to minimize variability, and although they have been shortening, there are still differences observed between methods of analysis from different commercial brands.[9,27,28]

The estimation of longitudinal function by MAPSE is a simple, generic measurement, with less interobserver variability, presenting a high correlation to the degree of myocardial fibrosis, measured with cardiac MRI in patients with AS.[29,30] And that could be a marker of advanced damage, as LF has proven to be.

LIMITATIONS

The estimation of the area was made by continuity equation, with the probability of underestimating AVA. In spite of this, this estimation method was used in all these tests.

Larger studies are needed to establish values and cutoff points for MAPSE in its possible association with LF. In turn, follow-up studies are required to be able to establish the possible prognostic value of MAPSE.

CONCLUSION

MAPSE is decreased in patients with LF, both in MAS and SAS. MAPSE presented a high predictive capacity for LF and it persists, in a multivariate analysis, as the only independent echocardiography parameter associated to LF.

Acknowledgements

The authors of this article acknowledge the human and academic influence of Dr. Carlos Becker†.

BIBLIOGRAPHY

1. Vahanian A, Beyersdorf F, Praz F, et al. 2021 ESC/EACTS Guidelines for the management of valvular heart disease: Developed by the Task Force for the management of valvular heart disease of the European Society of Cardiology (ESC) and the European Association for Cardio-Thoracic Surgery (EACTS). Eur Heart J **2022**; 43: 561 – 632.
2. Dayan V, Vignolo G, Magne J, et al. Outcome and Impact of Aortic Valve Replacement in Patients with Preserved LVEF and Low-Gradient Aortic Stenosis. J Am Coll Cardiol **2015**; 66: 2594 – 2603.
3. Lancellotti P, Magne J, Donal E, et al. Clinical outcome in asymptomatic severe aortic stenosis: insights from the new proposed aortic stenosis grading classification. J Am Coll Cardiol **2012**; 59: 235 – 243.
4. Hachicha Z, Dumesnil JG, Bogaty P, et al. Paradoxical Low-Flow, Low-Gradient Severe Aortic Stenosis Despite Preserved Ejection Fraction Is Associated with Higher Afterload and Reduced Survival. Circulation **2007**; 115: 2856 – 2864.
5. Briand M, Dumesnil JG, Kadem L, et al. Reduced Systemic Arterial Compliance Impacts Significantly on Left Ventricular Afterload and Function in Aortic Stenosis. J Am Coll Cardiol **2005**; 46: 291 – 298.
6. Hachicha Z, Dumesnil JG, Pibarot P. Usefulness of the Valvuloarterial Impedance to Predict Adverse Outcome in Asymptomatic Aortic Stenosis. J Am Coll Cardiol **2009**; 54: 1003 – 1011.
7. Cramariuc D, Cioffi G, Rieck ÅE, et al. Low-Flow Aortic Stenosis in Asymptomatic Patients: Valvular–Arterial Impedance and Systolic Function from the SEAS Substudy. JACC Cardiovasc Imaging **2009**; 2: 390 – 399.
8. Luis SA, Chan J, Pellikka PA. Echocardiographic Assessment of Left Ventricular Systolic Function: An Overview of Contemporary Techniques, Including Speckle-Tracking Echocardiography. Mayo Clin Proc **2019**; 94: 125 – 138.
9. Farsalinos KE, Daraban AM, Ünlü S, et al. Head-to-Head Comparison of Global Longitudinal Strain Measurements among Nine Different Vendors. J Am Soc Echocardiogr **2015**; 28: 1171 -1181.
10. Støylen A, Mølmen HE, Dalen H. Relation between Mitral Annular Plane Systolic Excursion and Global longitudinal strain in normal subjects: The HUNT study. Echocardiography **2018**; 35: 603 – 610.
11. Lang RM, Badano LP, Mor-Avi V, et al. Recommendations for Cardiac Chamber Quantification by Echocardiography in Adults: An Update from the American Society of Echocardiography and the European Association of Cardiovascular Imaging. J Am Soc Echocardiogr **2015**; 28: 1 -39.
12. Saybolt MD, Fiorilli PN, Gertz ZM, et al. Low-Flow Severe Aortic Stenosis. Circ Cardiovasc Interv **2017**; 10: e004838.
13. Stassen J, Ewe SH, Singh GK, et al. Prevalence and Prognostic Implications of Discordant Grading and Flow-Gradient Patterns in Moderate Aortic Stenosis. J Am Coll Cardiol **2022**; 80: 666 – 676.
14. Wagener M, Reuthebuch O, Heg D, et al. Clinical Outcomes in High-Gradient, Classical Low-Flow, Low-Gradient, and Paradoxical Low-Flow, Low-Gradient Aortic Stenosis After Transcatheter Aortic Valve Implantation: A Report from the Swiss TAVI Registry. J Am Heart Assoc Cardiovasc Cerebrovasc Dis **2023**; 12: e029489.
15. Bridonneau V, Galli E, Auffret V, et al. Management of aortic valve replacement according to the gradient across symptomatic aortic valve stenosis and its prognostic impact. Echocardiography **2019**; 36: 2136 – 2144.
16. Maréchaux S, Rusinaru D, Altes A, et al. Prognostic Value of Low Flow in Patients with High Transvalvular Gradient Severe Aortic Stenosis and Preserved Left Ventricular Ejection Fraction: A Multicenter Study. Circ Cardiovasc Imaging **2019**; 12: e009299.
17. Strange G, Stewart S, Celermajer D, et al. Poor Long-Term Survival in Patients with Moderate Aortic Stenosis. J Am Coll Cardiol **2019**; 74: 1851 – 1163.
18. Delesalle G, Bohbot Y, Rusinaru D, et al. Characteristics and Prognosis of Patients with Moderate Aortic Stenosis and Preserved Left Ventricular Ejection Fraction. J Am Heart Assoc **2019**; 8: e011036.
19. Stassen J, Pio SM, Ewe SH, et al. Left Ventricular Global Longitudinal Strain in Patients with Moderate Aortic Stenosis. J Am Soc Echocardiogr **2022**; 35: 791 - 800.
20. Stassen J, Singh GK, Pio SM, et al. Incremental value of left ventricular global longitudinal strain in moderate aortic stenosis and reduced left ventricular ejection fraction. Int J Cardiol **2023**; 373: 101 – 106.
21. Nuis RJ, Goudzwaard JA, de Ronde-Tillmans MJAG, et al. Impact of Valvulo-Arterial Impedance on Long-Term Quality of Life and Exercise Performance After Transcatheter Aortic Valve Replacement. Circ Cardiovasc Interv **2020**; 13: e008372.
22. Huded CP, Kusunose K, Shahid F, et al. Novel Echocardiographic Parameters in Patients with Aortic Stenosis and Preserved Left Ventricular Systolic Function Undergoing Surgical Aortic Valve Replacement. Am J Cardiol **2018**; 122: 284 – 293.
23. Adda J, Mielot C, Giorgi R, et al. Low-flow, low-gradient severe aortic stenosis despite normal ejection fraction is associated with severe left ventricular dysfunction as assessed by speckle-tracking echocardiography: a multicenter study. Circ Cardiovasc Imaging **2012**; 5: 27 – 35.
24. Sato K, Seo Y, Ishizu T, et al. Prognostic Value of Global Longitudinal Strain in Paradoxical Low-Flow, Low-Gradient Severe Aortic Stenosis With Preserved Ejection Fraction. Circ J **2014**; 78: 2750 – 2759.
25. Magne J, Cosyns B, Popescu BA, et al. Distribution and Prognostic Significance of Left Ventricular Global Longitudinal Strain in Asymptomatic Significant Aortic Stenosis: An Individual Participant Data Meta-Analysis. JACC Cardiovasc Imaging **2019**; 12: 84 – 92.
26. Gutierrez-Ortiz E, Olmos C, Carrión-Sanchez I, et al. Redefining cardiac damage staging in aortic stenosis: the value of GLS and RVAc. Eur Heart J - Cardiovasc Imaging **2023**; 24: 1608 –1617.
27. Negishi T, Negishi K, Thavendiranathan P, et al. Effect of Experience and Training on the Concordance and Precision of Strain Measurements. JACC Cardiovasc Imaging **2017;** 10: 518 –522.
28. Ünlü S, Mirea O, Duchenne J, et al. Comparison of Feasibility, Accuracy, and Reproducibility of Layer-Specific Global Longitudinal Strain Measurements Among Five Different Vendors: A Report from the EACVI-ASE Strain Standardization Task Force. J Am Soc Echocardiogr **2018**; 31: 374 - 380.
29. Thorstensen A, Dalen H, Amundsen BH, et al. Reproducibility in echocardiographic assessment of the left ventricular global and regional function, the HUNT study. Eur J Echocardiogr **2010**; 11: 149 – 156.
30. Herrmann S, St örk S, Niemann M, et al. Low-gradient aortic valve stenosis myocardial fibrosis and its influence on function and outcome. J Am Coll Cardiol **2011**; 58: 402 – 412.