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Transcateter Aortic Valve Implantation (TAVI) in Patients: Relationship between Renal Resistive Index and Central Aortic Pressure

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Abstract

Aim of study: Transcatheter Aortic Valve İmplantation (TAVI) is an alternative to surgical procedure for patients with severe aortic stenosis, which has been applied in recent years. It is widely accepted that the Resistive İndex (RI) examined in renal Doppler Ultrasonography is associated with renal vascular resistance. In our study, we investigated how aortic central pressures affect renal blood flow after TAVİ in aortic stenosis patients and evaluated according to the Resistive İndex (RI) value showing renal vascular resistance.

Materials and methods: In our study, 60 (68.3% (n=41) female, 31.7% (n=19) male) patients who underwent successful TAVI due to symptomatic severe aortic stenosis were included in the study. Central aortic pressure and renal resistive index values of patients were evaluated before and after the TAVI procedure.

Results: In our study, a significant statistical relationship was found between patients with increased creatinine, glomerular filtration rate, BNP, diastolic blood pressure, pulse pressure, NYHA>2, mild paravalvular aortic regurgitation, and patients whose renal resistive index did not increase with TAVI. (p value<0,05). In the logistic regression analysis; BNP, NYHA>2, the presence of critical coronary artery disease and pulse pressure were determined as independent variables that could be effective in the change of renal resistive index value.

Conclusion: Increased renal resistive index values can be determined by non-invasive measurement technique as a reflection of decreased diastolic blood pressure and increased pulse pressure caused by mid-advanced paravalvular aortic regurgitation after TAVI.

Keywords: Aortic Stenosis; TAVI; Renal Resistive Index.

Introduction and objective

Aortic Stenosis (AS) is most commonly caused by the calcific degeneration of the aortic valve, and its prevalence increases in individuals over 75 years of age. According to data from the Euro Heart Survey, AS is the most frequently encountered valvular disease in hospital-based records, accounting for 43%, followed by mitral insufficiency at 32%, and less frequently, aortic insufficiency (13%) [1].

In the United States, the prevalence of moderate to severe valvular diseases is 2.5%, with a noticeable increase with age; for example, the prevalence is 0.7% in the 18-44 age group, rising to 13.3% in those over 75 years old [2]. The incidence of AS also rises with age, with the condition being rare in individuals under 60 years but reaching approximately 10% in those over 80 years old [3].

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Transcatheter Aortic Valve İmplantation (TAVI) was first performed by Cribier in 2002, and since then, it has been applied to over one million patients worldwide [4,5].

Calcific AS is a chronic, progressive disease. Patients remain asymptomatic for an extended latent period, with the duration of this asymptomatic phase varying greatly among individuals. Sudden cardiac death is a frequent cause of death in symptomatic patients; however, in asymptomatic patients with severe AS, it is rare, occurring at a rate of ≤1% per year. For asymptomatic patients with severe AS, the reported 2-year event-free survival rate ranges between 20% and 50% [6,7].

As aortic stenosis progresses due to degenerative changes over time, the left ventricle attempts to compensate for the increasing systolic pressure load by developing concentric hypertrophy. However, when the left ventricle can no longer compensate for the pressure load, diastolic dysfunction, reduced coronary reserve, myocardial ischemia, and left ventricular systolic dysfunction may develop [8,9].

Current guidelines define severe AS as aortic valve Effective Orifice Area (EOA) ≤1 cm^2, indexed EOA≤0.6 cm^2/m^2 (EOA/body surface area), an average transaortic pressure gradient ≥40 mmHg, and a peak jet velocity ≥4 m/s [10].

For symptomatic severe AS patients, Aortic Valve Replacement (AVR) surgery improves both quality of life and survival [11]. Transcatheter aortic valve implantation has emerged as a promising alternative for patients with severe AS who are at high surgical risk, those who are not candidates for surgery, or those with other comorbidities preventing surgery. With increasing operator experience and advances in valve technology, TAVI has demonstrated superior outcomes compared to traditional surgical approaches, offering less procedural risk, better patient comfort, and improved postoperative outcomes [12].

The renal resistive index is a prognostic parameter with clinical significance. It has been widely studied and utilized in various clinical situations, including renal allograft rejection [13,14], renal artery stenosis in hypertensive patients [15,16], and the progression of Chronic Kidney Disease (CKD).

The RI can vary depending on age and sampling location. Values are lower in the main renal arteries and hilum (0.65 ± 0.17) compared to distal smaller renal arteries. The lowest values are found in interlobar arteries (0.54 ± 0.20). Furthermore, RI tends to increase with age [17]. In healthy adults, an RI value between 0.56 and 0.70 and a PI between 0.7 and 1.40 are considered normal [18].

The resistance measured in Doppler ultrasound reflects the total resistance due to all factors affecting the flow, and this is represented by specific indices. In practice, the following indices are commonly used for this purpose:

1. **Resistive Index (RI)** = (Peak Systolic Velocity − End Diastolic Velocity) / Peak Systolic Velocity

2. **Pulsatility Index (PI)** = (Peak Systolic Velocity − End Diastolic Velocity) / Mean Velocity

3. **Systolic/Diastolic Velocity Ratio**

The Resistive Index (RI), obtained through Doppler ultrasonography, is commonly accepted as being directly related to renal vascular resistance. There is an inverse relationship between the RI value and renal blood flow-higher RI values indicate reduced renal blood flow. Various studies have shown that RI may be influenced by systolic and diastolic blood pressure, pulse pressure, pulse rate, age, and proteinuria [19-21]. Our study aimed to examine the changes in aortic central pressure and RI in patients with aortic stenosis who underwent TAVI.

Materials and methods

Patient population

This prospective study included 60 patients (68.3% female, n=41; 31.7% male, n=19) diagnosed with symptomatic severe Aortic Stenosis (AS) and considered at high surgical risk for Aortic Valve Replacement (AVR), who underwent Transcatheter Aortic Valve İmplantation (TAVI) between January 2018 and December 2019 at the Health Sciences University Adana City Training and Research Hospital, Cardiology Clinic. Informed consent was obtained from all patients prior to participation.

Patient selection

The decision regarding surgical risk and eligibility for TAVI was made in a multidisciplinary meeting, which included at least one cardiologist and one cardiovascular surgeon. Patients were evaluated for anatomical suitability, clinical eligibility, and surgical risk scores, with the final decision made by the heart team.

Inclusion criteria

- Symptomatic severe aortic stenosis.
- STS PROM score ≥8 or contraindication for open surgical intervention.

Exclusion criteria

- Narrow or very wide aortic valve annulus (≤18 mm or >30 mm) as assessed by transthoracic echocardiography.
- Distance from the annulus to the left main coronary artery <8 mm.
- Myocardial infarction within the last 30 days.
- Severe coronary artery disease (e.g., significant left main coronary artery stenosis or severe coronary artery disease not amenable to revascularization).
- Acute endocarditis.
- Life expectancy <12 months due to non-cardiac causes.
- Patients whose quality of life improvement would be <25% within 2 years after successful TAVI.

Preoperative preparation

Patients presenting with symptoms such as shortness of breath, chest pain, or syncope, and whose physical examination and ECG were suggestive of aortic stenosis, underwent echocardiography. Transthoracic echocardiography was performed using a Siemens EPIQ 7C system (Philips Healthcare, Andover, MA) with 2.5-3.5 MHz transducers. Left ventricular ejection fraction was automatically calculated using M-mode images, following the guidelines of the American Society of Echocardiography.

Multislice CT imaging was performed to assess critical factors for valve implantation, including the degree and distribution of calcification, aortic root morphology, sinotubular junction diameter, coronary ostial distance, and ascending aorta. This imaging helped select the appropriate valve size for each patient.

Hydration was optimized before CT imaging. For patients with a heart rate >70 bpm, oral metoprolol (50-100 mg) or IV metoprolol (50-100 mg) was administered to achieve a target heart rate of <65 bpm. Additionally, coronary angiography was performed in patients who had not undergone coronary angiography in the past six months. If coronary artery disease was present, simultaneous peripheral angiography and aortography were conducted.

Renal resistive index measurement

Renal Doppler ultrasound was performed on all patients preoperatively, 24 hours post-procedure, and at 6 months post-TAVI. Measurements were taken using a Philips EPIQ7 Spark device with a 3.5 MHz abdominal probe, after a minimum 6-hour fast and 20 minutes of rest. The Doppler study was performed on the interlobar arteries of both kidneys, using a 30-60° angle, and Peak Systolic Velocity (PSV) and End-Diastolic Velocity (EDV) were measured. The Resistive İndex (RI) was automatically calculated using the formula:

RI = (PSV - EDV) / PSV.

TAVI procedure

All procedures were performed via the transfemoral approach. A pacing electrode was inserted into the right ventricle apex, and a 7F sheath was placed in the femoral artery for pressure monitoring and contrast injection. A pigtail catheter was positioned in the distal aorta. The puncture site for the transfemoral approach was chosen under fluoroscopic guidance to avoid areas of significant calcification. A percutaneous closure system (ProGlide) was used post-procedure.

Before valve implantation, aortic and ventricular systolic and diastolic pressures were measured. Predilation was performed if necessary using a balloon selected based on the aortic annulus diameter from CT angiography. After valve implantation, pressure measurements were repeated to assess the Aortic Regurgitation İndex (ARI), calculated as:

ARI = (Aodp - LVdP) / AoSp x 100

where AoDp is the aortic diastolic pressure, LVdP is the left ventricular diastolic pressure, and AoSp is the aortic systolic pressure.

Statistical analysis

Statistical analyses were performed using SPSS 17.0 (Chicago, IL, USA). Continuous variables were presented as means ± standard deviations, and categorical variables were reported as counts and percentages. Student's t-test was used for comparing continuous variables, while the Chi-square test was used for categorical variables. Univariate and multivariate logistic regression analyses were performed to identify factors influencing the changes in renal resistive index ($p<0.10$). Statistical significance was set at $p<0.05$.

Results

A total of 60 patients with severe aortic stenosis who successfully underwent TAVI were included in our study. During the six-month follow-up period, there were six (10%) deaths. The patients' ages ranged from 49 to 91 years, with a mean age of 78.52 ± 8.58 years. Of the patients, 68.3% (n=41) were female, and 31.7% (n=19) were male. Clinical characteristics of patients is summarized in Table 1.

Table 1: Clinical Characteristics of Patients (n=60).

Variable	Value
Mean Age (years)	78.5 ± 8.5
Women, n(%)	41 (68.3)
Body Mass Index (kg/m²)	27 ± 5.33
STS PROM Score	13.8 ± 1
Atrial Fibrillation, n(%)	7 (11.7)
Chronic Obstructive Pulmonary Disease (COPD), n(%)	2 (3.3)
Smoking, n(%)	6 (10)
Diabetes Mellitus (DM), n(%)	14 (23.3)
Hypertension (HT), n(%)	36 (60)
CABG History, n(%)	12 (20.3)
Percutaneous Coronary Intervention (PCI) History, n(%)	10 (16.9)
Stroke History, n(%)	4 (6.7)
Glomerular Filtration Rate (GFR, ml/min)	66.8 ± 21.2
ACE Inhibitor Use, n(%)	9 (15)
ARB Use, n(%)	9 (15)
Beta-Blocker Use, n(%)	30 (50)

COPD: Chronic Obstructive Pulmonary Disease; BKI: Body Mass Index; ACE Inh: Angiotensin-Converting Enzyme Inhibitor; ARB: Angiotensin Receptor Blocker; GFR: Glomerular Filtration Rate; STS PROM: The Society of Thoracic Surgery Predicted Risk of Mortality; DM: Diabetes Mellitus; HT: Hypertension.

Table 2: Procedural findings.

Variable	Value (N=60)
Evolut R (%)	9 (15)
26 mm	5
29 mm	2
34 mm	2
PORTICO (%)	51 (85)
23 mm	3
25 mm	12
27 mm	16
29 mm	20
Predilatation (%)	34 (56)
18 mm	6
20 mm	23
22 mm	4
23 mm	1
Postdilatation (%)	23(38)
20	1
22	3
23	4
25	13
26	2
Femoral Occlusion (%)	3 (5)
Femoral Dissection (%)	3(5)

The following comorbidities were present: Diabetes Mellitus (DM) in 23.3% (n=14), Hypertension (HT) in 60% (n=36), Chronic Obstructive Pulmonary Disease (COPD) in 3.3% (n=2), prior Coronary Artery Bypass Grafting (CABG) in 20.3% (n=11), ischemic stroke (IS) in 6.7% (n=4), and prior Percutaneous Coronary İnterventions (PCI) in 16.9% (n=10). The mean STS PROM score was 13.8 (range: 11.7 to 16.3).

Regarding heart rhythm, 86.7% of the patients (n=52) had sinus rhythm, 11.7% (n=7) had atrial fibrillation, and 1.7% (n=1) had a pacemaker rhythm.

Procedural findings is summarized in Table 2. All patients received self-expanding valves (Evolut R in 13.3% and Portico in 86.6%). Valve sizes ranged from 23 mm to 34 mm. Predilatation was performed in 56% of the patients, while postdilatation was done in 38%. In two cases, a second valve was implanted in the same session due to severe Aortic Regurgitation (AR) after the first valve was deployed.

During the procedure, 3 (5%) patients experienced femoral artery occlusion, and 3 patients developed femoral artery dissection. In patients with occlusion, a peripheral balloon was deployed in the same session. In those with dissection, a stent graft was implanted in the same session.

When comparing the demographic characteristics of patients with increased vs. stable Renal Resistive İndex (RRI) (Table 3.), no statistically significant differences were found in terms of age, gender, or Body Mass İndex (BMI). No significant correlation was found between RRI increase and the presence of diabetes, hypertension, stroke, COPD, or smoking history. Similarly, WBC count and hemoglobin levels showed no significant correlation with RRI changes.

Table 3: Baseline demographic characteristics of patients according to changes in RRI.

Variables	RRİ Stable Group (n=60)	RRİ Increased Group (n=60)	P-value
Age (years)	79.6 ± 6.6	76.6 ± 10.9	0.197
Gender (Male), [n (%)]	10 (27)	9 (39.1)	0.327
BMI (kg/m²)	27.5 ± 5.2	26.1 ± 5.4	0.336
Hypertension, [n (%)]	19 (51.4)	9 (39.1)	0.356
DM, [n (%)]	9 (24.3)	8 (34.8)	0.382
Smoking, [n (%)]	4 (10.8)	2 (8.7)	1.000
Critical Coronary Artery Disease, [n (%)]	12 (32.4)	14 (60.9)	0.037
Stroke, [n (%)]	1 (2.7)	3 (13)	0.153
ACE Inhibitor Use, [n (%)]	4 (10.8)	5 (21.7)	0.284
ARB Use, [n (%)]	7 (18.9)	2 (8.7)	0.460
Beta Blocker Use, [n (%)]	20 (54.1)	10 (43.5)	0.426
COPD, [n (%)]	2 (5.4)	0 (0)	0.519
STS PROM Score (%)	13.8 ± 0.8	13.7 ± 1.1	0.784
WBC (cells/μL)	7624.3 ± 2145.07	8447.8 ± 3603.01	0.271
Hemoglobin (mg/dL)	11.4 ± 1.4	11.4 ± 1.7	0.908
Pre-TAVİ Creatinine (mg/dL)	0.8 ± 0.3	1.0 ± 0.4	0.125
Post-TAVİ Creatinine (mg/dL)	0.7 ± 0.2	1.0 ± 0.4	0.014
Post-TAVİ 6-Month Creatinine (mg/dL)	0.7 ± 0.2	0.9 ± 0.3	0.031
Pre-TAVİ GFR (mL/min)	67.4 ± 19.2	65.9 ± 24.6	0.783
Post-TAVİ GFR (mL/min)	73.0 ± 17.8	60.3 ± 22.8	0.020
Post-TAVİ 6-Month GFR (mL/min)	73.1 ± 17.1	63.3 ± 20.1	0.052
Pre-TAVİ Microalbumin	2.8 ± 3.9	8.2 ± 25.0	0.222
Post-TAVİ BNP (pg/mL)	3337.5 ± 4346	7654.1 ± 9668.8	0.021
Post-TAVİ 6-Month BNP (pg/mL)	1395.3 ± 1890.7	3811.8 ± 6940.6	0.049
Post-TAVİ SBP (mmHg)	132.2 ± 25.8	133.2 ± 25.6	0.888
Post-TAVİ DBP (mmHg)	59.8 ± 13.8	47.6 ± 10.7	0.001
Post-TAVİ Pulse Pressure	45.8 ± 13.0	56.1 ± 13.6	0.005
Pre-TAVİ AVMG (mmHg)	49.9 ± 12.2	51.3 ± 15.9	0.707
Post-TAVİ AVMG (mmHg)	10.6 ± 4.8	8.6 ± 5.3	0.151
Pre-TAVİ LVEF (%)	55.1 ± 6.7	52.3 ± 9.9	0.187
Post-TAVİ LVEF (%)	56.2 ± 7.3	55.2 ± 8.4	0.629
Post-TAVİ NYHA Class >2, [n (%)]	4 (10.8)	8 (34.8)	0.044
PAR > Mild, [n (%)]	1 (2.7)	6 (26.1)	0.010
AR Index	0.32 ± 0.04	0.28 ± 0.06	0.017
Post-TAVİ Pacemaker Implantation, [n (%)]	4 (12.1)	2 (9.5)	0.905

However, a significant correlation was found between RRI increase and post-procedural creatinine, GFR, and BNP levels ($p<0.05$). There was no significant correlation between systolic blood pressure and RRI increase, but significant correlations were found between RRI increase and post-procedural diastolic blood pressure and pulse pressure ($p<0.05$). Additionally, an increased NYHA class >2, elevated PAR (Figure 1), and higher ARI (Figure 2) were significantly correlated with RRI increase ($p<0.05$).

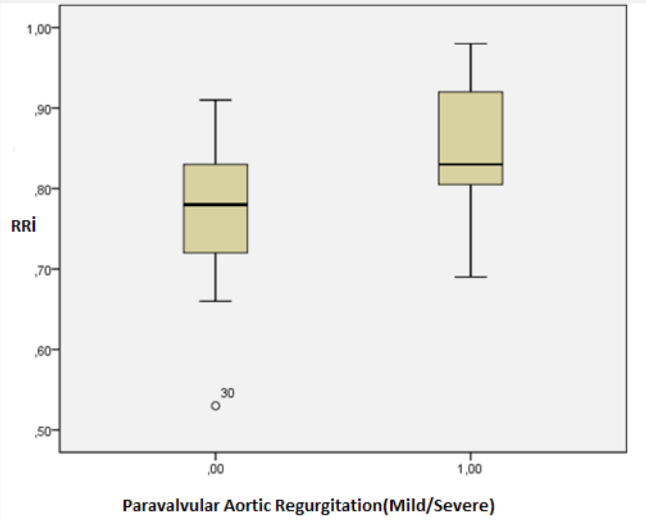

Figure 1: The relationship between renal resistive index (RRI) and paravalvular aortic regurgitation After TAVI.

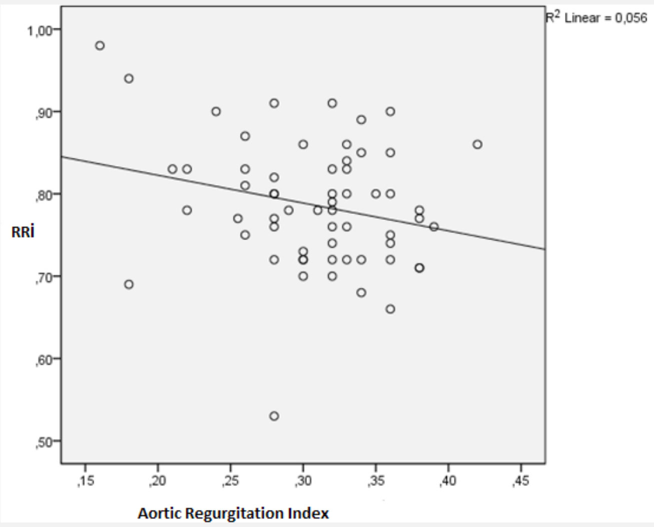

Figure 2: The relationship between renal resistive index (RRI) and aortic regurgitation index (ARI) after TAVI.

Multivariate logistic regression analysis (Table 4) revealed that pulse pressure and BNP were positively and significantly associated with changes in RRI ($p<0.05$). Patients with critical Coronary Artery Disease (CAD) and those with NYHA>2 had a significant positive impact on RRI changes compared to those without these conditions.

Table 3: Independent variables affecting RRI after TAVI.

Variables	β	SE	%95 CI	P-value
Critical CAD	0.125	0.774	0.027 - 0.571	0.007
NYHA >2	0.153	0.908	0.026 - 0.905	0.038
BNP Level	1.064	0.026	1.006 - 1.122	0.045
Pulse Pressure	1.051	0.025	1.001 - 1.103	0.045

β= β coefficient; SE: Standard Error; CI: Confidence Interval.

Discussion

Transcatheter Aortic Valve Implantation (TAVI) has emerged as a promising alternative to surgical treatment for patients with symptomatic severe Aortic Stenosis (AS), particularly for those at high surgical risk. Initially introduced in 1992 in animal models with bioprosthetic aortic valve implantation, TAVI was first successfully performed in humans in 2002 by Cribier et al. [4]. Since then, over one million patients have undergone TAVI due to severe AS. Data from large multicenter registries and the randomized "PARTNER" trial (Placement of Aortic Transcatheter Valves) have demonstrated improvements in symptoms, quality of life, and exercise capacity after TAVI [22,23].

During Doppler assessments, the Renal Resistive İndex (RRI) is the most commonly used parameter to evaluate intrarenal hemodynamics [24]. RRI is an important indicator of renal vascular resistance, particularly in atherosclerosis [25], and can offer valuable insights into target organ damage and cardiovascular outcomes in hypertensive patients [26]. In our prospective study involving TAVI patients, we evaluated the importance of Doppler-based non-invasive RRI, which integrates arterial compliance, pulsatility, and peripheral renal resistance.

The mean age of our patients was 78.52 ± 8.58 years, and all procedures were performed via the transfemoral route. There were no periprocedural deaths. In the 30-day period, two patients died-one from retroperitoneal hemorrhage and the other from stroke. The 30-day mortality rate in the PARTNER B trial for the TAVI group was 5%, and in PARTNER 2, it was 3.9%. In our population, the mortality rate was 3.3%.

While TAVI has led to significant improvements in hemodynamic parameters, Paravalvular Aortic Regurgitation (PAR) remains one of the most important complications, particularly with self-expanding valves. The rate of moderate-to-severe PAR in the literature ranges from 5% to 40% [27,28]. In our study, the paravalvular regurgitation rate was found to be 11.7% (n=7).

In the presence of significant AR, it is assumed that RRI may not accurately reflect renal resistance due to the significant reduction in renal artery diastolic velocity, which could lead to misinterpretation of renal blood flow as a result of increased renal vascular resistance [29,30]. Since RRI correlates directly with diastolic renal perfusion, renal function, and the development of Acute Kidney İnjury (AKI), it could serve as a crucial indicator for renal function and mortality post-TAVI. In our study, RRI increase was associated with moderate-to-severe PAR, decreased systemic diastolic blood pressure, and consequently, increased pulse pressure, and it correlated with the invasive AR index.

We also identified BNP levels, NYHA class>2, the presence of critical Coronary Artery Disease (CAD), and pulse pressure as independent variables affecting changes in RRI. Multivariate analysis revealed that BNP levels and functional capacity independently influence RRI values. This finding may be related to PAR development after TAVI. PAR may lead to increased BNP levels, reduced functional capacity, and, due to decreased diastolic blood pressure, an increase in RRI. However, there is no existing literature on this specific relationship.

A histological study by Ikee et al. found renal atherosclerosis to be the sole independent risk factor for increased RRI [31]. Thus, RRI should be considered a marker of systemic atherosclerotic vascular damage rather than a direct indicator of kidney damage. Atherosclerosis is a systemic process, and its pathophysiology is nearly identical in all affected vessels. Based on this, a relationship between CAD and RRI can be hypothesized. Mostbeck et al. observed that RRI increased with age due to atherosclerosis [32]. In another study of 10,000 cases, a positive correlation between RRI and the severity of atherosclerosis was found [33]. In our study, the presence of extensive CAD had a significant impact on RRI increase.

The kidneys are among the most perfused organs in the human body, receiving 15-25% of cardiac output. Therefore, they are directly affected by hemodynamic changes. Recently, RRI has been suggested as a tool to evaluate renal perfusion changes in cardiac surgery patients. Pulse pressure and RRI are closely related.

Ohuchi et al. demonstrated a linear relationship between RRI and pulse pressure [34]. Studies in patients with essential hypertension have shown a linear relationship between central pulse pressure and RRI [35]. In a study of 135 healthy individuals, RRI showed a negative correlation with diastolic blood pressure, but no significant correlation was found between systolic blood pressure, pulse pressure, or mean arterial pressure and RRI [36]. In our study, we found an independent and linear relationship between pulse pressure and RRI.

This may be related to the decrease in diastolic blood pressure caused by the development of PAR after TAVI.

Conclusion

In conclusion, increased RRI values, reflecting decreased diastolic blood pressure and increased pulse pressure due to moderate-to-severe PAR after transcatheter aortic valve implantation, may serve as a non-invasive measurement technique.

Study limitations

The main limitations of our study include the small sample size and the single-center design. The follow-up period was relatively short, and there was incomplete optimization of medical treatments (e.g., beta-blockers, ACE inhibitors, ARBs) among the patients.

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