# Doppler Imaging in Aortic Stenosis: The Importance of the Nonapical Imaging Windows to Determine Severity in a Contemporary Cohort

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*Background:* Although the highest aortic valve velocity was thought to be obtained from imaging windows other than the apex in about 20% of patients with severe aortic stenosis (AS), its occurrence appears to be increasing as the age of patients has increased with the application of transcatheter aortic valve replacement. The aim of this study was to determine the frequency with which the highest peak jet velocity ($V_{max}$) is found at each imaging window, the degree to which neglecting nonapical imaging windows underestimates AS severity, and factors influencing the location of the optimal imaging window in contemporary patients.

*Methods:* Echocardiograms obtained in 100 consecutive patients with severe AS from January 3 to May 23, 2012, in which all imaging windows were interrogated, were retrospectively analyzed. AS severity (aortic valve area and mean gradient) was calculated on the basis of the apical imaging window alone and the imaging window with the highest peak jet velocity. The left ventricular–aortic root angle measured in the parasternal long-axis view as well as clinical variables were correlated with the location of highest peak jet velocity.

*Results:* $V_{max}$ was most frequently obtained in the right parasternal window (50%), followed by the apex (39%). Subjects with acute angulation more commonly had $V_{max}$ at the right parasternal window (65% vs 43%, $P = .05$) and less commonly had $V_{max}$ at the apical window (19% vs 48%, $P = .005$), but $V_{max}$ was still located outside the apical imaging window in 52% of patients with obtuse aortic root angles. If nonapical windows were neglected, 8% of patients (eight of 100) were misclassified from high-gradient severe AS to low-gradient severe AS, and another 15% (15 of 100) with severe AS (aortic valve area < 1.0 $cm^2$) were misclassified as having moderate AS (aortic valve area > 1.0 $cm^2$).

*Conclusions:* In this contemporary cohort, $V_{max}$ was located outside the apical imaging window in 61% of patients, and neglecting the nonapical imaging windows resulted in the misclassification of AS severity in 23% of patients. Aortic root angulation as measured by two-dimensional echocardiography influences the location of $V_{max}$ modestly. Despite increasing time constraints on many echocardiography laboratories, these data confirm that routine Doppler interrogation from multiple imaging windows is critical to accurately determine the severity of AS in contemporary clinical practice. (J Am Soc Echocardiogr 2015;28:780-5.)

*Keywords:* Doppler echocardiography, Aortic stenosis, Peak velocity, Low gradient, Aortic root angulation

Aortic stenosis is one of the most prevalent valvular lesions occurring in developed nations and increases in prevalence with aging. Mild or greater stenosis is thought to occur in approximately 3% to 8% of those aged > 60 years and as many as 20% of those aged > 80 years.[1-4] Management decisions rely on the accurate assessment of stenosis severity in conjunction with ventricular function and the symptom status of the patient.[5] Doppler echocardiography emerged in the 1980s as the dominant diagnostic modality for aortic stenosis, with multiple studies confirming good correlation between invasive hemodynamic measurements and continuous-wave Doppler echocardiography for calculating aortic valve mean gradient[6-10] and aortic valve area (AVA).[6,11]

Accurate Doppler assessment of peak jet velocity, mean gradient, and estimated AVA all rely on proper alignment of the ultrasound beam parallel with the stenotic jet.[12] Improper alignment of the ultrasound beam could result in underestimation of the peak jet velocity and mean gradient and overestimation of AVA. Classical teaching suggests that low-gradient severe aortic stenosis typically occurs because of low stroke volume, but low-gradient severe aortic stenosis more commonly occurs in the setting of normal Doppler stroke volume, and to our knowledge there are no data on the role of improper alignment of continuous-wave Doppler as a cause of misclassification of low-gradient severe aortic stenosis.[13-15]

Acute angulation of the aortic root has been described in several patient cohorts[16-18] and is felt to be more common with aging. This altered aortic root geometry could result in a more anteriorly

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**Abbreviations**

**AVA** = Aortic valve area

**LVOT** = Left ventricular outflow tract

**2D** = Two-dimensional

directed stenotic jet in aortic stenosis, making it more difficult to align the ultrasound beam properly from the apical position and thus making it more likely the peak velocity would be located outside the apical window (e.g., right parasternal or right supraclavicular). With increased use of transcatheter aortic valve replacement, the mean age of patients being evaluated with aortic stenosis is growing older, which could result in a change in the location or relative importance of the various imaging windows in more contemporary cohorts.

Previous studies examining the frequency with which the peak velocity is obtained from the various standard imaging windows found that the apical window was the most common location of highest jet velocity, but these prior studies involved patients who were significantly younger than those in contemporary cohorts and did not examine any potential relationship between aortic root angulation and the direction of the stenotic jet.[6,7,19-22] Given the recent rise of transcatheter valve replacement, resulting in older patients' being considered for intervention, and the increased time constraints of many echocardiographic laboratories, we believed that it was warranted to revisit the utility of routine Doppler interrogation of multiple imaging windows in patients with aortic stenosis. We sought to determine (1) the frequency with which the peak velocity is found from each imaging window in a contemporary cohort with aortic stenosis, (2) whether aortic root angulation as well as certain clinical variables correlate with the location of peak aortic jet velocity, and (3) whether neglecting the nonapical imaging windows results in significant misclassification of aortic stenosis severity and type.

## METHODS

The study protocol was approved by our institutional review board, and all patients gave informed consent to participate in the study. We retrospectively analyzed echocardiograms from 118 consecutive subjects with severe native valve aortic stenosis (AVA $< 1.0$ cm$^2$) referred for surgery between January 3, 2012, and May 23, 2012. Thirteen patients were excluded for inadequate parasternal image quality that precluded determination of the left ventricular–aortic root angle, and five patients were excluded because at least one imaging window was not interrogated during the clinical study, leaving a cohort of 100 patients with adequate image quality in which all imaging windows were interrogated. Each patient underwent comprehensive transthoracic two-dimensional (2D) and Doppler echocardiography for the evaluation of aortic stenosis. In all patients, this included assessment of the aortic valve in the short-axis view to determine valve morphology (e.g., bicuspid vs tricuspid), measurement of the left ventricular outflow tract (LVOT) diameter from the parasternal long-axis view, pulse-wave Doppler assessment of the LVOT from the apical window, and continuous-wave Doppler interrogation of the aortic jet peak velocity using imaging as well as nonimaging transducers from the apical, suprasternal notch, right supraclavicular, and right parasternal windows according to American Society of Echocardiography and European Association of Echocardiography guidelines.[12] When the right parasternal velocity was significantly higher than the apical velocity and significant mitral regurgitation was present, the preejection time (onset of QRS complex to onset of ejection) and total ejection time were measured and compared with the apical signal to be sure that the aortic outflow signal was measured and not the mitral regurgitant signal. For aortic root angulation, we measured the angle between the plane of the left ventricular cavity and the LVOT from the parasternal long-axis view at the peak of the T wave during systole (Figure 1). All echocardiograms were subsequently reviewed to determine peak aortic jet velocity and mean gradient from each imaging window. The imaging window with the highest peak velocity averaged over three beats in sinus rhythm or five beats in atrial fibrillation was recorded.

The continuity equation was used for the calculation of AVA using the LVOT diameter, LVOT peak velocity by pulse-wave Doppler, and the highest aortic valve continuous-wave Doppler peak velocity obtained from any window (averaged over three beats). In patients with the highest peak velocity obtained outside the apical window, we also estimated aortic stenosis severity using only the peak velocity and mean gradient acquired from the apical imaging window (neglecting nonapical imaging windows). Because LVOT diameter and LVOT peak velocity remain constant in the continuity equation, overestimation of AVA is inversely proportional to the underestimation of the peak jet velocity at the apical window (e.g., underestimation of peak velocity at the apex by 20% results in a 20% overestimation of AVA).

Statistical analysis was performed using JMP Pro version 9.0.1 (SAS Institute Inc, Cary, NC). Continuous variables were compared using two-tailed $t$ tests, and nominal variables were compared using contingency tables and $\chi^2$ analysis. Receiver operating characteristic curves were used to determine the aortic root angle that maximized sensitivity and specificity to predict the presence of the highest jet velocity being located outside the apical imaging window. For analysis of interobserver variability, left ventricular–aortic root angulation was repeated in the first 30 consecutive patients by a second observer who was blinded to other clinical data (K.J.L.). Correlation coefficients and Bland-Altman analysis were used to assess for interobserver correlation and overall bias, respectively.

## RESULTS

Clinical and echocardiographic characteristics of the study patients are listed in Table 1. The mean age was 75 years, and 38% were women. Women tended to have smaller body surface areas ($1.79 \pm 0.22$ vs $2.04 \pm 0.24$ m$^2$, $P < .0001$) and smaller AVAs ($0.75 \pm 0.12$ vs $0.82 \pm 0.12$ cm$^2$, $P = .003$) but similar indexed AVAs ($0.42 \pm 0.07$ vs $0.40 \pm 0.07$ cm$^2$/m$^2$, $P = .33$). Men were more likely to have had prior myocardial infarctions (24% vs 8%, $P = .04$) and impaired ejection fractions (26% vs 5%, $P = .009$) and had lower mean gradients on average ($48 \pm 13$ vs $57 \pm 14$ mm Hg, $P = .004$). The average aortic root angle in our cohort was $118 \pm 8°$ (range, 97°–135°). Interobserver correlation was modest on repeat measurement ($r = 0.65$), and a significant bias was observed ($114 \pm 6°$ vs $117 \pm 7°$ for K.J.L. vs J.J.T., respectively, $P = .006$).

Factors associated with a more acute aortic root angle included age $> 75$ years ($116 \pm 8°$ vs $120 \pm 7°$, $P = .004$), left ventricular end-diastolic dimension $< 55$ mm ($116 \pm 7°$ vs $124 \pm 9°$, $P = .01$), and having a trileaflet aortic valve ($117 \pm 8°$ vs $121 \pm 5°$, $P = .01$). However, the younger age of those with bicuspid aortic valves ($64 \pm 10$ vs $79 \pm 7$ years, $P < .0001$) likely accounted for the difference in angle between those with bicuspid versus tricuspid valves. Neither gender nor a history of hypertension was associated with left ventricular–aortic root angulation.