Aortic Upper Wall Tissue Doppler Image Velocity: Relation to Aortic Elasticity and Left Ventricular Diastolic Function

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Background: Aortic stiffening contributes to the left ventricular (LV) afterload, hypertrophy, and substrate for diastolic dysfunction. It is also known that aortic elastic properties could be investigated with color tissue Doppler imaging (TDI) in aortic upper wall. The purpose of this study is to evaluate the relation of aortic upper wall TDI and aortic stiffness and other parameters of LV diastolic function. Methods: We examined aortic upper wall by TDI at the 3 cm above the aortic valves because of patient’s chest discomfort or dyspnea. We excluded the patient with arterial hypertension or reduced left ventricular ejection fraction (LVEF) or significant valvular heart disease. So a total of 126 (mean age 53.8 ± 13.9 years, male 49.2%) patients were enrolled in this study and divided normal LV filling group (N = 31) and abnormal LV filling group (N = 95). Results: Aortic upper wall early systolic velocity and late diastolic velocity were not different between the two groups. Only aortic upper wall early diastolic velocity (AWEDV) was related to aortic stiffness index (r = −0.25, P = 0.008), distensibility (r = 0.28, P = 0.003), early diastolic (Em) (r = 0.45, P = 0.001), E/Em (r = −0.26, P = 0.003), and significantly reduced in abnormal LV filling group (6.19 ± 2.50 vs 8.18 ± 2.87, P = 0.001). Conclusions: AWEDV is decreased significantly in abnormal LV filling patients. It is statistically related to aortic stiffness, distensibility and parameters of abnormal LV filling, Em, E/Em. TDI velocity of the aortic upper wall can be a helpful tool for evaluating aortic stiffness, distensibility, and diastolic function. (ECHOCARDIOGRAPHY, Volume **, ******** ****)

Aortic stiffness, diastolic function, tissue Doppler

The aorta has an elastic structure that provides a conduit function to cardiovascular system.1 Also it partly regulates left ventricular (LV) performance and coronary flow. Increased aortic stiffness may increase afterload and induce LV myocardial change and consequently impact on LV diastolic function. The change in aortic elastic property could be shown with color Doppler tissue imaging2,3 and these finding could be related to aortic stiffness, distensibility, and LV diastolic function. Several studies have shown that aortic stiffness is related with LV mass and diastolic function.4–10 However, aortic systolic and diastolic wall motion velocity measured by tissue Doppler imaging (TDI) has been reported sparsely especially concerning a parameter of aortic stiffness and LV diastolic function. So we investigated whether aortic upper wall TDI velocity is useful in detection of aortic stiffness and LV diastolic function.

Methods

Study Population

We enrolled subjects who visited our out patient clinic from March to May 2007 because of patient’s chest discomfort or dyspnea. Patients with arrhythmia, heart failure, hypertension, significant valvular disease, coronary artery disease, cardiomyopathy, and poor-quality echocardiographic imaging were excluded from this study. We also excluded the patient under cardiovascular medication.
Therefore, a total of 126 (mean age 53.8 ± 13.9 years, male 49.2%) patients were enrolled in this study and divided normal LV filling group (N = 31) and abnormal LV filling group (N = 95) according to early (E), late (A), and the deceleration time (DT).

**Study Protocol**

*Echocardiographic measurement.* Echocardiographic examinations were conducted using commercially available ultrasound machine (iE 33, Philips, Philips Ultrasound, Bothell, WA, USA) with a 5 MHz phased-array probe. After routine echocardiographic examination according to American Society of Echocardiography guideline, the aortic diameter was recorded by M-mode echocardiography 3 cm above the aortic valve. Aortic systolic diameter was measured at the time of full opening of the aortic valve, and diastolic diameter was measured at the peak of the QRS complex of the simultaneous recorded echocardiogram (Fig. 1A).

Aortic upper wall velocity (m/sec, Fig. 1B) was measured at the same point as in the M-mode measurement. Aortic upper wall systolic velocity had a positive profile, indicating that the aorta expands toward the cursor during ventricular systole. Transmitral pulsed-wave velocities were recorded from the apical four-chamber with a 2 mm Doppler sample placed between the tips of the mitral leaflets. The E and A-wave velocities, DT of early filling, and E/A ratio were all measured from the mitral inflow profile. The systolic (Sm), early diastolic (Em), and late diastolic (Am) velocities were measured from the apical four-chamber view using TDI at the septal mitral annulus.

Blood pressure was measured after echocardiographic measurement using a mercury sphygmomanometer.

**Definition of normal LV filling.** Normal LV filling was defined by E:A of 0.75–1.5 and a deceleration time of 160–250 ms. Abnormal LV filling was defined by the combination of E:A < 1 and E wave deceleration time > 250 ms. Pulmonary vein velocities were used to differentiate normal from pseudonormal filling in patients who had a normal transmitral Doppler profile.\(^\text{11,12}\)

**Aortic distensibility and stiffness measurement.** Aortic distensibility and stiffness index were used as indices of aortic function and as follows.\(^\text{13}\)

\[
\text{Aortic root distensibility } (10^{-6}\text{cm}^2\text{dyn}^{-1}) = 2 \times (\text{AoS} - \text{AoD})/(\text{SBP} - \text{DBP}) \times \text{AoD} \\
\text{Aortic stiffness index} = \ln(\text{SBP/DBP})/(\text{AoS} - \text{AoD})/\text{AoD}
\]

where AoS: aortic diameter at LV systole, AoD: aortic diameter at LV diastole, SBP: systolic blood pressure, DBP: diastolic blood pressure.

**Statistical Analysis**

Data are expressed as mean ± SD and frequencies are expressed as percentages. The differences between the measurements were tested using two tailed student’s *t*-test and Categorical variables were compared using the chi-square test. Pearson’s correlation coefficients were calculated for pairs of continuous variables. Multiple stepwise linear regression analysis was performed to examine the independent predictors of increased Em. Intraobserver
variability was established by having one observer measure data on at least two occasions in 15 subjects selected at random from the patient population under the study. Interobserver variability as determined by having second operator independently measures the same parameters in these subjects. A probability value of \( P < 0.05 \) was considered significant. The SPSS statistical software (version 11.0: SPSS Inc., Chicago, IL, USA) was used.

**Results**

**Patient's Characteristics**

The baseline demographic characteristics of the study population are shown in Table I. Abnormal LV filling groups were more likely to be older (58.2 ± 10.8 vs 40.4 ± 13.7, \( P = 0.001 \)) and higher BMI. There were no differences in sex, diabetes, smoking status, SBP, DBP, heart rate, LV systolic ejection fraction (EF), total cholesterol, HDL, and LDL between the two groups.

**Aortic Elastic Properties**

The values of aortic stiffness index, distensibility, and color Doppler tissue imaging measurements were compared between patient with normal and abnormal LV filling group (Table II). Aortic stiffness index was significantly higher (3.39 ± 0.84 vs 3.01 ± 0.72, \( P = 0.028 \)) and aortic distensibility was significant lower (2.22 ± 1.80 vs 3.20 ± 2.88 \( P = 0.035 \)) in patients of abnormal LV filling group than in those of normal LV filling group.

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**TABLE I**

Demographic Characteristics, Clinical and Biochemical Parameters of the Study Population

<table>
<thead>
<tr>
<th></th>
<th>Normal LV Filling Group (N = 31)</th>
<th>Abnormal LV Filling Group (N = 95)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>40.4 ± 13.7</td>
<td>58.2 ± 10.8</td>
<td>0.001</td>
</tr>
<tr>
<td>Male (%)</td>
<td>17 (54.8 %)</td>
<td>45 (47.4 %)</td>
<td>NS</td>
</tr>
<tr>
<td>DM (%)</td>
<td>2 (6.5 %)</td>
<td>10 (10.5 %)</td>
<td>NS</td>
</tr>
<tr>
<td>Smoker (current)</td>
<td>6 (19.4 %)</td>
<td>15 (15.8 %)</td>
<td>NS</td>
</tr>
<tr>
<td>Systolic blood pressure (mmHg)</td>
<td>119 ± 11.1</td>
<td>128 ± 18.8</td>
<td>NS</td>
</tr>
<tr>
<td>Diastolic blood pressure (mmHg)</td>
<td>64 ± 12.1</td>
<td>76 ± 12.6</td>
<td>NS</td>
</tr>
<tr>
<td>Heart rate (/min)</td>
<td>64 ± 12.1</td>
<td>67 ± 12.6</td>
<td>NS</td>
</tr>
<tr>
<td>BMI</td>
<td>22.6 ± 2.3</td>
<td>23.9 ± 2.4</td>
<td>0.01</td>
</tr>
<tr>
<td>EF (%)</td>
<td>63 ± 5.7</td>
<td>66 ± 7.9</td>
<td>NS</td>
</tr>
<tr>
<td>Total cholesterol (mg/dL)</td>
<td>173 ± 32.5</td>
<td>184 ± 40.2</td>
<td>NS</td>
</tr>
<tr>
<td>LDL (mg/dL)</td>
<td>108 ± 24.5</td>
<td>112.3 ± 33.3</td>
<td>NS</td>
</tr>
<tr>
<td>HDL (mg/dL)</td>
<td>57 ± 13.7</td>
<td>55 ± 13.4</td>
<td>NS</td>
</tr>
</tbody>
</table>

**TABLE II**

Aortic Functional and Tissue Doppler Imaging Parameters and Diastolic Parameters

<table>
<thead>
<tr>
<th></th>
<th>Normal LV Filling Group (N = 95)</th>
<th>Abnormal LV Filling Group (N = 95)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aortic wall early systolic velocity (cm/s)</td>
<td>8.76 ± 2.44</td>
<td>9.14 ± 3.16</td>
<td>NS</td>
</tr>
<tr>
<td>Aortic wall early diastolic velocity (cm/s)</td>
<td>8.18 ± 2.87</td>
<td>6.19 ± 2.50</td>
<td>0.001</td>
</tr>
<tr>
<td>Aortic wall late diastolic velocity (cm/s)</td>
<td>9.36 ± 2.84</td>
<td>8.93 ± 3.16</td>
<td>NS</td>
</tr>
<tr>
<td>Aortic distensibility (10^-6 cm^2 dyn^-1)</td>
<td>3.20 ± 2.88</td>
<td>2.22 ± 1.80</td>
<td>0.035</td>
</tr>
<tr>
<td>Aortic stiffness index</td>
<td>3.01 ± 0.72</td>
<td>3.39 ± 0.84</td>
<td>0.028</td>
</tr>
<tr>
<td>E (cm/s)</td>
<td>76.1 ± 18.3</td>
<td>61.4 ± 14.5</td>
<td>0.001</td>
</tr>
<tr>
<td>A (cm/s)</td>
<td>56.1 ± 16.2</td>
<td>71.4 ± 17.6</td>
<td>0.001</td>
</tr>
<tr>
<td>DT (ms)</td>
<td>181.1 ± 44.4</td>
<td>294.4 ± 42.1</td>
<td>0.001</td>
</tr>
<tr>
<td>Em (cm/s)</td>
<td>10.2 ± 2.24</td>
<td>5.9 ± 2.12</td>
<td>0.001</td>
</tr>
<tr>
<td>Am (cm/s)</td>
<td>7.7 ± 1.49</td>
<td>8.8 ± 1.72</td>
<td>0.002</td>
</tr>
<tr>
<td>E/Em</td>
<td>7.7 ± 2.47</td>
<td>11.3 ± 3.86</td>
<td>0.001</td>
</tr>
</tbody>
</table>
### Table III

<table>
<thead>
<tr>
<th>Aortic Stiffness Index</th>
<th>Aortic Distensibility</th>
<th>Em</th>
<th>E/Em</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aortic wall early systolic velocity (cm/s)</td>
<td>-0.13 NS</td>
<td>0.100 NS</td>
<td>-0.06 NS</td>
</tr>
<tr>
<td>Aortic wall early diastolic velocity (cm/s)</td>
<td>-0.25 0.008</td>
<td>0.279 0.003</td>
<td>0.45 0.001</td>
</tr>
<tr>
<td>Aortic wall late diastolic velocity (cm/s)</td>
<td>-0.16 NS</td>
<td>0.131 NS</td>
<td>0.001 NS</td>
</tr>
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</table>

**Relationship between Aortic Elastic Properties with LV Diastolic Function**

The relationships between aortic stiffness and aortic distensibility to the color Doppler tissue imaging measurements were evaluated (Table III). Only aortic upper wall early diastolic velocity (AWEDV) was related to aortic stiffness index ($r = -0.25$, $P = 0.008$, Fig. 2A), distensibility ($r = 0.28$, $P = 0.003$, Fig. 2B), Em ($r = 0.45$, $P = 0.001$, Fig. 2C), E/Em ($r = -0.26$, $P = 0.003$, Fig. 2D) statistically in this study patients. Multiple stepwise linear regression analysis was applied to examine the relationship between aortic wall motion velocity with variables (age, sex, diabetes, aortic upper wall early systolic velocity, late systolic, and diastolic velocity), it revealed age ($\beta = -0.628$, $P = 0.001$), and AWEDV ($\beta = 0.234$, $P = 0.001$) as the main predictors of increased Em. Logistic regression analysis also showed increased odd ratio (1.21, CI 1.01–1.44, $P = 0.034$) in the prediction of abnormal LV filling (Table IV).

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**Figure 2.** Linear regression curves of the relation between aortic wall velocity and A. aortic stiffness index, B. aortic distensibility, C. Em, and D. E/Em.
TABLE IV

<table>
<thead>
<tr>
<th>Odd Ratio in the Prediction of Abnormal LV Filling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Odd Ratio</td>
</tr>
<tr>
<td>------------</td>
</tr>
<tr>
<td>Aortic stiffness index</td>
</tr>
<tr>
<td>Age</td>
</tr>
<tr>
<td>Aortic upper wall early diastolic velocity (m/s)</td>
</tr>
</tbody>
</table>

**Discussion**

In the previous study, aortic elastic property has been studied with several other methods. Increased aortic stiffness and decreased distensibility indicated impairment in the elastic structure of the aorta. From a mechanical standpoint, increased vascular stiffness poses an increased load on the heart by increasing systolic wall stress. The heart appears to respond to this stress by a tandem increased in both systolic and diastolic ventricular stiffness. Our study used the TDI velocity of the aortic wall in evaluating the relation between aortic elastic property and LV diastolic function. Direct measurement of stiffness may give a greater help than other methods, because it is not affected by hematological and cardiovascular physiology. Wall movement of the aorta is synchronous but reverse with the heart. In other word, during the ventricular systole, the aorta expands, while the ventricle diastole, the aorta contracts. So we hypothesized that the aortic expansion depends on the ventricular systolic pressure, but aortic contraction depends on the elastic property, not depends on systolic or diastolic LV pressure. Therefore, we expected that there would be no differences in aortic wall systolic velocity using DTI at the systole of the aorta. In this study, our result showed that aortic stiffness index is increased and aortic distensibility is decreased in abnormal LV filling group significantly (Table II). It also revealed no differences in aortic upper wall early systolic and late diastolic velocity between normal and abnormal LV filling groups, so it supported our belief, and revealed the AWEDV is significantly different and reduced in abnormal LV filling group (Table II). The aortic elastic property in abnormal LV filling group is decreased and only AWEDV was an important parameter of the evaluating the elastic property of the aorta in these three aortic wall TDI velocities.

Decreased mitral annular velocity in early diastole (Em) has been known as an important parameter of diastolic dysfunction. Only aortic wall early diastolic velocity is also related to Em (r = 0.45, P = 0.001) and reversely related to E/Em significantly (r = −0.26, P = 0.003). So it also supported the importance of AWEDV that can be a new feasible tool for evaluating aortic stiffness, distensibility, and diastolic function in this study.

However, an increase in arterial stiffness is a common feature of aging process. So we used multiple stepwise linear regression analysis to examine the relationship between aortic wall motion velocity with variables, it revealed age (β = −0.628, P = 0.001), and AWEDV (β = 0.234, P = 0.001) as the main predictors of increased Em. Logistic regression analysis also showed increased odd ratio (1.21, CI 1.01–1.44, P = 0.034) in the prediction of abnormal LV filling (Table IV).

One of the possible potential mechanisms for relationship between aortic stiffness and LV diastolic dysfunction is that increased aortic stiffness may also increase afterload, inducing myocardial structural changes of the left ventricle and through that LV diastolic dysfunction. So the main finding of this study are that abnormal LV diastolic filling group is associated with significant changes in the elastic properties of the aorta, and the AWEDV was decreased and it can be a helpful important parameter in evaluating for aortic stiffness, distensibility, and LV diastolic function.

**Limitations**

We investigated the aortic elastic property only one vessel bed (ascending aorta) but in different point the wall elastic property may be different.

The study number is quite small and the correlation efficiency were low (0.25–0.45) so it is statistically underpowered and it may not have significant biological correlation.

We didn’t perform cardiac catheterization to evaluate intraventricular pressure, dp/dt that can influence aortic wall TDI.

**Conclusion**

In this study, AWEDV is decreased significantly in abnormal LV filling patients. And it is statistically related to aortic stiffness,
distensibility, and parameters of abnormal LV filling, $Em$, $E/Em$. The velocity of TDI of the aortic upper wall can be a helpful tool for evaluating aortic stiffness, distensibility, and diastolic function.

References