ORIGINAL RESEARCH

# Application and Evaluation of Real-time Three-dimensional Echocardiography in Transcatheter Aortic Valve Implantation

Jing Li, MMed; Xi Yu, MMed; Xiaojing Ma, MD


## ABSTRACT

**Objective** • This assessed the value of real-time three-dimensional echocardiography in patients with aortic valve lesions before and after transcatheter aortic valve implantation.

**Methods** • A total of 61 patients were admitted for transcatheter aortic valve implantation due to aortic valve lesions between October 2021 and August 2022 (research group), and 55 patients who underwent a healthy physical examination during the same period (control group) were included. All participants underwent real-time three-dimensional echocardiography. Changes in left ventricular end-diastolic volume index, left ventricular end-systolic volume index, left ventricular ejection fraction, maximum velocity, and left ventricular mass index were observed at 1 week and 1 month after the surgery. Additionally, the research group was further divided based on the type of lesion to investigate the differences in real-time three-dimensional echocardiography findings between patients with moderate to severe aortic stenosis and moderate to severe aortic insufficiency. The occurrence of postoperative complications in the research group was also recorded to assess the role of real-time three-dimensional echocardiography in postoperative complication assessment after transcatheter aortic valve implantation.

**Results** • Preoperative left ventricular ejection fraction did not differ significantly between the two groups ($P > .05$). However, the research group exhibited higher preoperative left ventricular end-diastolic volume index, left ventricular end-systolic volume index, left ventricular mass index, and maximum velocity compared to the control group ($P < .05$). At 1 week postoperatively, the research group showed significant reductions in left ventricular end-diastolic volume index, left ventricular end-systolic volume index, left ventricular mass index, and maximum velocity compared to preoperative values ($P < .05$). Furthermore, at 1 month postoperatively, the left ventricular mass index was further reduced ($P < .05$). Among the research group, patients with aortic stenosis had lower preoperative left ventricular end-diastolic volume index and left ventricular end-systolic volume index compared to patients with aortic insufficiency, while maximum velocity was higher ($P < .05$). Patients who experienced postoperative complications after transcatheter aortic valve implantation had lower left ventricular end-diastolic volume index, left ventricular end-systolic volume index and left ventricular mass index, and higher maximum velocity before and at 1 week after surgery ($P < .05$).

**Conclusions** • Real-time three-dimensional echocardiography demonstrated excellent assessment capabilities for aortic valve lesions and accurately guided the determination of left ventricular mass index, showcasing its significant clinical applications. (*Altern Ther Health Med.* 2023;29(6):294-299).


**Jing Li,** MMed; **Xi Yu,** MMed; **Xiaojing Ma,** MD; Department of Ultrasound, Wuhan Cardiovascular Imaging Clinical Medical Research Center, Wuhan Asia General Hospital of WuHan University of Science and Technology, Wuhan, Hubei, China.

*Corresponding author: Xiaojing Ma,* MD
*E-mail: lijing@wust.email.cn*

## INTRODUCTION

With the increasing trend of an aging society in China, the incidence of degenerative valve disease among the elderly is rising. Among these conditions, aortic valve disease has emerged as the most common valvular heart disease in this population, often causing symptoms such as chest pain or tightness, palpitations, weakness, and shortness of breath, particularly worsened by physical activity.[1,2] In the past, surgical replacement of aortic valves was the primary clinical treatment option. However, surgery is often contraindicated for elderly patients due to advanced age, frailty, severe lesions, or the presence of other comorbidities.[3]

Recently, transcatheter aortic valve implantation (TAVI) has gained widespread adoption, and several previous studies have highlighted its high clinical value in the management of aortic valve lesions. TAVI has emerged as a preferred treatment option due to its advantages, including reduced trauma, faster postoperative recovery, and avoiding open-heart surgery.[4-6]

However, as an interventional procedure, TAVI is accompanied by the challenge of its complexity, necessitating multidisciplinary teamwork wherein the medical imaging department plays a pivotal role.[7] Prior to performing TAVI, patients typically undergo multiple imaging studies to enhance the healthcare provider's understanding of the intricate cardiac anatomy and improve the precision of the procedure.[8] Real-time three-dimensional echocardiography (RT-3DE) is a commonly employed clinical tool for assessing cardiac status. It enables direct visualization of the three-dimensional morphology of the heart chambers, accurate depiction of valve morphology, and precise determination of the extent of valve stenosis. Consequently, it holds significant clinical value in diagnosing and treating heart diseases.[9]

We discovered a paucity of studies examining the utilization of RT-3DE for intraoperative monitoring and postoperative follow-up assessment of TAVI, leading to a dearth of reliable references in clinical practice. Therefore, this study aims to investigate and analyze the application of RT-3DE in TAVI to furnish more precise references and guidance for the optimal execution of TAVI in the future.

## MATERIALS AND METHODS

### Study Design and Clinical Data

This study employed a prospective observational design to investigate the application of RT-3DE in TAVI. A total of sixty-one patients with aortic valve lesions who were admitted to Wuhan Asia General Hospital of Wuhan University of Science and Technology for TAVI between October 2021 and August 2022 were included in the study. Additionally, fifty-five patients who underwent a healthy physical examination during the same period were selected as the control group. All participants underwent RT-3DE at our hospital, and the same surgical team performed TAVI procedures. The patients who underwent TAVI constituted the research group, while the individuals who underwent a physical examination served as the control group. The study adhered strictly to the principles outlined in the Declaration of Helsinki, and all study subjects provided informed consent. The ethics committee approved the study protocol (Approval No. 2021-WHAGH159).

### Inclusion and Exclusion Criteria

The inclusion and exclusion criteria for research and control groups are described in the following.

**Research Group.** Inclusion criteria: (1) Patients diagnosed with aortic valve lesion; (2) left ventricular ejection fraction (LVEF) >50%; (3) confirmed sinus rhythm through coronary angiography and electrocardiogram; and (4) Patients with complete medical history were included. Exclusion criteria: (1) Patients with concomitant cardiac conditions such as coronary artery disease; (2) hypertension and arrhythmia; (3) Patients with unclear or unrecognizable RT-3DE acquisition, and (4) those with coronary stenosis >50% were also excluded.

**Control Group.** Inclusion criteria: (1) Individuals who underwent a health check-up at our hospital; (2) with no significant previous medical history and (3) normal results from the physical examination. Exclusion criteria: The exclusion criteria for the control group were the same as those for the research group.

### RT-3DE Check

**Examination and Analysis Protocol.** A color echocardiography examination (EPIQ 7C) was conducted using an X5-1 probe with a frequency of 1.5 MHz. The patient was positioned horizontally or in the left lateral position for perioperative electrocardiographic monitoring. Prior to surgery, measurements were taken in the long-axis view of the sternum, including the left atrial end-diastolic internal diameter, left atrial internal diameter, ascending aortic internal diameter, sinotubular junction, aortic sinus, aortic annulus, and left ventricular outflow tract. In the short-axis view of the aorta, the distribution, degree of calcification, mobility, morphology, and number of aortic valve leaflets were observed. LVEF was measured using Simpson's method in the apical four-chamber view. The mean transvalvular pressure difference across the aortic valve orifice during systole was measured using continuous Doppler in the apical four-chamber or five-chamber view. A standard apical four-chamber view was captured and switched to Full-Volume mode in 3D to acquire echocardiographic images. Patients were instructed to hold their breath for 5-6 seconds with deep inspiration during image acquisition. Special attention was given to the aortic valve structure. The acquired images were then transferred for offline analysis using 3DQAdvanced. Left ventricular end-diastolic volume index (LVEDVI), left ventricular end-systolic volume index (LVESVI), LVEF, and velocity maximum ($V_{max}$) were automatically generated from the image sequences, and left ventricular mass index (LVMI) was calculated.[10] The X8-2t and X7-2t probes were used during the operation. In cases of emergency, valve release, or guidewire transmural, RT-3DE was employed to observe any abnormal ventricular wall motion, pericardial effusion, or abnormal aortic coarctation.

### Postoperative Follow-Up

At 1 week and 1 month postoperatively, RT-3DE was performed to measure relevant indexes and assess any related complications. Patients in the research group underwent preoperative, intraoperative, and postoperative examinations, while the control group only received routine preoperative examinations.

**Outcome Measures**

The study observed the changes in RT-3DE results before the operation, at 1 week, and 1 month after the operation in the research group, as well as the differences in RT-3DE results between groups. Subsequently, the patients in the research group were further categorized based on their lesion type, and the differences in RT-3DE findings between patients with aortic stenosis (AS) and those with aortic insufficiency (AI) were assessed. Additionally, the postoperative complications of patients in the research group were recorded to evaluate the role of RT-3DE examination results in assessing postoperative complications following TAVI.

**Statistical methods**

The data were analyzed using SPSS 22.0 software. Measurement data were presented as mean ± standard deviation ($\bar{x} \pm s$) and compared using independent samples *t* test, analysis of variance (ANOVA), and post hoc test with the least significant difference (LSD). Counting data were presented as percentages (%) and compared using the chi-square ($\chi^2$) test. A statistically significant difference between groups was defined as $P < .05$.

## RESULTS

**Comparison of Clinical Baseline Data between Groups**

No statistically significant differences were observed in the comparison of clinical baseline data, including age, gender composition, and heart rate, between the research and control groups ($P > .05$, Table 1). These findings indicate that the two groups were comparable in terms of their baseline characteristics.

**Preoperative RT-3DE Findings**

The preoperative RT-3DE findings revealed no statistically significant differences in the preoperative LVEF between the control and research groups ($P > .05$). However, significant differences were observed in the preoperative LVEDVI, LVESVI, LVMI, and $V_{max}$. The LVEDVI was (70.98 ± 14.94) mL/m$^2$, LVESVI was (27.92 ± 9.27) mL/m$^2$, LVMI was (2.56 ± 0.25) m/s, and $V_{max}$ was (141.57 ± 26.71) g/m$^2$ in the research group, which were all higher compared to the control group ($P < .05$, Figure 1).

**Changes in RT-3DE Test Results Before and After Treatment in the Research Group**

In the research group, no significant changes were observed in LVEF during TAVI treatment ($P > .05$). However, there were significant reductions in LVEDVI, LVESVI, LVMI, and $V_{max}$ at the 1-week postoperative time compared to the preoperative time ($P < .05$). At 1 month postoperatively, there were no significant differences in LVEDVI, LVESVI, and $V_{max}$ compared to the measurements at 1 week postoperatively ($P > .05$). However, LVMI showed a further decrease compared to the 1-week postoperative measurement ($P < .05$, Figure 2).

**Table 1.** Clinical Baseline Data

| Group | Control Group (n = 55) | Research Group (n = 61) | t/$\chi^2$ value | *P* value |
|---|---|---|---|---|
| Age | 62.84 ± 5.95 | 62.33 ± 5.62 | 0.47 | .64 |
| Height (cm) | 169.42 ± 9.74 | 167.34 ± 10.20 | 1.12 | .26 |
| Weight (kg) | 66.16 ± 12.74 | 65.26 ± 8.73 | 0.45 | .66 |
| Heart rate (beats/min) | 81.45 ± 14.41 | 80.74 ± 8.69 | 0.32 | .75 |
| Gender Composition | | | 0.47 | .49 |
| Male | 35 (63.64) | 35 (57.38) | | |
| Female | 20 (36.36) | 26 (42.62) | | |
| Smoking | | | 0.03 | .86 |
| Yes | 19 (34.55) | 22 (36.07) | | |
| No | 36 (65.45) | 39 (63.93) | | |
| Type of Disease | | | - | - |
| Aortic Insufficiency (AI) | - | 35 (457.38) | | |
| Aortic Stenosis (AS) | - | 26 (42.62) | | |

Note: Values are presented as mean ± standard deviation (for continuous variables) or number (percentage) (for categorical variables). Comparison of clinical baseline data between groups was assessed using an independent samples *t* test (for continuous variables) or chi-square test (for categorical variables). Statistically significant results were defined as $P < .05$.

**Abbreviations**: AS, Aortic Stenosis; AI, Aortic Insufficiency.

**Differences in RT-3DE Findings between AS and AI Patients**

In the research group, no significant differences were observed in LVEF and LVMI between AS and AI patients preoperatively ($P > .05$). However, AS patients had lower preoperative LVEDVI and LVESVI values and higher $V_{max}$ compared to AI patients ($P < .05$). There were no significant differences between AS and AI patients in the RT-3DE indices at 1 week and 1 month postoperatively $P > .05$, Figure 3).

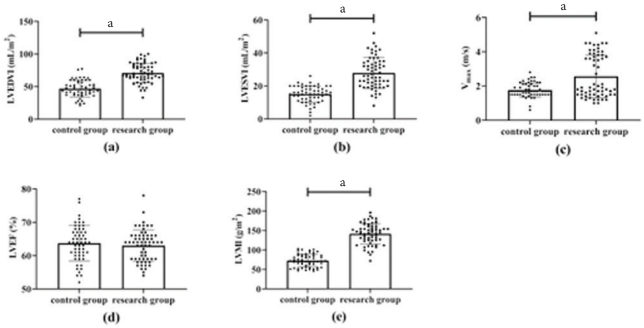
**Relationship between RT-3DE and Post-TAVI Complications**

Among the patients in the research group, a total of 22 individuals developed complications after undergoing TAVI, including pericardial effusion and perivalvular leakage. These patients were classified as the risk group, while those without complications formed the normal group. No significant differences were found in LVEF before and after surgery between the risk group and the normal group ($P > .05$). However, the risk group exhibited lower values of LVEDVI, LVESVI, and LVMI, and higher $V_{max}$ values compared to the normal group before and at the preoperative stage ($P < .05$). At 1 month postoperatively, there were no significant differences in the RT-3DE results between the two groups ($P > .05$, Figure 4).

## DISCUSSION

Aortic valve lesions can significantly impact the morphology and structure of the left ventricle in patients due to prolonged volume overload, ultimately leading to left ventricular remodeling and the risk of heart failure and mortality.[11] Recently, the application of TAVI in treating aortic valve lesions has gained widespread acceptance.[12,13] To

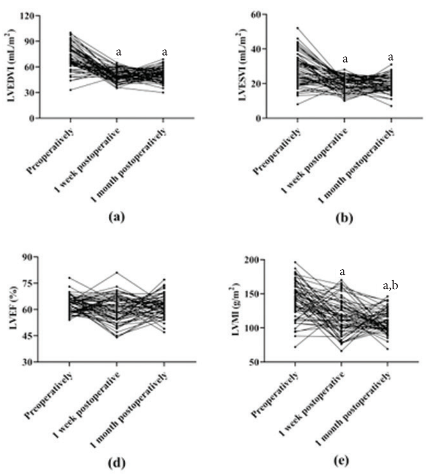
**Figure 1.** Preoperative RT-3DE findings. (a) LVEDVI; (b) LVESVI; (c) $V_{max}$; (d) LVEF; (e) LVMI.




[a]$P < .05$

**Abbreviations**: RT-3DE, real-time three-dimensional echocardiography; LVEDVI, left ventricular end-diastolic volume index; LVESVI, left ventricular end-systolic volume index; $V_{max}$, velocity maximum; LVEF, left ventricular ejection fraction; LVMI, left ventricular mass index.

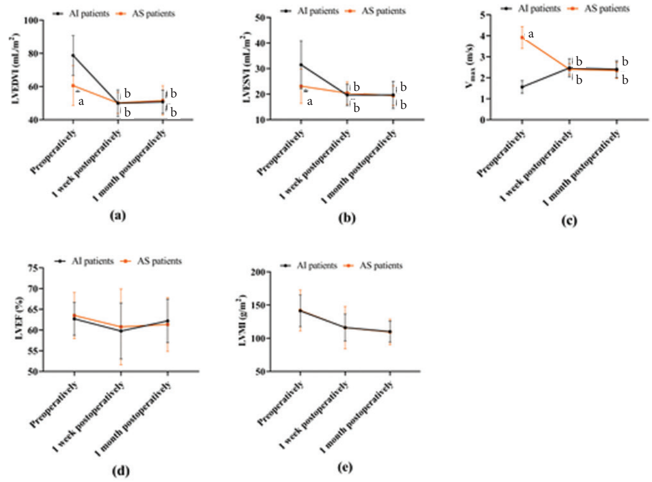
**Figure 2.** Changes in RT-3DE test results before and after treatment. (a) LVEDVI; (b) LVESVI; (c) $V_{max}$; (d) LVEF; (e) LVMI.




[a]$P < .05$, comparison with preoperative
[b]$P < .05$, comparison with 1 week postoperatively

**Abbreviations:** RT-3DE, real-time three-dimensional echocardiography; LVEDVI, left ventricular end-diastolic volume index; LVESVI, left ventricular end-systolic volume index; $V_{max}$, velocity maximum; LVEF, left ventricular ejection fraction; LVMI, left ventricular mass index.

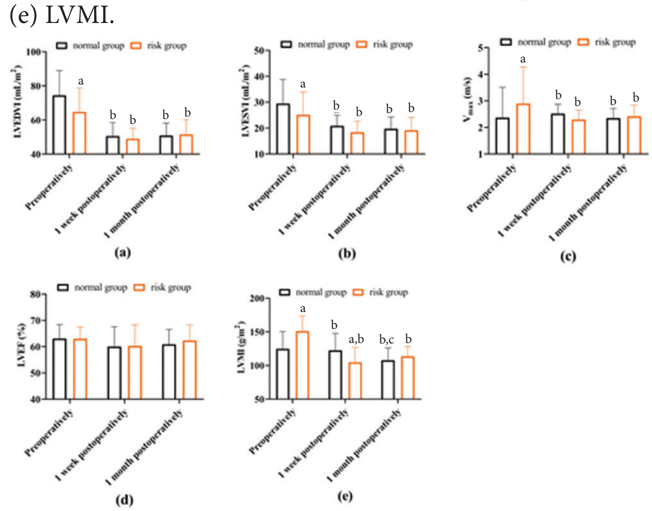
**Figure 3.** Differences in RT-3DE findings between AS and AI patients. (a) LVEDVI; (b) LVESVI; (c) $V_{max}$; (d) LVEF; (e) LVMI.




[a]$P < .05$, comparison with AI patients
[b]$P < .05$, comparison with preoperative

**Abbreviations:** RT-3DE, real-time three-dimensional echocardiography; LVEDVI, left ventricular end-diastolic volume index; LVESVI, left ventricular end-systolic volume index; $V_{max}$, velocity maximum; LVEF, left ventricular ejection fraction; LVMI, left ventricular mass index; AS, Aortic Stenosis; AI: Aortic Insufficiency.

**Figure 4.** Relationship between RT-3DE and post-TAVI complications. (a) LVEDVI; (b) LVESVI; (c) $V_{max}$; (d) LVEF; (e) LVMI.




[a]$P < .05$, comparison with AI patients
[b]$P < .05$, comparison with preoperative
[c]$P < .05$, comparison with 1 week postoperatively

**Abbreviations**: RT-3DE, real-time three-dimensional echocardiography; LVEDVI, left ventricular end-diastolic volume index; LVESVI, left ventricular end-systolic volume index; $V_{max}$, velocity maximum; LVEF, left ventricular ejection fraction; LVMI, left ventricular mass index; AI, Aortic Insufficiency.

enhance the efficiency of diagnosis and treatment for aortic valve lesions, it is crucial to evaluate the development of these lesions through RT-3DE assessment and optimize the quantitative evaluation of TAVI surgery. This study examines the changes in RT-3DE findings before and after TAVI, providing valuable insights for a deeper clinical understanding of aortic valve lesion progression and the future improvement of TAVI procedures.

In this study, we examined the differences in RT-3DE findings between the normal population and patients with aortic valve lesions. The results demonstrated significant variations in LVEDVI, LVESVI, and LVMI between the two groups, with higher values observed in the research group. These findings indicate a substantial remodeling of the left ventricle in patients with aortic valve lesions, which aligns with previous research findings.[14]

After TAVI, reductions were observed in LVEDVI, LVESVI, LVMI, and $V_{max}$ in the research group. These changes indicated an improvement in cardiac structure and function, gradually approaching that of the normal population. Additionally, within the research group, AS patients exhibited lower preoperative LVEDVI and LVESVI values and higher $V_{max}$ values compared to AI patients. This finding further supports the excellent assessment capability of our RT-3DE in determining the specific lesion type in aortic valve lesions, consistent with previous research findings.[15]

It is widely recognized that aortic insufficiency primarily manifests as centrifugal hypertrophy, while aortic stenosis is characterized by centripetal hypertrophy.[16] RT-3DE enables real-time 3D imaging of the heart chambers and provides multiple views and angles, allowing clinicians to accurately identify the precise location of the heart and surrounding vessels. This technology facilitates the acquisition of full-volume cardiac data and enables detailed analysis of left ventricular volume and function at different stages.[17]

In addition, the automatically calculated left ventricular mass index provided by the system accurately reflects the mass and volume of the left ventricle, thereby further elucidating its functional and structural characteristics.[18] Numerous studies have highlighted the advantages of RT-3DE, including its non-invasiveness, rapid imaging, ease of use, and reproducibility. This imaging modality enables the early prediction of cardiac structural changes and facilitates timely intervention to prevent abnormal cardiac remodeling, ultimately leading to the selection of the optimal treatment plan in clinical practice.[19,20] However, in the present study, no significant difference in LVMI was observed between patients with aortic insufficiency and aortic stenosis. This finding could potentially be attributed to the challenges in accurately measuring LVMI in patients with significantly enlarged left ventricles. The presence of ventricular wall stumps and the inability to encompass the apical region during measurement may lead to potential inaccuracies, resulting in a smaller observed difference between AI and AS patients.[21]

In the evaluation of postoperative complications, we observed that perivalvular leakage remained the most common complication after TAVI. However, it is worth noting that all patients in our study experienced mild perivalvular leakage, and no other serious complications were observed. This finding suggests that the use of RT-3DE for monitoring greatly improves the safety of TAVI. It is also indicated that RT-3DE allows for a comprehensive assessment of aortic valve function and left ventricular status during the procedure. This enables the selection of an optimal valve size and puncture site, as well as precise adjustments during guidewire placement to avoid any potential damage to the aortic root or aortic valve caused by guidewire deviation.[22] Additionally, the release of the valve followed by RT-3DE assessment allows for the timely identification of perivalvular leaks, facilitating prompt dilation in affected patients and further enhancing the safety of TAVI.[23]

Furthermore, significant differences were observed in LVEDVI, LVESVI, LVMI, and $V_{max}$ between the risk group and the normal group, indicating that RT-3DE also plays a role in assessing postoperative complications of TAVI. This finding could be attributed to the substantially greater cardiac load and increased likelihood of postoperative cardiomyocyte hypertrophy in the at-risk group. These factors contribute to a more pronounced increase in left ventricular mass and a higher risk of postoperative perivalvular leakage. However, it is important to note that RT-3DE imaging can be influenced by various factors, including heart shift, heart rate, and respiration, which can lead to reduced imaging quality.[24] Therefore, it is crucial to improve the proficiency of operators during RT-3DE procedures in order to maximize the effectiveness of the imaging.

### Study Limitations

It is important to acknowledge the limitations of our study. Firstly, the sample size of our study was relatively small, which may have limited the generalizability of our findings to a broader population. Additionally, the follow-up period for patients was relatively short, potentially introducing bias and limiting our ability to observe long-term outcomes. Despite these limitations, our study provides valuable insights into the topic and serves as a foundation for future research with larger sample sizes and extended follow-up periods to further validate our findings.

## CONCLUSION

RT-3DE plays a crucial role in guiding intraoperative procedures and assessing postoperative outcomes in patients with aortic valve lesions. Its significance extends across the entire spectrum of diagnosis, treatment, and prognosis assessment of these lesions. By providing a more reliable diagnosis and treatment framework, RT-3DE enhances the effectiveness of LVMI treatment and promotes patients' rehabilitation and overall prognosis. Given its immense potential for clinical application, RT-3DE holds great promise in improving patient care and ensuring better health outcomes in managing aortic valve lesions. Furthermore, the non-invasive nature, fast imaging capabilities, and ease of operation of RT-3DE make it highly suitable for routine clinical use. Its ability to provide real-time 3D imaging and accurate assessment of cardiac structures opens avenues for early detection, personalized treatment planning, and timely intervention in patients with aortic valve lesions. With further advancements and continued research, RT-3DE holds the potential to become a standard tool in the clinical management of aortic valve lesions, ultimately improving patient outcomes and quality of life.

## CONFLICT OF INTEREST

The authors have no potential conflicts of interest to report relevant to this study.

## AUTHORS' CONTRIBUTIONS

Jing Li and Xi Yu contributed equally to the work.

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## AVAILABILITY OF DATA

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

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