Left Ventricular Early Diastolic Inflow Velocity and Atrial Ventricular Plane Downward Velocity: Useful Parameters to Test Diastolic Function in Clinical Practice? Diastolic Parameters Tested in a Clinical Setting

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Aims: To study the clinical value of the colour-M-mode slope of the early diastolic left ventricular filling phase (Vp) and the early diastolic downward M-mode slope of the left atrioventricular plane displacement (EDS), compared with diastolic function assessed by traditional Doppler evaluation.

Methods and Results: In 65 consecutive patients EDS and Vp were compared with a four-degree traditional diastolic function classification, based on pulsed Doppler assessment of the early to atrial transmitral flow ratio (E/A), the E-wave deceleration time (Edt), and the systolic to diastolic (S/D) pulmonary venous inflow ratio. Vp (P=0.006) and EDS (P=0.045) were related to traditional diastolic function (Kruskal–Wallis analysis). EDS showed a trend brake between the moderate and severe diastolic dysfunction groups by traditional Doppler evaluation. Vp and EDS correlated weakly in simple linear regression analysis (r=0.33). Vp and EDS discriminated poorly between normal and highly abnormal diastolic function.

Conclusions: Vp and EDS were significantly related to diastolic function by traditional Doppler evaluation. They were, however, not useful as single parameters of left ventricular diastolic function due to a small difference between normal and highly abnormal values, allowing for little between-measurement variability. Consequently, these methods for the evaluation of left ventricular diastolic function do not add significantly to traditional Doppler evaluation.

Introduction
Assessment of left ventricular diastolic function has in recent years become increasingly important in the everyday clinical practice of cardiology. Diastolic dysfunction has been suggested to be responsible for a considerable part of the symptoms in heart failure[1–8]. At least one-third of patients with heart failure have preserved global left ventricular systolic function, and these patients with isolated diastolic dysfunction have a similar symptomatology compared to those with systolic dysfunction.

Diastolic Dysfunction
Diastolic dysfunction is often difficult to diagnose in routine clinical practice. This is partly due to the lack of agreement on a definition of diastole, but also due to the lack of a definition of diastolic dysfunction. Such a definition was suggested at the 1st European Diastology meeting in 1996: ‘A condition resulting from an increased resistance to ventricular filling and leading to symptoms of congestion caused by an inappropriate shift of the diastolic pressure–volume relation'[2]. In order to fulfil the requirements of this definition the diagnosis of diastolic dysfunction requires invasive methods, which of course is not possible in everyday clinical routine. Non-invasive methods have been

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developed over the recent years and the most widely used methods are echocardiographic Doppler methods. These methods are, however, still lacking in accuracy and feasibility.

Echocardiographic Doppler Methods

The Doppler-derived ratio of the early to atrial (E/A) transmitial peak inflow to the left ventricle was the first parameter to be used in clinical practice. The E/A ratio is >1 when the left ventricle is relaxing in a normal way.

The pseudonormalization of the E/A ratio is, however, a well-known limitation of this method[2,9–11]. The same problem applies to the Doppler-derived deceleration time of the E-wave (Edt)[2,10,11].

Echocardiographers of today therefore often use a combination of E/A, Edt and Doppler assessment of the pulmonary venous inflow to the left atrium. With increasing filling pressures the pulmonary venous systolic velocity (S) becomes lower than the diastolic (D), and the atrial regurgitant flow into the pulmonary vein (AR) becomes more prominent[2,10]. Thus, this combined assessment can be used to separate a pseudonormal E/A from that seen in a patient with normal diastolic function. However, registration of the pulmonary venous flow is sometimes difficult and the interpretation may be complicated by contradictory information. Therefore there is a need for reliable and feasible diastolic parameters for clinical use that could replace the traditional Doppler-derived tools of today.

In the past few years new methods have been investigated with different degrees of success, and without any single parameter being the ‘key’ to diagnosing diastolic dysfunction and solving the problem with pseudonormalization[9–11]. Two of the new parameters, the slope of the colour Doppler M-mode registration of the early diastolic flow into the left ventricle (Vp) and the atrioventricular plane displacement (AVPD) downward slope in early diastole (EDS), may be less preload-dependent[2,10–12,18]. In a small series using invasive assessment as control, Bruch et al. showed that the power of EDS to detect pseudonormalization was good; the sensitivity and specificity for pseudonormalization was 77% and 87%, respectively, in this study[11].

M-mode registration of the AVPD is easy to obtain in any laboratory, as is colour-M-mode during the early diastolic filling of the left ventricle. Assessment of Vp, EDS or a combination of the two could provide a relatively simple way of evaluating left ventricular diastolic function.

The aim of this study was to investigate whether Vp and EDS are feasible and accurate enough to be used in clinical practice. The hypothesis was that Vp and EDS would be significantly related to left ventricular diastolic function as assessed by a combination of E/A, Edt and S/D.

Material and Methods

Study Population

The study population consisted of 65 consecutive patients who underwent echocardiographic examination in connection with a coronary angiography or due to heart failure or myocardial infarction. Of the 65 included patients, 43 (66%) were men. Mean age was 65 ± 13 years, range 25–96. Twenty-two (34%) patients were outpatients examined prior to coronary angiography, and 44 (66%) were inpatients. Half of the inpatients had an acute myocardial infarction. The rest of the inpatients were admitted either due to heart failure, angina or non-ischaemic chest pain. Twenty-one (33%) of the patients had had a previous myocardial infarction. Seven patients (11%) had diabetes and 21 (33%) were receiving treatment for hypertension. Nine patients (14%) had done a PTCA and 9 (14%) a CABG. Fifteen subjects (23%) underwent coronary angiography during the hospital stay. The mean NYHA and CC-classes were 1 · 6 ± 0·9 and 2 · 2 ± 1·1, respectively.

Echocardiography

The echocardiographic equipment used was a Hewlett-Packard Sonos 2500 or Sonos 2000 and a 2·5 MHz transducer. Patients were examined in a left lateral recumbent position. Measurements were acquired during silent respiration or end-expiratory apnoea. The echocardiographic examination was performed in the four standard views: parasternal long and short axis, and apical four and two-chamber views.

Vp was measured in the apical four-chamber view. The M-mode cursor was placed from the apex through the mitral tip in the colour Doppler mode. A colour Doppler M-mode registration (colour-M-mode) was then obtained from the tip of the mitral leaflets towards the apex of the left ventricle. The horizontal sweep propagation speed was set at 100 mm s−1. The slope of the colour flow propagation (Vp) was then measured by placing a calliper line alongside the first aliasing line of the colour propagation (Fig. 1). Vp was expressed as the mean value of three measurements.

The EDS was measured in the apical four and two-chamber views and expressed as the average of the mean values of two measurements at each of the septal, lateral, inferior and anterior regions. A calliper line was placed along the early downward slope of the M-mode line from the four regions of the atrioventricular plane, as shown in Figure 2.

The classification of diastolic function was a predefined modification of classifications used in prior studies[2,3,9,10,15,19]: (i) normal diastolic function, E/A within the age-adjusted reference interval (based on a reference material used in our echolab)[8], and not <0·75, Edt within the age-adjusted reference interval[9], and S>D; (ii) mild diastolic dysfunction, E/A below the age-adjusted reference interval and/or <0·75, Edt within

or above the age-adjusted reference interval, and S>D;
(iii) moderate diastolic dysfunction, E/A above the age-
adjusted reference interval, and S<D or Edt<150 ms;
(iv) severe diastolic dysfunction, E/A above age-adjusted
reference interval, S>D and Edt<150 ms.

The systolic function of the left ventricle was deter-
mined both in terms of visually assessed ejection fraction
and AVPD.

Left AVPD was determined in two-dimensionally
guided M-mode in the four-and two-chamber views, as
described previously[20–22]. The regional AVPD (mm)
was the distance covered by the atrioventricular plane
between the position most remote from the apex (corre-
sponding to the onset of contraction) and the location
closest to the apex (corresponding to the end of contrac-
tion, including any post-ejection shortening), i.e. the full
extent of the displacement. AVPD was measured in the
septal, lateral, posterior and anterior regions, and was
calculated from an average of two heart cycles at each
site in patients with regular rhythm, and four in patients
with irregular rhythm. The mean of the displacement in
the four regions was calculated.

Statistics

Correlation between continuous variables was tested
by simple linear regression analysis. In order to test
diastolic function in linear regression analysis the four
degrees were used as a continuous variable. The
Kruskal–Wallis analysis was used to test any relation-
ship between Vp/EDS and the four degrees of diastolic
dysfunction. Results are expressed as mean ± SD. A
P-value<0·05 was considered significant.

Results

The mean left ventricular ejection fraction was
49 ± 13%, (range 15–70%) and the mean left AVPD was
11·0 ± 2·7 mm (range 5·0–16·4 mm). Two patients (3%)
had severe aortic stenosis and 12 (19%) had moderate
valvular dysfunction of some kind.
Diastolic parameters are shown in Table 1. Registrations of Vp were missing in three patients, Edt in two, E/A in one and EDS in one patient. In linear regression analysis age did not significantly \((P=0.067)\) correlate with diastolic function by traditional Doppler-based classification. Using the Kruskal–Wallis test we found a significant trend of diminishing Vp values with an increasing degree of diastolic dysfunction (Fig. 3).

However, the difference between Vp values in the four groups of diastolic function were small, ranging from a mean of 50.7 ± 15.4 in patients with normal diastolic function to 36.6 ± 13.6 in those with severe diastolic dysfunction by traditional classification. Notably, the Vp value at the 75th percentile in the group with severe diastolic dysfunction was higher than at the 75th percentile in the group having moderate diastolic dysfunction, illustrating the relatively large spreading of Vp.

There was a significant trend of diminishing EDS values with worsening diastolic function, however, with a trend break in the group with severe diastolic dysfunction, where the EDS was higher than in the group with moderate diastolic dysfunction (Fig. 4). Similar to Vp, the difference between EDS values in the four groups of diastolic function were small, ranging from a mean of 5.7 ± 1.6 in patients with normal diastolic function to 4.5 ± 1.6 in those with severe diastolic dysfunction. EDS and Vp correlated weakly in linear regression analysis; \(r=0.331, P=0.042\) (Fig. 5).

**Figure 4.** The mean values of the early diastolic atrioventricular plane displacement (AVPD) downward slope (EDS) plotted against the four different groups of diastolic function: normal diastolic function (white) and mild (grey), moderate (vertical lines) and severe (diagonal lines) diastolic dysfunction. A significant trend was seen \((P=0.045)\). A downward trend was seen in the three first groups, with a trend break in the group with severe diastolic dysfunction, where the EDS was higher than in the group with moderate diastolic dysfunction. The lower and upper lines in the boxes represents the 25th and the 75th percentiles, respectively, with the median marked in the box. Outliers are marked as rings.

**Figure 5.** Regression plot. The slope of the colour-M-mode (Vp) during the early diastolic left ventricular filling plotted against the mean value of the early diastolic downward movement slope of the atrioventricular plane (EDS). \(r=0.331, P=0.042\), SEE=1.13. \(V_p=26.81+3.38\ EDS\).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean ± SD</th>
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<tbody>
<tr>
<td>Vp</td>
<td>44.9 ± 15.5</td>
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<tr>
<td>EDS</td>
<td>5.2 ± 1.6</td>
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<tr>
<td>Edt</td>
<td>222 ± 67</td>
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<tr>
<td>E/A</td>
<td>1.16 ± 0.48</td>
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<tr>
<td>Diastolic function</td>
<td>1.86 ± 1.1</td>
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**Discussion**

Using Kruskal–Wallis analysis, Vp was significantly related to diastolic function as defined by traditional Doppler assessment. It did not pseudonormalize, which is in agreement with the findings of prior studies\[^{12}\]. However, there is a problem in the clinical setting because of the relatively small differences between Vp values in patients with various degrees of diastolic function, even between the patients classified as having normal diastolic function and those with severe diastolic dysfunction. Consequently, this method allows for very little measurement variability, suggesting that Vp alone may not be a very useful diastolic parameter in clinical practice. However, since Vp does not seem to pseudonormalize it could be useful as a supplement to E/A and Edt in patients where the pulmonary venous flow is difficult to register or where the registration is inconclusive.

Similar to Vp, EDS values showed relatively small differences between patients with various degrees of diastolic function, although there was a significant
relationship between EDS and diastolic function according to traditional classification. Furthermore, values in the group with severe diastolic dysfunction were higher compared to those with moderate dysfunction. This decreases the value of EDS for the assessment of left ventricular diastolic function in the clinical setting. The somewhat time-consuming assessment of EDS, where the four atrioventricular plane regions are evaluated separately and the mean value is calculated, further indicates that EDS is unsuitable to use in daily clinical practice. In a relatively recent publication by Bruch et al. [11], the EDS was shown to be an accurate marker of pseudonormalization. However, of the nine patients showing a pseudonormal pattern in that study, no subject had a restrictive pattern. In our study there was a trend towards more normalized values of EDS in the group having severe diastolic dysfunction. Our results suggest that EDS is less accurate for identifying patients with high filling pressures and a restrictive Doppler pattern.

The weak correlation between EDS and Vp is probably at least partly due to the fact that they are measurements of different things. Vp reflects the propagation of the blood flow into the left ventricle during the early diastolic filling phase, whereas EDS is the velocity of the AVPD in early diastole. EDS is likely to be affected by several factors (for instance the amplitude of the AVPD and the heart rate) which are not directly linked to the filling rate of the ventricle. However, both provide information about the diastolic function and they could be linked in a non-linear or a more complex way.

Our classification of the diastolic function could be questioned from different points of view. For example, we did not include an assessment of the velocity or duration of the AR. However, it is often difficult to obtain a useful registration of AR, which is why we did not include it. We also did not assess the isovolumetric relaxation time. Furthermore, the use of the 0.75 E/A limit is a compromise between the use of age-adjusted values derived from earlier studies and the more practical use of fixed values. The same applies to the use of a fixed Etd limit in this study. It could obviously also be argued that invasive measurements should be used as gold standard in a study where new parameters are tested. However, we simply aimed to test the clinical value of these new parameters as compared with the standard method for the assessment of diastolic function in clinical practice.

In conclusion, Vp and EDS are diastolic parameters significantly related to traditional Doppler-based classification of left ventricular diastolic function. Both EDS and Vp showed only small differences even between values in patients with normal and in those with severely abnormal diastolic function, which allows for very little measurement variability. Consequently, these methods are of limited use in a clinical setting to discriminate between normal diastolic function and various degrees of diastolic dysfunction. However, these parameters could be of value in patients where a classical assessment of diastolic dysfunction using transmitral and pulmonary venous Doppler is suboptimal or impossible.

References

Exaggerated Pectinate Muscles Mimicking Multiple Left Atrial Appendage Thrombi

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A 65-year-old female with known non-obstructive hypertrophic cardiomyopathy and suspected of having bacterial endocarditis underwent omniplane transesophageal echocardiography to exclude valvaral vegetations. During examination the patient demonstrated sinus rhythm with first degree atrioventricular block. There was no history of thromboembolism, palpitations or atrial fibrillation. Both atria were significantly dilated and demonstrated impaired systolic function. The left ventricle showed concentric hypertrophy and a hyperdynamic systolic function. Three large piriform non-floating structures were seen in the dilated left atrial appendage, which did not show spontaneous echocoustic effect. The structures were interpreted as pectinate muscles primarily on the basis of their symmetry and the lack of floating movements.

Of more than 5530 transesophageal studies performed within the last 9 years, this is the first patient with such prominent pectinate muscles. Although rare, they may pose problems in differential diagnosis from thrombus (LA: left atrium; LV: left ventricle; arrows: pectinate muscles).

References