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Myocardial Deformation and Remodeling Following Transcatheter Aortic Valve Implantation in Severe Aortic Stenosis: A Narrative Review

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Abstract

Chronic pressure overload due to severe aortic stenosis is also linked to myocardial remodeling that usually inhibits identifying the changes in the conventional systolic indices. Transcatheter aortic valve implantation (TAVI) has also changed the way of trying to treat severe cases of aortic stenosis, successfully reducing afterload and reverse ventricular remodelling. Nevertheless, the conventional echocardiographic measures, especially left ventricular ejection fraction has its limitations in detecting subclinical myocardial dysfunction and also in precise monitoring of myocardial recovery after the intervention. Two-dimensional speckle tracking echocardiography (2D-STE) has become a sensitive and reproducible imaging mode that can be used to quantitatively assess myocardial deformation to provide detailed longitudinal, circumferential, and radial myocardial mechanics. This is a review of the current evidence published between 2020 and 2025 on patterns of myocardial deformation before and after TAVI with particular attention to global longitudinal strain as an indicator of early dysfunction, therapeutic response and prognosis. The review defines the presence of immediate, mid-term, and long-term myocardial remodeling after TAVI and explores an important role of strain-based parameters as prognostic indicators and a comparison of 2D-STE and other imaging modalities. Also, the existing gaps in the research are mentioned, such as the absence of standardized strain cut-offs and lack of long-term data. On the whole, 2D-STE can be discussed as an effective instrument of holistic assessment of the myocardium and individual risk stratification of patients undergoing TAVI.

Keywords: *Aortic stenosis, Transcatheter aortic valve implantation, Myocardial remodeling, Two-dimensional speckle tracking echocardiography, Global longitudinal strain.*

1. Introduction

Severe aortic stenosis (AS) is a disease that is marked by the gradual calcific stenosis of the aortic valve, causes chronic left ventricular (LV) pressure overload, concentric hypertrophy, myocardial fibrosis, and subsequent systolic and diastolic dysfunction [1]. These hemodynamic changes usually come before a reduction in left ventricular ejection fraction (LVEF), which restricts the sensitivity of the conventional echocardiographic parameters [2]. Transcatheter aortic valve implantation (TAVI) has become one of the standard therapeutic interventions in patients with severe AS regardless of all types of surgical risks and provides substantial positive results in terms of survival and functional status [3]. In addition to valve replacement, TAVI causes myocardial unloading which can lead to reverse ventricular remodeling. In AS, myocardial remodeling is the process of structural and functional changes, which directly determine the prognosis. Persistent fibrosis and impaired myocardial mechanics following intervention are linked to the adverse outcomes in the presence of preserved LVEF [4]. The 2D speckle tracking echocardiography (2D-STE) makes it possible to measure myocardial deformation (including global longitudinal strain) in an angle-independent manner, which facilitates the realization of a subclinical dysfunction that can be detected early and post-TAVI recovery [5].

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1.1.Purpose and extent of the Review

This review summarizes the current evidence (2020-2025) of myocardial deformation remodeling after TAVI, the importance of 2D-STE in the ventricular mechanics, prognostication, and post-interventional clinical management.

2. Pathophysiology of Myocardial Remodeling in Severe Aortic Stenosis

Severe aortic stenosis places chronic pressure overload on the left ventricle, which causes concentric hypertrophy as an early-compensatory response to cardiac output. Whereas hypertrophy corrects the wall stress, the long-term exposure leads to more myocardial stiffness, poor relaxation, and high filling pressures [1], [2]. Traditional echocardiographic measures like left ventricular ejection fraction are insensitive to early myocardial impairment as they are normal until late disease manifestations. This means that the use of LVEF can be used to underestimate myocardial injury and reduce the time of intervention [4]. With worsening of hypertrophy, myocardial oxygen demand rises and coronary microvascular reserve decreases, leading to endangering the subendocardial layers to ischemia. Such ischemic conditions enhance interstitial and substitutive fibrosis that is a primary predictor of permanent myocardial infarction and unfavorable prognosis of aortic stenosis. The longitudinally oriented subendocardial fibers are mainly involved in myocardial fibrosis and fiber disarray causing premature impairment of longitudinal strain in a situation where left ventricular ejection fraction remains normal. Such mechanical changes are the progenitors of overt systolic dysfunction and are associated with symptoms load and severity of the disease [6].

3. Principles of Two-Dimensional Speckle Tracking Echocardiography

3.1.Basic Methodology and Technical Principles

A relatively new technology is known as two-dimensional speckle tracking echocardiography (2D-STE) which analyses the speckles which are present in the existing grayscale echocardiographic images on the myocardial tissue. It is possible to quantitate myocardial deformation at each frame of the cardiac cycle as speckles are tracked at a specific insonation angle [7].

3.2.The Strain-Rate and Strain Analysis

The percentage change in length of the myocardium is defined to be strain and the rate of deformation of the myocardium is referred to as strain rate. The parameters provide beautiful measurements of myocardial performance in the region and globally and can identify slight contractile dysfunction early [8].

4. Types of parameter myocardial Deformation

4.1.Global Longitudinal Strain (GLS)

GLS is an index that measures longitudinal shortening of the left ventricle and it is primarily influenced by subendocardial fibres. It is the most confirmed strain parameter and a powerful predictor of the outcomes in aortic stenosis [4].

4.2.Advantages of 2D-STE over the traditional echocardiography

The technique 2D-STE is objective and reproducible in measuring myocardial mechanics and image of subclinical dysfunction at an earlier stage compared to traditional variables, such as left ventricular ejection fraction [5].

4.3.Radial Strain

Radial strain is a strain measure that can be applied to measure myocardial thickening during systole, but with higher variability and lack of reproducibility that compared to other strain indices [7].

4.4.Circumferential Strain

Circumferential strain denotes a short-axis contraction of the myocardial fibres and assists in ventricular ejection functioning particularly during end-stage disease [9].

5. Baseline Myocardial Deformation Patterns in Severe Aortic Stenosis

The severely stenosed aorta patients usually show markedly decreased global longitudinal strain (GLS) at baseline because they have intact left ventricular ejection fraction. This is an indicator of early subendocardial fibrosis due to the long-term pressure overload and myocardial fibrosis [5]. Symptom

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burden GLS has been demonstrated to be positively associated with impaired GLS (decreased exercise capacity and increased New York Heart Association functional class). The strain abnormalities frequently occur before the manifestation of active clinical worsening, which is why they can be considered early indicators of the severity of the disease [10].GLS reduction at baseline is a strong independent predictor of all cause mortality, heart failure hospitalization, and adverse cardiovascular outcomes in patients who undergo TAVI. GLS offers prognostic value in addition to traditional parameters of an echocardiogram. This has been provisively established by various studies that have shown that impaired GLS is closely related to the degree of myocardial fibrosis, as determined by cardiac magnetic resonance imaging. The presence of a greater fibrosis load is also associated with a reduced recovery of the myocardium and worse long-term outcomes after valve intervention [11].

6. Immediate Myocardial Deformation Changes Following TAVI

TAVI produces the immediate release of left ventricular afterload, which produces a positive effect on the myocardial wall stress and contractile mechanisms in hours of the procedure [12]. One of the notable early improvements is observed in GLS in several days to weeks after TAVI, which represents a quick regaining of functional activity of subendocardial fibers due to less pressure overload [5]. Reduction in transvalvular gradients and improvements in stroke volume during the initial post-procedural modifications in myocardial deformation are associated with hemodynamic and myocardial coordination [1]. The early GLS recovery following TAVI is linked to improved short-term functional condition and positive prognosis in the mid-term, which highlights its utility as a therapeutic response indicator [13].

7. Mid-Term and Long-Term Myocardial Remodeling After TAVI

The parameters of myocardial deformation improve after transcatheter aortic valve implantation, and they do not decrease at such early post-procedural stages. Gradual normalization during a number of months is shown by longitudinal strain; it represents the ongoing decrease of the afterload on the ventricles and the elevated myocardial efficiency [14]. Follow-up research shows that TAVI encourages structural reverse remodeling, which is a regression of left ventricular hypertrophy and diastolic enhancement. These modifications help to maintain a permanent improvement in myocardial mechanics and functional capacity [15]. Longitudinal strain is usually recovers more and faster than circumferential strain and radial strain. The radial strain is slower to improve and less consistent, which may be due to the continued presence of myocardial stiffness and fibrosis [16]. The fact that residual myocardial fibrosis remains restricts the scope of functional follow-up of TAVI and relates to incomplete reverse remodelling and poorer long-term prognosis [17].

8. Prognostic Value of 2D-STE in Post-TAVI Patients

GLS and other post-TAVI strain indices have also proved to be strong predictors of mortality and cardiovascular morbidity not dependent on conventional risk factors. Continued impaired GLS following TAVI correlates with increased heart failure hospitalization as well as progressive impaired functional recovery [18]. The serial GLS test allows risk stratification and individualized follow-up planning of post-TAVI patients. GLS continues to be better than left ventricular ejection fraction in identifying subclinical dysfunction and adverse outcome, endorsed as a clinical monitoring tool in the long term [19].

9. Discussion

More recent studies are also highlighted the prognostic significance in the strain imaging in patients undergoing TAVI. Stens et al. (2023) has demonstrated that the baseline GLS measured by speckle-tracking echocardiography is the strong predictor of outcomes following by TAVI and may help identify patients at higher risk of the adverse cardiovascular events [3]. In addition, research are evaluating the ventricular mechanics has suggested both left and right ventricular strain parameters are provide incremental prognostic information beyond conventional echocardiographic indices the patients with severe aortic stenosis undergoing valve replacement [4].aseline myocardial strain parameters, particularly global longitudinal strain (GLS) measured by two-dimensional speckle tracking echocardiography. Reduced pre-procedural GLS indicates subclinical left ventricular systolic dysfunction and is associated with poorer myocardial recovery and adverse ventricular remodeling after the procedure [5]. In patients with low-flow, Low-gradient aortic stenosis, baseline with GLS can also be predict the presence of the left ventricular flow reserve and the potential for reverse remodeling following TAVI. Moreover, severe Global Longitudinal Strain (GLS) before the intervention is often linked to the limited functional recovery despite successful valve implantation and suggesting in the presence of irreversible myocardial damage or myocardial fibrosis. Therefore, Global Longitudinal Strain (GLS) is assessment plays a significant role in risk stratification and prediction of clinical outcomes in patients undergoing TAVI [6].Several clinical studies are demonstrated that Transcatheter Aortic Valve Implantation leads to the significant of improvement in the myocardial deformation parameters and promotes the reverse ventricular remodeling. Nosir et al. (2020) observed that the progressive improvement in the Global Longitudinal Strain (GLS) from that−15.3% at the baseline to −17.2% at six months after Transcatheter Aortic Valve Implantation (TAVI), accompanied by the significant of reduction in the left ventricular mass, indicating the regression of hypertrophy and improved in myocardial mechanics following by relief of the pressure overload [8]. Similarly that, Takeuchi et al. (2023) reported that the early improvement in the Global Longitudinal Strain (GLS) after the TAVI is the associated with the better functional recovery and reflect the rapid improvement in the myocardial contractility once that valvular obstruction are relieved [9].Myocardial deformation imaging by using two-dimensional speckle tracking echocardiography (2D-STE) has a significantly improved in the evaluation of ventricular mechanics in patients with the severe aortic stenosis undergoing transcatheter aortic valve implantation (TAVI). Chronic pressure overload in the aortic stenosis leads to left ventricular hypertrophy, myocardial fibrosis, and progressive impairment of myocardial contractility. Although the left ventricular ejection fraction (LVEF) is a commonly used to assess the systolic function, it often remains preserved until late stages of the disease, limiting its ability to detect the early myocardial dysfunction. In the contrast, strain parameters such as global longitudinal strain (GLS) derived from 2D-STE provide a more sensitive indicator of myocardial performance and can identify subclinical ventricular dysfunction before changes in LVEF occur [11].The process of ventricular reverse remodeling is a following transcatheter aortic valve implantation (TAVI) involves the regression of Left ventricular hypertrophy (LVH), reduction in myocardial wall stress, and improvement in the myocardial fiber shortening. In the Speckle tracking echocardiography allows for detailed assessment of these changes by analyzing longitudinal, circumferential, and radial strain components of myocardial deformation. Previous studies are demonstrated the significant improvement in the longitudinal and circumferential strain during follow-up and after valve implantation, reflecting recovery of the myocardial function and adaptive remodeling of the left ventricle in response to the reduction in pressure overload [16].

Conclusion

The myocardial deformation imaging displays early and persistent functional alterations in severe aortic stenosis patients undergoing TAVI, which frequently occur ahead of the improvement of traditional parameters.

Post-TAVI Clinical Relevance.

Myocardial strain assessment, especially GLS, has an incremental prognostic value and supplements the risk stratification after the procedure.

Final Remarks

Two-dimensional speckle tracking echocardiography is becoming a vital part of the overall assessment of myocardial remodeling following TAVI, and its application shows an increasing number of prospects regarding personalized patient treatment.

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