# The Importance of the Acceleration Time to Aortic Ejection Time Ratio in Assessing the Severity of Aortic Valve Stenosis

# Intérêt du rapport temps d'accélération/temps d'éjection aortique dans l'évaluation de la sévérité du rétrécissement aortique

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## Summary

**Introduction:** The management of aortic stenosis (AS) relies on echocardiography, which assesses severity using three main parameters: effective orifice area, mean aortic gradient, and peak jet velocity. This study aimed to determine if systolic ejection dynamics, specifically acceleration time (AT) and the AT/ejection time (ET) ratio, could also help diagnose the severity of AS.

**Methods:** We prospectively included 88 patients with native valvular AS. Patients with other significant valvular diseases or suboptimal imaging windows were excluded.

**Results:** Out of 88 patients, 65 (73.86%) had severe AS. Patients with severe AS had significantly higher AT and AT/ET ratios than those with moderate AS. An AT greater than 110.5 ms had a 72.3% sensitivity and 87% specificity for predicting severe AS, while an AT/ET ratio greater than 0.36 had a 70% sensitivity and 91% specificity. These parameters were also effective in differentiating «discordant» severe AS (low flow, low gradient) from moderate AS.

**Conclusion:** This study demonstrates that acceleration time and the AT/ET ratio are straightforward and reliable indicators of aortic stenosis severity. They can serve as valuable complementary tools in the echocardiographic assessment of the disease.

## Keywords

Aortic valve stenosis, Echocardiography, Ejection parameters, acceleration time, ejection time, quantification

## Résumé

**Introduction :** Le rétrécissement aortique (RA) est généralement évalué par échocardiographie en utilisant l'aire de l'orifice (EOA), le gradient moyen et la vélocité maximale. L'objectif de cette étude est de montrer l'intérêt du temps d'accélération (TA) et du rapport TA/temps d'éjection (TE) pour diagnostiquer la sévérité du RA.

**Méthode :** Nous avons inclus 88 patients adultes avec un RA valvulaire, et avons exclu ceux présentant d'autres maladies valvulaires significatives ou des conditions sous-jacentes.

**Résultats :** Sur les 88 patients, 65 (73,86 %) avaient un RA sévère. Les patients avec un RA sévère présentaient un TA et un rapport TA/TE significativement plus élevés que ceux avec un RA modéré. Un TA supérieur à 110,5 ms a montré une sensibilité de 72,3 % et une spécificité de 87 % pour prédire un RA sévère. De même, un rapport TA/TE supérieur à 0,36 avait une sensibilité de 70 % et une spécificité de 91 %. Ces paramètres se sont également avérés utiles pour différencier les cas de RA sévère «discordant» (à faible débit et faible gradient) du RA modéré.

**Conclusion :** Cette étude montre que le temps d'accélération et le rapport temps d'accélération/temps d'éjection sont des indicateurs simples et fiables de la sévérité du rétrécissement aortique. Ils peuvent être utilisés comme des mesures complémentaires pour évaluer la maladie.

## Mots-clés

Rétrécissement aortique ; Échocardiographie, Paramètres d'éjection, Temps d'accélération, Temps d'éjection, Quantification

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## INTRODUCTION

Aortic stenosis (AS) has emerged as the most prevalent primary heart valve disease, significantly contributing to cardiovascular morbidity and mortality (1,2).

The management of aortic stenosis (AS) depends on accurately diagnosing its cause and assessing the severity stage, necessitating a comprehensive and integrated approach for therapeutic management.

Echocardiography is the primary method for assessment, and three parameters are recommended for evaluating the severity of aortic stenosis (AS): effective orifice area (EOA) using the continuity equation, mean aortic gradient, and peak jet velocity.(3)

However, peak velocity and mean gradient are influenced by the flow rate and may not accurately reflect the severity of aortic stenosis (AS) under extreme physiological flow conditions (4). Estimating the effective orifice area (EOA) using the continuity equation can be limited when left ventricular systolic function is severely impaired (4). Furthermore, the measurement of the left ventricular outflow tract diameter represents the most significant potential source of error in the continuity equation(5,6).

On the other hand, low-flow, low-gradient paradoxical aortic stenosis poses a significant diagnostic challenge in echocardiography, and it is crucial to distinguish between severe and non-severe aortic stenosis.

Indeed, the guidelines (ESC/ASE/AHA) emphasize the importance of studying, among other criteria, the shape of the velocity curve in continuous-wave Doppler of the transaortic flow. This aids in distinguishing the level and severity of the obstruction(1), However, there have been limited investigations that have examined ejection dynamics parameters in cases of native aortic valve disease.

The aim of this study was to assess the contribution of ejection dynamics, particularly acceleration time (AT) and the AT/ejection time (ET) ratio, in diagnosing the severity of aortic stenosis.

## METHODS

We prospectively included 88 patients between June 2020 and December 2020 with valvular native AS (peak velocity > 2 m/s) in the cardiology department of The Military Hospital of Tunis. The non-inclusion criteria were age < 18 years, suboptimal acoustic window, concomitant moderate or severe aortic regurgitation, moderate or severe mitral or tricuspid valvular disease, subvalvular or supravalvular AS. All participants gave their consent to participate in the study.

### *Echocardiographic Evaluation*

Two-dimensional transthoracic echocardiography and Doppler studies were carried out using clinical ultrasound machines equipped with transducers operating at frequencies ranging from 2.5 to 3.5 MHz. In the parasternal long-axis view with zoom, the measurement of the aortic annular diameter during early systole was performed. Pulsed Doppler imaging in the left ventricular outflow tract was employed, with the sample volume positioned 1 cm below the aortic valve, in order to obtain the time-velocity integral. Stroke volume was then determined, assuming a circular cross-section of the left ventricular outflow tract. Continuous-wave Doppler was used to record flow through the aortic valve from the five-chamber and right parasternal windows to capture maximal instantaneous and mean pressure gradients across the aortic valve.

The Effective Orifice Area (EOA) was computed using the continuity equation. An indexed EOA was estimated by taking into account the patient's body surface area. The mean transvalvular pressure gradient was calculated using the modified Bernoulli equation. A Doppler velocity index, a simplified representation of the continuity equation, was computed as the ratio of the time-velocity integral in the left ventricular outflow tract to that in the aortic jet. For patients in sinus rhythm, all measurements represent averages taken over three cardiac cycles, while for patients with rhythms other than sinus, a minimum of six cardiac cycles were averaged to reduce measurement variability.

Severe AS was defined as EOA < 1.0 $cm^2$, mean gradient ≥ 40 mm and peak jet velocity ≥ 4m/s.

In patients with severe AS, discordance was defined as EOA < 1 cm2 and mean gradient < 40 mm Hg, which includes patients with classical low-flow, low-gradient severe AS (Stroke volume index (SVi) ≤ 35ml/$m^2$ and LVEF < 50%) and paradoxical low-flow, low-gradient severe AS (SVi ≤ 35ml/$m^2$ and LVEF ≥ 50%).

### *Systolic Timing Parameters*

To assess the systolic time intervals of aortic valve flow, we used the velocity profile obtained from the continuous-wave Doppler recording in the apical view. Specifically, we measured the Ejection Time (ET), which signifies the duration from the onset of systolic flow to its end. Additionally, we defined the Acceleration Time (AT) as the time interval spanning from the commencement of systolic flow to the point of its peak velocity (Figure 1). To further analyze this data, we calculated the AT/ET ratio.

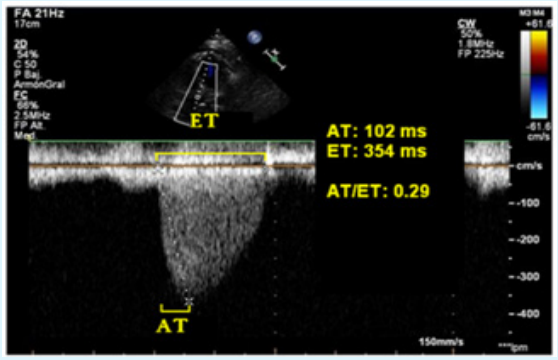


**Figure 1.** Systolic time intervals for AT/ET calculation.

### *Statistical Analysis*

For data analysis, the statistical program SPSS version 23.0 was used.

## RESULTS

A final sample of 88 patients was enrolled. The mean age was 73.8 ±10.88 years, with 52.3% men. The mean body mass index was 27.18 ±5.04 Kg/m$^2$, and a mean body surface area was 1.85±0.19 m$^2$.

The comorbidities associated with severe aortic stenosis include the following (figure 2):

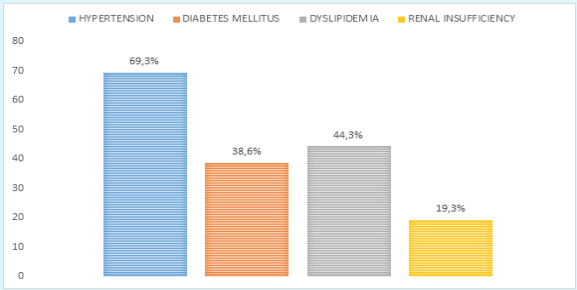


**Figure 2.** Comorbidities associated with severe aortic stenosis

In the total sample, 65 (73.86%) had severe AS, among them 17 had "discordant" severe AS and 23 (26.14%) had moderate AS.

We included 16 patients with left ventricular dysfunction (left ventricular ejection fraction ≤ 50%), of whom 5 had low-flow, low-gradient severe AS.

Acceleration time (AT) ranged from 73 to 180 ms (mean ±SD = 118.8 ± 24.6 ms) while AT/ET ratio ranged from 0.24 to 0.57 (mean ±SD = 0.37 ±0.064).

Aortic valve area ranged from 0.3 to 1.5 cm$^2$ (mean ±SD =0.88±0.26 cm$^2$).

Ejection dynamics parameters (AT, ET, and AT/ET ratio) are studied:

Compared with moderate aortic stenosis, AT was higher in patients with severe AS (126.22±23.24ms VS 97±14 ms) as was AT/ET ratio (0.39±0.05 VS 0.31±0.41).

Receiver operating characteristic analysis (Figure 3) showed that AT and AT/ET ratio could discriminate severe AS, whereas ET could not.

An AT > 110.5 ms provided the optimal cutoff for predicting the incidence of severe aortic stenosis in the total study sample with 72.3% of sensitivity and 87% of specificity.

Likewise, a cut-off of 0.36 ms for AT/ET has a sensitivity of 70% and a specificity of 91%.

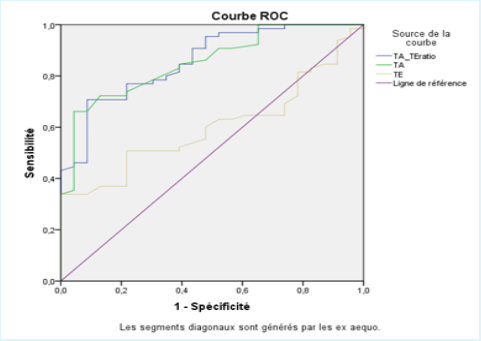


**Figure 3.** Receiver operating characteristic curves to differentiate severe AS from moderate AS on the basis of measurements of AT, ET, and AT/ET ratio

In our sample, among the patients with severe aortic stenosis, 72.3% had AT greater than 110 ms and 70.76% had AT/ET more than 0.36.

Nevertheless, we failed to find differences in ejection time (ET) between severe and moderate AS (308±26 ms for moderate AS and 320 ±37 ms for severe AS).

Correlation between ejection dynamics parameters (AT and AT/ET ratio) and other parameters recommended for the evaluation of AS severity is summarized in tables 1 and 2:

**Table 1**. Correlation between AT and other echocardiographic parameters

| Variable | Pearson coefficient (r) | p | p-value |
|---|---|---|---|
| Mean gradient | 0.551 | <0.001 | |
| Peak velocity | 0.527 | <0.001 | 0.83 |
| Valve area | -0.481 | <0.001 | 0.031 |

**Table 2**. Correlations between AT/ET ratio and other echocardiographic variables

| Variable | Pearson coefficient (r) | p |
|---|---|---|
| **Mean gradient** | 0.533 | <0.001 |
| **Peak velocity** | 0.493 | <0.001 |
| **Valve area** | -0.475 | <0.001 |

We found good correlations between both ejection parameters (AT and AT/ET ratio) and the usual echocardiographic methods for assessing AS (Figure 4 and figure 5).

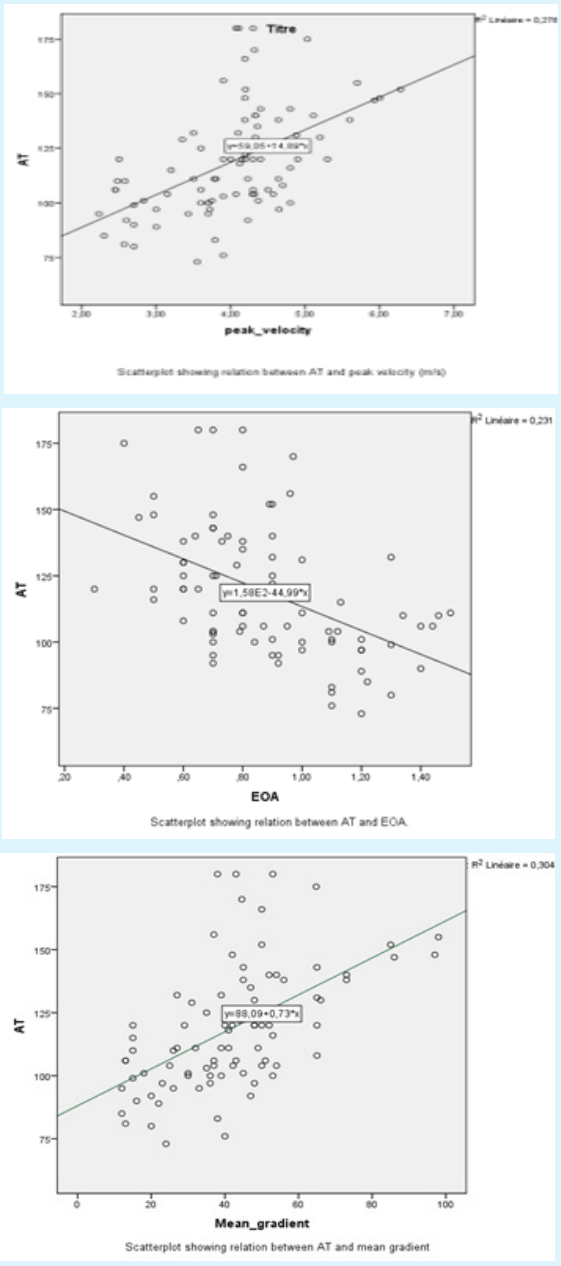


**Figure 4.** Scatterplots showing relations between AT and EOA, mean gradient, and peak velocity.

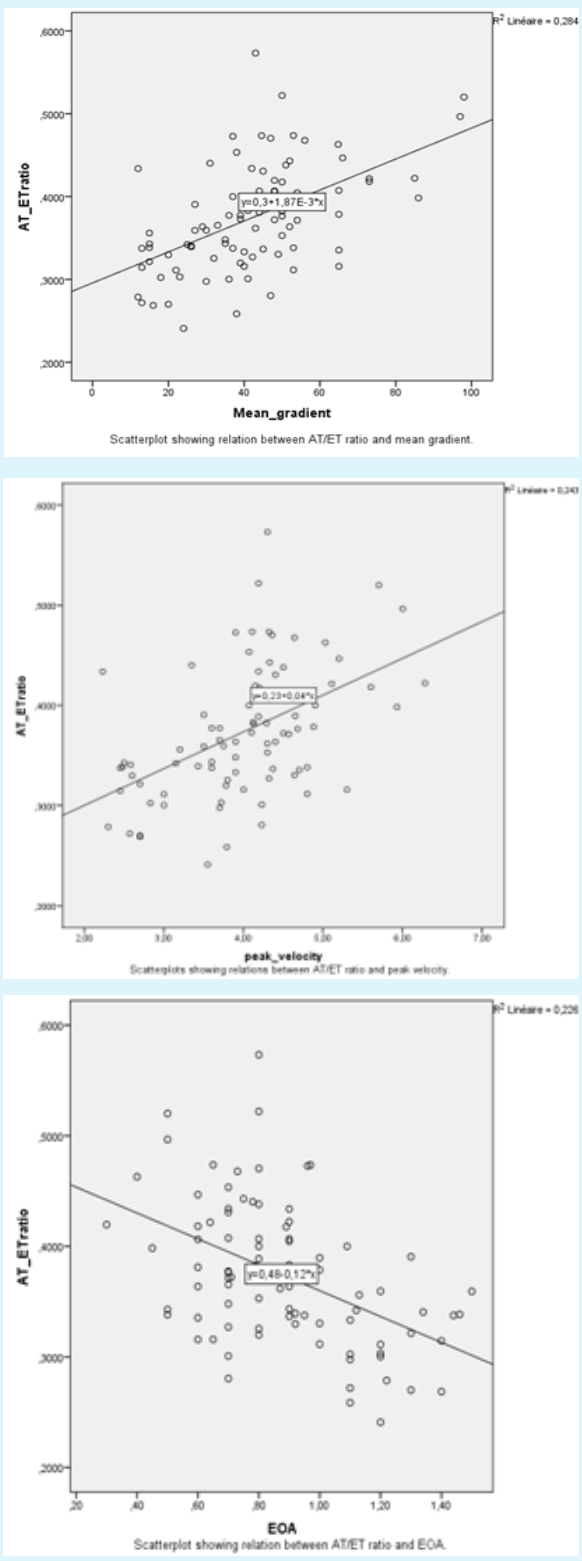


**Figure 5.** Scatterplots showing relations between AT and EOA, mean gradient, and peak velocity.

Ejection dynamics parameters were compared between patients with "discordant" severe AS (low flow, low-gradient severe AS and paradoxical low flow, low-gradient severe AS) and moderate AS: AT (115.88±23.66ms VS 97±14ms, p= 0.005) AT/ET (0.37±0.047ms VS 0.31±0.41ms, p ≤0.001) were higher in the "discordant" severe AS. ET (310.8±46.3ms vs 308±26ms, p=0.85) was similar in the 2 groups.

## DISCUSSION

In our study, we have shown that AT ≥ 110ms or an AT/ET ratio ≥ 0.36 identified severe AS with good accuracy. These ejection dynamics, in contrast to assessment of gradients, are angle-independent and relatively simple to acquire and measure.

Key studies on aortic stenosis (AS) have established that, in cases of moderate AS, there is a rapid upstroke and a gradual down stroke in the flow pattern. In contrast, severe calcified AS exhibits a slower upstroke, leading to an aortic flow pattern characterized by a rounded contour. The quick early systolic opening of a normal aortic valve, as seen on Doppler spectrograms, is replaced by a slow end-systolic opening of the stenotic aortic valve in severe AS.

For over four decades, ejection dynamics parameters have been used in the assessment of aortic stenosis (AS) utilizing techniques such as carotidography and phonocardiography. During this period, researchers were successful in demonstrating that the prolongation of the timing of the peak of the systolic murmur and the deceleration of the carotid upstroke were dependable indicators of significant AS. In one particular study, a comprehensive analysis was conducted, comparing carotid pulse tracings and phonocardiography across all degrees of AS severity. The investigators discovered strong correlations between the maximal rate of rise of the carotid pulse and the timing of the peak of the murmur, thus underscoring the utility of these methods in diagnosing and assessing AS (7).

While the guidelines suggest the visualization of the shape of the aortic waveform to aid in distinguishing between moderate and severe aortic stenosis (AS), there has been limited emphasis on the evaluation of ejection dynamics in the echocardiographic assessment of AS (3).

Ben Zekry et al (8) showed that as the severity of obstruction worsens, both the velocity and gradient across prosthetic aortic valves (PAVs) increase. Simultaneously, there is a prolongation of the ejection time and a delay in reaching the maximal velocity across the valve, leading to a rounded jet velocity contour, similar findings as in our study.

Beauchesne et al (9) also demonstrated that in 15 patients with severe aortic stenosis (AS), the maximum velocity occurred later in the ejection phase when compared to a control group (n=15) but they did not establish a cutoff point.

The primary factor influencing Acceleration Time (AT) was found to be the Effective Orifice Area (EOA). In other words, for every decrease of 0.1 $cm^2$ in EOA, there was an associated increase in AT of 6.2 milliseconds (10).

Many investigators have studied the effect of aortic stenosis on ejection time (ET):

Bruch et al (11) found that in patients with severe aortic stenosis and preserved left ventricular (LV) function, the LV Ejection Time (EJT) lengthened, and the isovolumic EJT and relaxation time shortened. This resulted in a shortening of the Tei index. Conversely, in patients with aortic stenosis and a low LV ejection fraction (EF), the EJT shortened, and the isovolumic times lengthened.

The results of Zoghbi et al (12) highlight that ejection time had a poor correlation with aortic valve area and peak-to-peak Cather gradients. But they discovered a notably significant inverse curvilinear relationship between the differences in Ejection Time (ET) derived from pulsed Doppler and the aortic valve area. By establishing a value for the ET difference (The ejection time difference was defined as Doppler-measured ET minus the predicted ET) at 0.060 seconds, they were able to differentiate between critical (less than 0.75 $cm^2$) and noncritical aortic stenosis (assessed by cardiac catheterization) with a predictive accuracy of 89%.

However, Bache (13) showed that the typical progressive increase in ejection time, which normally takes place with an increasing stroke volume (as described by Weissler et al (14) and Harley et al (15), was absent in these patients with aortic stenosis. But it is apparent that an inverse relationship between ejection time and heart rate was preserved.

While some other researchers have reported an association between left ventricular systolic time

and ejection fraction, our study did not reveal a significant correlation between Acceleration Time (AT) or Ejection Time (ET) and stroke volume or left ventricular ejection fraction. It's possible that this lack of correlation is attributed to the limited number of patients with low stroke volumes in our study. Nonetheless, our findings demonstrated that AT and the AT/ET ratio were effective predictors of severe aortic stenosis, regardless of systolic function.

Altes et al (16) suggested that an Acceleration Time to Ejection Time (AT/ET) ratio of 0.34 may serve as a diagnostic threshold for severe aortic stenosis (AS). In addition, setting the cut-off at 0.36 for the AT/ET ratio may identify patients with a significantly poor prognosis or outcome. Consistently, the AT/ET ratio cut-off of 0.34 identifies patients who are likely to have severe aortic stenosis (AS) based on CT-AVC (computed tomography aortic valve calcium) scoring. However, for the identification of patients with a very high likelihood of having severe AS using this imaging technique, the best threshold was found to be a cut-off value of 0.37 (16).

Furthermore, Sergio et al (17) Showed that a cut-off value for the AT/ET ratio of 0.35 had a high level of sensitivity and specificity for detecting symptoms. Patients with a ratio greater than 0.35 exhibited higher levels of serum NT-proBNP (N-terminal pro B-type natriuretic peptide).

Moreover, He observed a non-significant tendency toward higher values of the AT/ET ratio in patients with low-flow low-gradient aortic stenosis (AS) and those with normal-flow AS, both of whom had normal left ventricular systolic function (17).

Computed tomography aortic valve calcium (CT-AVC) scoring is recommended for specific challenging population with paradoxical low-gradient severe aortic stenosis (AS) who have preserved left ventricular ejection fraction (LVEF) (18). Interestingly, both haemodynamic indices of AS severity by echo Doppler and anatomical calcium load by CT were related to the AT/ET ratio in a multivariable analysis (16).

AT/ET is a simple and reproducible method for a quantitative estimation of aortic Doppler waveform, but the main reason, in our view, is that AT/ET is a flow-independent index, that can be very useful in low-flow severe valve disease.

## CONCLUSION

The present study reveals that systolic time intervals, especially Acceleration Time (AT) and the AT/ET ratio, are easy and accurate methods that could be used as an alternative in the echocardiographic assessment of this disease. We've established that Acceleration Time (AT) and the AT/ET ratio can effectively distinguish patients at various stages of aortic stenosis (AS). An AT greater than 110 milliseconds or an AT/ET ratio exceeding 0.36 identified severe AS with a high degree of accuracy.

The main reason may account for the good diagnostic efficacy of this index is that AT/ET is a flow-independent index, which can be particularly useful in cases of low-flow severe valve disease.

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