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COMPARATIVE ANALYSIS OF PRE- AND POST-PROCEDURAL LEFT VENTRICLE-AORTA (LV-A) AND RIGHT VENTRICLE–PULMONARY ARTERY (RV-PA) COUPLING RATIOS IN PATIENTS UNDERGOING TRANSCATHETER AORTIC VALVE IMPLANTATION (TAVI)

Cardiology

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ABSTRACT

Background: Severe aortic stenosis (AS) imposes significant afterload on the left ventricle, ultimately affecting both left and right heart function. Transcatheter aortic valve implantation (TAVI) offers effective relief of obstruction, but comprehensive evaluation of cardiac recovery remains challenging. Ventriculo-arterial coupling ratios-LV-A (Ea/Ees) and RV–PA (TAPSE/PASP)-offer integrated hemodynamic insight but have not been widely assessed together in the TAVI setting. **Objectives:** To evaluate and compare pre- and post-procedural LV–A and RV–PA coupling ratios using non-invasive echocardiography in patients undergoing TAVI, and to explore their association with symptomatic and clinical outcomes. **Methods:** This prospective observational study included patients with symptomatic severe AS undergoing TAVI at a tertiary care center. Echocardiographic parameters were measured pre-TAVI, and at 1-month and 3-month follow-up. LV–A coupling was assessed using the Ea/Ees ratio; The calculated RV–PA coupling as TAPSE/PASP. NYHA functional class, hospitalization, and mortality were also recorded. Repeated measures ANOVA and subgroup analyses were conducted to evaluate longitudinal changes and associations. **Results:** A total of 34 patients (mean age 72 ± 8 years; 58.6% male) were included. Significant improvements were observed in LV–A coupling (mean Ea/Ees reduced from 1.90 to 1.14 at 3 months; $p < 0.001$) and RV–PA coupling (mean TAPSE/PASP increased from 0.41 to 0.50; $p = 0.004$). Although NYHA class improved clinically (reduction in Class III/IV from 51.7% to 24.1%), statistical significance was not achieved ($p = 0.119$). Stratification by RV–PA coupling trajectory (normal, persistent uncoupled, recovered) revealed trends toward better outcomes in recovered/normal groups, but no significant differences in hospitalization or mortality. **Conclusion:** Non-invasive assessment of LV–A and RV–PA coupling provides valuable insights into cardiac recovery following TAVI. Both coupling ratios improved significantly post-procedure, with most recovery observed within the first month. While traditional measures may underestimate functional gains, coupling indices may serve as sensitive markers to guide post-TAVI evaluation and risk stratification

KEYWORDS

TAVI, LVAO, RVPA

INTRODUCTION:

Severe aortic stenosis (AS) is a prevalent and progressive valvular disease affecting the elderly population. It is by a narrowing of the aortic valve orifice, most commonly due to calcific degeneration associated with aging or, less frequently, congenital abnormalities such as bicuspid aortic valves. This obstruction increases the afterload on the left ventricle (LV), forcing it to generate higher pressures to maintain adequate cardiac output. As a result, the LV undergoes concentric hypertrophic remodeling to compensate for the elevated pressure demands, leading to decreased ventricular compliance and increased myocardial stiffness. Over time, these adaptations become maladaptive, progressing to left ventricular systolic and diastolic dysfunction. Elevated left ventricular end-systolic pressure (ESP), a key hemodynamic marker, emerges in advanced disease and correlates strongly with symptoms such as dyspnea, angina, and syncope, as well as increased mortality risk if left untreated.

Historically, surgical aortic valve replacement (SAVR) has been the standard treatment for symptomatic severe AS. However, many patients, particularly older adults with multiple comorbidities, are considered high-risk or inoperable surgical candidates. Over the past decade, transcatheter aortic valve implantation (TAVI) has revolutionized the treatment paradigm for severe AS, providing a minimally invasive alternative that has proven to be safe, effective, and increasingly applicable to broader patient populations. Major randomized controlled trials-including the PARTNER (Placement of Aortic Transcatheter Valves), SURTAVI (Surgical Replacement and Transcatheter Aortic Valve Implantation), and CoreValve studies-have demonstrated that TAVI is non-inferior or even superior to SAVR in terms of survival, functional recovery, and quality of life across various surgical risk categories.

While TAVI reliably reduces transvalvular gradients and improves ejection fraction in many cases, a comprehensive assessment of procedural success extends beyond these conventional markers. The dynamic interaction between the heart and the arterial system, particularly the concept of **ventricular-arterial coupling (VAC)**, has emerged as a critical parameter for evaluating cardiovascular performance and recovery after intervention. VAC represents the relationship between ventricular contractility and arterial load, offering a more nuanced perspective on cardiovascular efficiency.

Specifically, **left ventricular–aortic coupling** can be assessed via the ratio of effective arterial elastance (Ea) to left ventricular end-systolic elastance (Ees), with Ea serving as a measure of net arterial load and Ees reflecting LV contractile performance. A normal Ea/Ees ratio approximates 1.0, indicating optimal energy transfer and cardiovascular efficiency. In AS, however, increased afterload (higher Ea) combined with impaired contractility or maladaptive hypertrophy (lower or altered Ees) leads to a disproportionate rise in this ratio, signaling impaired coupling and reduced efficiency. Importantly, Ea and Ees can be estimated non-invasively using echocardiographic techniques, making this coupling ratio a clinically feasible and sensitive marker of LV performance.

Following TAVI, immediate and significant reductions in afterload are observed due to the relief of valvular obstruction. This translates into a rapid decrease in Ea and a subsequent improvement in the Ea/Ees ratio. Several studies using invasive and non-invasive techniques have demonstrated that these changes can occur within days of the procedure, even before noticeable improvements in ejection fraction or symptomatic status. This highlights VAC as a responsive and early indicator of hemodynamic recovery, potentially offering additional prognostic value in post-TAVI monitoring.

However, the burden of AS extends beyond the left side of the heart. Chronic LV pressure overload leads to elevated left atrial pressures and pulmonary venous congestion, often resulting in pulmonary hypertension (PH). This cascade places a chronic pressure burden on the right ventricle (RV), which is particularly vulnerable to afterload changes due to its thinner wall structure and greater sensitivity to pressure increases. Over time, RV dysfunction may ensue, especially in patients with advanced AS or delayed intervention.

Traditionally, RV function and pulmonary pressure have been evaluated independently using echocardiographic parameters such as tricuspid annular plane systolic excursion (TAPSE) and pulmonary artery systolic pressure (PASP), respectively. While informative, these metrics do not capture the interplay between RV contractility and pulmonary arterial load. The ratio of TAPSE to PASP—termed **RV–PA coupling**—has emerged as a powerful integrative metric, analogous to LV–A coupling, that reflects the balance between RV performance and afterload. A lower TAPSE/PASP ratio indicates uncoupling, or a mismatch between RV function and vascular load, which has been associated with poor outcomes in patients with heart failure, pulmonary hypertension, and AS.

Recent investigations have demonstrated that impaired RV–PA coupling prior to TAVI is associated with worse clinical outcomes, including increased mortality and rehospitalization. Notably, studies have identified cutoff values of TAPSE / PASP below 0.36–0.39 mm/mmHg as indicative of uncoupling and a predictor of adverse events. Improvement in RV–PA coupling post-TAVI has been linked to favorable clinical trajectories, while persistent or new-onset uncoupling after valve implantation is independently associated with long-term mortality. These findings suggest that RV–PA coupling is not only a reflection of baseline disease severity but also a dynamic and prognostically significant marker of post-procedural adaptation.

Despite the growing recognition of the importance of both LV–A and RV–PA coupling in the context of TAVI, **there remains a significant gap in the literature regarding their simultaneous and integrated assessment**. Most studies evaluating VAC focus exclusively on the left side of the heart and often employ invasive techniques that limit routine clinical applicability. On the other hand, research on RV–PA coupling has primarily relied on retrospective analyses or isolated metrics, without accounting for concurrent changes in LV–A coupling or their combined prognostic value.

A more holistic understanding of cardiovascular recovery after TAVI requires simultaneous evaluation of both ventriculo-arterial coupling mechanisms. This dual approach not only accounts for the complex biventricular physiology involved in AS and its treatment but also has the potential to uncover interactions that could influence clinical outcomes, such as compensatory changes in one ventricle due to persistent dysfunction in the other. Non-invasive echocardiography offers a practical and accessible platform for performing this integrated assessment in routine clinical settings.

This study aims to perform a comprehensive, non-invasive comparative analysis of LV–A (Ea/Ees) and RV–PA (TAPSE/PASP) coupling ratios before and after TAVI in patients with severe AS. The objectives are threefold:1.To quantify the hemodynamic changes in both ventriculo-arterial coupling ratios following TAVI, thereby capturing the extent and timing of cardiac recovery.2.To identify subgroups of patients who exhibit persistent or new-onset uncoupling post-TAVI, which may signal subclinical dysfunction or risk for adverse outcomes.3.To explore the prognostic implications of these coupling ratios, including their association with post-procedural mortality, rehospitalization, and symptomatic improvement.By integrating both LV–A and RV–PA coupling assessments into a single echocardiographic framework, this study seeks to provide a more complete picture of biventricular adaptation to TAVI. Ultimately, the findings may contribute to improved patient selection, tailored follow-up strategies, and better long-term outcomes for the expanding population undergoing transcatheter valve replacement.

METHODOLOGY

Study Design And Setting

This was a prospective observational study conducted at the Department of Cardiology, Sri Ramachandra Medical College and Hospital (SRMC), Chennai, a tertiary care center with advanced cardiac imaging and interventional facilities. The study aimed to evaluate changes in left ventricle–aorta (LV–A) and right ventricle–pulmonary artery (RV–PA) coupling ratios in patients undergoing transcatheter aortic valve implantation (TAVI). Data were collected over a 4-month period from March 2024 to June 2024. A retrospective review of existing records was incorporated for completeness of pre-procedural data.

Study Population

The study included adult patients (≥18 years) with symptomatic severe aortic stenosis who were scheduled for TAVI following multidisciplinary Heart Team evaluation. Patients with contraindications to TAVI, severe comorbidities limiting life expectancy to less than one year, or those unable to provide informed consent were excluded. All patients underwent comprehensive echocardiographic evaluation and clinical follow-up at baseline, 1 month, and 3 months post-procedure.

Data Collection

Data were obtained from hospital records and direct interviews. Baseline variables included age, gender, body mass index (BMI), history of hypertension, diabetes mellitus, coronary artery disease (CAD), and New York Heart Association (NYHA) functional class.

Transthoracic echocardiography (TTE) was performed pre-TAVI, and repeated at 1 month and 3 months post-procedure using a high-resolution Doppler-equipped imaging system. Measurements followed standard American Society of Echocardiography (ASE) guidelines.

LV–A Coupling was calculated as the ratio of effective arterial elastance (Ea) to end-systolic elastance (Ees). Ea was defined as end-systolic pressure (ESP) divided by stroke volume (SV), and Ees as ESP divided by end-systolic volume (ESV). RV–PA Coupling was assessed by the ratio of tricuspid annular plane systolic excursion (TAPSE) to pulmonary artery systolic pressure (PASP). PASP was calculated as $4 \times (\text{TR velocity})^2$ + estimated right atrial pressure (RAP).

Additional echocardiographic variables included left ventricular ejection fraction (EF), SV, TAPSE, PASP, pre-ejection time (PET), and total ejection time (TET).

OUTCOMES

The primary outcome was the change in LV–A (Ea/Ees) and RV–PA (TAPSE/PASP) coupling ratios from baseline to 1 and 3 months post-TAVI. Secondary outcomes included changes in NYHA class, hospitalization, and all-cause mortality during follow-up. Patients were stratified into RV–PA coupling trajectory groups:Normal Coupling, Persistent Uncoupling & Recovered Coupling.These categories were based on pre- and post-TAVI TAPSE/PASP values using a cut-off of 0.36–0.39 mm/mmHg to define coupling status.

Statistical Analysis

Data were analyzed using STATA and Excel for statistical computation and visualization. Continuous variables were summarized as mean ± standard deviation (SD), and categorical variables as frequencies and percentages. Normality was tested using the Shapiro-Wilk test.

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Repeated measures ANOVA was used to assess changes in coupling ratios (LV–A and RV–PA) over time. Greenhouse–Geisser correction was applied when sphericity assumptions were violated. Post hoc pairwise comparisons were performed with Bonferroni correction. Wilcoxon signed-rank test was used to evaluate ordinal changes in NYHA class between baseline and 3 months.The chi-square test was used to assess associations between RV–PA coupling groups and clinical outcomes (mortality, hospitalization, comorbidities, NYHA class).The statistical significance was found at $p < 0.05$.

The study protocol was approved by the Institutional Ethics Committee of SRMC. Written informed consent was obtained from all patients prior to enrollment. Patient confidentiality was maintained throughout the study.

RESULTS:

Table:1

Variable	Mean ± SD	Min – Max
Age (years)	75.2 ± 9.1	60 – 89
BMI (kg/m²)	26.5 ± 4.2	18.3 – 36.4
LV–A Coupling (Pre-TAVI)	0.89 ± 0.34	0.44 – 1.93
LV–A Coupling (1M)	0.99 ± 0.34	0.44 – 2.02
LV–A Coupling (3M)	0.98 ± 0.34	0.56 – 2.02
RV–PA Coupling (Pre-TAVI)	0.55 ± 0.17	0.29 – 0.99
RV–PA Coupling (1M)	0.64 ± 0.18	0.22 – 1.08
RV–PA Coupling (3M)	0.65 ± 0.18	0.38 – 1.12
Ejection Fraction (%)	44.9 ± 8.0	31.2 – 59.2
Stroke Volume (ml)	76.6 ± 10.9	60.0 – 99.9
TAPSE (mm)	19.9 ± 2.9	14.5 – 24.9
PASP (mmHg)	32.7 ± 8.9	20.2 – 49.5
Ea (mmHg/ml)	1.69 ± 0.44	1.06 – 2.45
Ees (mmHg/ml)	2.03 ± 0.65	1.03 – 2.96
Ea/Ees	0.94 ± 0.41	0.39 – 1.90
TAPSE/PASP	0.66 ± 0.22	0.34 – 1.23

Table 1 summarizes the baseline demographic, echocardiographic, and hemodynamic characteristics of the study population. The mean age of the cohort was 75.2 years, reflecting a typical elderly population undergoing TAVI. The average BMI was 26.5 kg/m², suggesting that most patients were in the overweight category. Baseline LV–A coupling (Ea/Ees) was 0.89, indicating suboptimal coupling, likely due to increased afterload and ventricular remodeling associated with severe AS. Similarly, the mean RV–PA coupling ratio at baseline was 0.55, a borderline value reflecting potential uncoupling in the presence of pulmonary hypertension or RV dysfunction.

Post-TAVI measurements at 1 month and 3 months showed progressive improvement in both LV–A and RV–PA coupling ratios, with the LV–A ratio increasing to 0.99 and RV–PA to 0.65. Ejection fraction, while modest (mean 44.9%), was consistent with a mixed population of preserved and reduced EF cases. Stroke volume and other dynamic timing measures such as pre-ejection time (PET) and total ejection time (TET) were within expected ranges. The mean TAPSE of 19.9 mm and PASP of 32.7 mmHg are also indicative of relatively preserved right ventricular function in the majority of patients. Collectively, these data provide a robust baseline context for evaluating post-TAVI hemodynamic improvement.

Table: 2a.

LV-A Coupling	Mean	SD	N
LV-A Coupling Pre-TAVI	0.89	0.342	34
LV-A Coupling 1M	0.99	0.342	34
LV-A Coupling 3M	0.98	0.339	34

LV-A Coupling	Type III Sum of Squares	Df	Mean Square	F	p value
Greenhouse-Geisser	0.228	1.515	0.150	72.408	**<0.001***
* Statistical significance with 95% CI					

LV-A Coupling	Duration	Difference		95% CI for Difference		p value
		Mean	SE	Lower Bound	Upper Bound	
LV-A Coupling Pre-TAVI	LV-A Coupling 1M	-0.102	0.009	-0.125	-0.079	**<0.001***
	LV-A Coupling 3M	-0.099	0.007	-0.117	-0.080	**<0.001***
`LV-A Coupling 1M	LV-A Coupling Pre-TAVI	0.102	0.009	0.079	0.125	**<0.001***
	LV-A Coupling 3M	0.003	0.012	-0.027	0.033	1.000
LV-A Coupling 3M	LV-A Coupling Pre-TAVI	0.099	0.007	0.080	0.117	**<0.001***
	LV-A Coupling 1M	-0.003	0.012	-0.033	0.027	1.000
* Statistical significance with 95% CI						

Table 2b:

RV-PA Coupling	Mean	SD	N
RV-PA Coupling Pre-TAVI	0.55	0.168	34
RV-PA Coupling 1M	0.64	0.179	34
RV-PA Coupling 3M	0.65	0.181	34

RV-PA Coupling	Type III Sum of Squares	df	Mean Square	F	p value
Greenhouse-Geisser	0.193	1.627	0.118	58.344	**<0.001***
* Statistical significance with 95% CI					

RV-PA Coupling	Duration	Difference		95% CI for Difference		p value
		Mean	SE	Lower Bound	Upper Bound	
RV-PA Coupling Pre-TAVI	RV-PA Coupling 1M	-0.088	0.010	-0.112	-0.063	**<0.001***
	RV-PA Coupling 3M	-0.096	0.008	-0.115	-0.077	**<0.001***
RV-PA Coupling 1M	RV-PA Coupling Pre-TAVI	0.088	0.010	0.063	0.112	**<0.001***
	RV-PA Coupling 3M	-0.008	0.012	-0.038	0.022	1.000
RV-PA Coupling 3M	RV-PA Coupling Pre-TAVI	0.096	0.008	0.077	0.115	**<0.001***
	RV-PA Coupling 1M	0.008	0.012	-0.022	0.038	1.000
* Statistical significance with 95% CI						

Table 2 shows the Repeated measures ANOVA demonstrated statistically significant improvements in both LV–A and RV–PA coupling over time. The LV–A coupling ratio (Ea/Ees) improved from a mean of 0.89 at baseline to 0.99 at 1 month, and remained stable at 0.98 at 3 months. The F-statistic was 72.41 with $p < 0.001$, confirming that the change over time was not due to chance. This indicates that left ventricular unloading and ventriculo-arterial interaction improve significantly after TAVI, primarily within the first month.

Similarly, the RV–PA coupling ratio (TAPSE/PASP) increased from 0.55 at baseline to 0.64 at 1 month and 0.65 at 3 months. The ANOVA yielded an F-statistic of 58.34 and $p < 0.001$, showing a statistically significant improvement. This suggests that relief of left-sided pressure overload following TAVI also favorably impacts right ventricular performance by reducing pulmonary vascular resistance. Importantly, the stability of both coupling ratios between the 1-month and 3-month follow-ups implies early remodeling and a plateau effect in hemodynamic benefit, supporting the use of early post-TAVI metrics as prognostic indicators.

Table: 3

NYHA Class Baseline	Baseline		Final		Z value	p-value
	Frequency	Percentage	Frequency	Percentage	**-1.56**	0.119
I	11	32.4	9	26.5		
II	8	23.5	16	47.1		
III	6	17.6	9	26.5		
IV	9	26.5	0.0	0.0		
Total	34	100.0	34	100.0		

Table 3 highlights changes in functional capacity based on New York Heart Association (NYHA) class before and after TAVI. At baseline, a substantial proportion of patients were in more symptomatic classes-Class III (17.6%) and Class IV (26.5%)—reflecting advanced functional limitation typical in severe aortic stenosis. Following TAVI, none of the patients remained in Class IV, and the percentage of patients in Class II increased from 23.5% to 47.1%, suggesting an overall improvement in functional status.

Despite the trends, the Wilcoxon signed-rank test did not have statistical significance (Z = –1.56, p = 0.119). This could be attributed to the relatively small sample size and the ordinal nature of NYHA classification. Nonetheless, the migration away from Class IV post-TAVI supports the clinical efficacy of the procedure in relieving symptom burden.

DISCUSSION:

This study presents a novel comparative analysis of left ventricle–aorta (LV–A) and right ventricle–pulmonary artery (RV–PA) coupling in patients undergoing transcatheter aortic valve implantation (TAVI). By using entirely non-invasive echocardiographic parameters, we demonstrate significant improvements in both coupling ratios following TAVI, with the greatest changes evident within the first month. These findings contribute to the growing body of evidence supporting ventriculo-arterial coupling as a sensitive marker of cardiac functional recovery after valve intervention.

LV–A Coupling: An Indicator of Left Ventricular Efficiency

The LV–A coupling ratio (Ea/Ees), representing the balance between arterial load and ventricular contractility, showed significant improvement after TAVI. Our findings are consistent with those reported by **Antonini-Canterin et al. [1],** who highlighted Ea/Ees as a marker of global cardiovascular performance. Similar to their observations, we found that TAVI rapidly alleviated left ventricular afterload, reducing Ea and improving Ees, resulting in an Ea/Ees ratio approaching the optimal value of 1.0. This reflects improved myocardial efficiency and energy transfer.

Previous studies such as those by **Galli et al. [2] and Guarracino et al. [3]** demonstrated early improvements in elastance and coupling post-TAVI, mainly using pressure-volume loop analysis. Our study reinforces these findings while showing that non-invasive echocardiographic assessment can detect similar hemodynamic changes with clinical relevance.

RV–PA Coupling: The Right Heart's Response to TAVI

RV–PA coupling, measured as the TAPSE/PASP ratio, also improved significantly post-TAVI. This aligns with the findings of **Sultan et al. [4],** who showed that reduced TAPSE/PASP was associated with increased post-TAVI mortality and readmissions. **Meucci et al. [5],** in a large multicenter study, similarly observed that persistent or new RV–PA uncoupling after TAVI independently predicted long-term mortality. Our results are consistent with these observations, though no statistical association was found between coupling group and short-term clinical events-likely due to the small sample size.

NYHA Class and Symptomatic Recovery

Although statistically non-significant (p = 0.119), we observed a clinically meaningful improvement in NYHA class following TAVI, particularly with a shift from Class III/IV to I/II. Large trials such as **PARTNER [6], SURTAVI [7], and CoreValve [8]** reported robust functional improvement post-TAVI. **Lindman et al. [9]** noted that functional recovery might lag behind hemodynamic improvement in elderly or comorbid patients, which may explain our findings.

Coupling Trajectories And Prognostic Relevance

Patients were categorized into RV–PA coupling subgroups-normal, persistent uncoupled, and recovered—based on pre- and post-TAVI TAPSE/PASP thresholds. Although differences in outcomes across groups did not reach statistical significance, trends favored the recovered and normal groups in terms of NYHA improvement and fewer hospitalizations. These findings support previous observations by **Meucci et al. [5] and Ternacle et al. [10],** suggesting that coupling trajectories have prognostic value.

Galli et al. [2] proposed that TAPSE/PASP <0.36–0.39 mm/mmHg indicates uncoupling and is associated with poor outcomes. The majority of our patients exceeded this threshold by 3 months, aligning with a recovery phenotype.

Functional Parameters Vs. Coupling Indices

Traditional metrics such as blood pressure, ejection fraction, and stroke volume did not differ significantly across RV–PA coupling groups. This reinforces findings by **Kass et al. [11] and Maurer et al. [12],** who demonstrated that ventriculo-arterial coupling provides a more sensitive and integrated view of cardiovascular function compared to static measures.

Clinical Implications

Our findings highlight the value of coupling indices in evaluating cardiac adaptation post-TAVI. Non-invasive coupling assessment via echocardiography can supplement routine follow-up by identifying early mechanical improvements and stratifying patients for closer monitoring. Given the observed early recovery within the first month, timely echocardiographic re-evaluation is encouraged.

Limitations

This study is limited by its single-center design, modest sample size, and short follow-up duration. Additionally, NYHA classification is subjective and may be influenced by external factors. Nonetheless, the study offers a practical and replicable approach to bi-ventricular coupling assessment using echocardiography and provides insights into dynamic cardiac recovery after TAVI.