Clinical Implication of Energy Loss Coefficient in Patients With Severe Aortic Stenosis Diagnosed by Doppler Echocardiography

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Background The Doppler-derived energy loss coefficient (ELCo), which can take into account the pressure recovery phenomenon and reconcile discrepancies between the aortic valve effective orifice area (EOA) obtained by the Gorlin formula using a catheter (EOA\text{cath}) and the EOA obtained by the Doppler continuity equation (EOA\text{Dop}), is proposed as an equivalent index to represent EOA\text{cath}. Therefore, the purpose of this study was to evaluate the clinical impact of ELCo in patients with severe aortic stenosis (AS).

Methods and Results Thirty-three patients with severe AS were assessed by Doppler examination [EOA obtained by the continuity equation (EOA\text{Dop}) ≤ 1.0 cm²], and referred to the cardiac catheterization laboratory for evaluation of EOA obtained by the Gorlin formula (EOA\text{cath}). Patients with ELCo ≤ 1.0 cm² (n=26) had significantly lower incidence of symptoms related to AS compared with those having ELCo > 1.0 cm² (n=7) (p=0.002). Superior concordance in severity of AS was demonstrated between EOA\text{cath} and ELCo compared with EOA\text{cath} and EOA\text{Dop} (Д=0.52, and Д=0.32, respectively).

Conclusions In 21% of patients with “severe” AS diagnosed by Doppler echocardiography, the ELCo value indicated moderate rather than severe AS. These patients had significantly lower incidence of symptoms compared with patients who had ELCo ≤ 1.0 cm². (Circ J 2008; 72: 1265–1269)

Key Words: Catheterization; Diagnosis; Echocardiography; Valvular diseases

Methods

Patients We enrolled a total of 33 patients (mean age 71±8 years; females 20, males 13) with severe AS by Doppler examination (EOA\text{Dop} ≤ 1.0 cm²), who were referred to the cardiac catheterization laboratory for evaluation of AS. Critical AS is considered to be present when EOA or ELCo is <0.75 cm², severe AS when EOA or ELCo is 0.75–1.0 cm², and moderate AS when EOA or ELCo is >1.0 cm². All patients were in sinus rhythm. We excluded patients with atrial fibrillation, other moderate to severe valvular heart diseases, dialysis and systolic left ventricular (LV) dysfunction (LV ejection fraction <40%). The study protocol was approved by the Ethics Committee of Kawasaki Medical School, and written informed consent was given by all patients.

Table 1 Patients’ Characteristics

<table>
<thead>
<tr>
<th>Group A (n=26)</th>
<th>Group B (n=7)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>71±8</td>
<td>69±6</td>
</tr>
<tr>
<td>Female sex, n (%)</td>
<td>15 (58)</td>
<td>5 (71)</td>
</tr>
<tr>
<td>Body surface area (m²)</td>
<td>1.49±0.18</td>
<td>1.42±0.03</td>
</tr>
<tr>
<td>Hypertension (%)</td>
<td>9 (35)</td>
<td>4 (57)</td>
</tr>
<tr>
<td>Diabetes mellitus (%)</td>
<td>6 (23)</td>
<td>1 (14)</td>
</tr>
<tr>
<td>Hyperlipidemia (%)</td>
<td>6 (23)</td>
<td>1 (14)</td>
</tr>
<tr>
<td>Smoking (%)</td>
<td>2 (8)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Symptoms (dyspnea/angina pectoris/synecope), n (%)</td>
<td>21 (81)</td>
<td>1 (14)</td>
</tr>
</tbody>
</table>

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Cardiac Catheterization

Cardiac catheterization was performed within 10 days of an echocardiographic examination by 2 experienced cardiologists who were unaware of the echocardiographic data. A standard procedure of catheterization was performed via the femoral approach in all patients, including coronary angiography and pressure measurements. The left ventricle was cannulated using a pigtail catheter. When direct crossing of the aortic valve was not possible with the pigtail catheter, a filled pigtail side-hole catheter was used. When direct crossing of the valve was still impossible, a coronary guidewire was inserted across the valve. After advancing a 0.014″ guidewire into the left coronary artery, a 4 Fr Swan-Ganz catheter was advanced into the pulmonary arteries through the guidewire. The pulmonary capillary wedge pressure was also measured.

Echocardiography

All echocardiographic procedures were performed by 3 experienced cardiologists and 2 sonographers. The transvalvular gradients were measured using a continuous wave Doppler technique, and the EOA was computed with the continuity equation, by measuring the area of the LV outflow tract, and the velocity–time integral in the outflow tract and in the vena contracta.6 The diameters of the tubular ascending aorta were recorded in the parasternal long-axis view. In order to correct the EOA for the pressure recovery phenomenon, the ELCo equation was used as previously reported: ELCo = (EOA × aortic cross-sectional area)/(aortic cross-sectional area – EOA Dop).9–11 Study patients were grouped according to the ELCo value: Group A (26 patients with ELCo ≤ 1.0 cm²) and Group B (7 patients with ELCo > 1.0 cm²). Symptoms related to AS (chest pain, syncope, and dyspnea), hemodynamic and echocardiographic data were compared between the 2 groups.

Statistical Methods

Continuous variables are reported as mean±SD. Unpaired Student’s t-test was used to differentiate between 2 sets of data with normal distribution. If normality tests failed, the Mann-Whitney U-test was used. Comparison of the incidence of symptoms and coronary risk factors was performed using Fisher’s exact test. Comparison of each parameter was made using linear regression and the Bland-Altman test. Agreement in the assessment of severity of AS between EOAcath, EOADop, and ELCo was quantified by the intraclass correlation coefficient.13 A p-value < 0.05 was considered statistically significant.

Results

Table 1 shows the characteristics of the 2 groups; age, gender, and coronary risk factors were similar. Patients in Group B had a significantly lower incidence of symptoms related to AS compared with Group A (p=0.002). The results of hemodynamic and echocardiographic investigations are summarized in Table 2. There was no significant difference between the 2 groups for medications (Table 3). Table 4 shows the severity of AS assessed by both cardiac catheterization and echocardiography. As expected, EOA was significantly smaller and the pressure gradient was significantly lower in Group B than in Group A.
greater in Group A than in Group B. There was a significant correlation between EOADop and EOAcath, and the Bland-Altman test showed good agreement between EOADop and EOAcath (mean difference, 0.08±0.19 cm²) (Fig 1). Six of the 33 patients (18%) had EOAcath >1.0 cm². There was a significant correlation between EOAcath and ELCo, and the Bland-Altman test showed good agreement between EOAcath and ELCo (mean difference: 0.02±0.18 cm²) (Fig 2). There was a better 1-to-1 correspondence between EOAcath and ELCo than between EOADop and EOAcath (y=0.94x+0.03 and y=1.19x–0.05, respectively). Seven of the 33 patients (21%) had ELCo >1.0 cm². Superior concordance was demonstrated between EOAcath and ELCo compared with EOAcath and EOADop (igail=0.52, and igil=0.32, respectively) (Fig 3).

**Discussion**

In this study, 6 of 33 patients (18%) with “severe” AS by EOADop had EOAcath >1.0 cm², which was classified as moderate AS by the ACC/AHA guidelines. This discrepancy between EOAcath and EOADop is thought to be related to the pressure recovery phenomenon in ELCo, which can take into account the pressure recovery phenomenon, is proposed as an equivalent index representing EOAcath, and in this study patients with ELCo >1.0 cm² (21%) had a significantly lower incidence of symptoms related to AS and a lower transvalvular aortic gradient. To the best of our knowledge, this is the first evaluation of the clinical impact of ELCo in patients with “severe” AS diagnosed by the continuity equation.

The ACC/AHA guidelines for defining AS severity are mainly based on data obtained from catheter measurements, as well as clinical outcomes in relation to those measurements. The same value for severe AS (<1.0 cm²) was extended to echocardiographic data on the assumption that EOADop and EOAcath were equivalent parameters, and the aforementioned guidelines do not distinguish between catheter and Doppler measurements. However, it has been reported that discrepancies of up to 20% between EOADop...
and EOAcath can occur, depending on the pressure recovery phenomenon. Therefore, measurements made from EOAdop might result in overestimations of the severity of AS compared with EOAcath, affecting clinical management. On the other hand, there is a strong linear correlation between ELCo and EOAcath compared between EOAdop and EOAcath. ELCo might be a more exact assessment of AS severity than EOAdop. In addition, ELCo can be calculated non-invasively from the echocardiogram. Therefore, ELCo might be more appropriate for quantifying AS severity.

The ratio of EO to the ascending aorta cross-sectional area is a major determinant of the pressure recovery phenomenon. For example, patients with EOAdop of 0.9 cm² and ascending aorta diameter <3.39 cm would have an ELCo >1 cm², shifting the patient’s severity from severe to moderate. Similarly, a patient with EOAdop of 0.8 cm² and ascending aorta diameter <2.26 cm would have an ELCo >1 cm². Therefore, in patients with severe AS who have EOAdop of approximately 1.0 cm², the evaluation of ELCo, taking into account pressure recovery, is necessary for the assessment of AS severity.

Kadem et al determined the effect of systemic arterial hypertension, induced by banding the distal thoracic aorta in 14 pigs, on the indices of AS severity, including ELCo. They reported that the changes in systemic arterial hemodynamic properties associated with systemic hypertension could cause a decrease in the mean flow rate and thus an increase in ELCo. In the present study, the ascending aorta maximum pressure was greater in Group B than in Group A, although the difference was not statistically significant, but may have affected the ELCo value in this study. On the other hand, hypotension associated with LV dysfunction could cause a decrease in ELCo. Measuring AS severity by calculating ELCo is recommended/should be performed when the patient is normotensive.

Study Limitations
Pressure recovery was not directly measured by invasive pressure measurement and usage of standard protocols meant that distal pressure measurements were not obtained at sites where pressure had recovered to the fullest extent. Theoretically, the distance required for full pressure recovery depends on the orifice size and aortic diameter. However, previous in vitro studies have shown that most pressure recovery occurs within several centimeters and that differences between wall measurements at 5 cm and central measurements at 10–20 cm downstream from the stenosis are small and clinically irrelevant. The distance for the occurrence of pressure recovery increases with the diameter of the aorta, whereas a large diameter aorta precludes clinically significant pressure recovery. In addition, clinical study suggests that all measurable increase of pressure occurs within the ascending aorta. Therefore, the measurement technique used in this study should reflect pressure recovery to a great extent.

Our study has the inherent limitations of any small, observational series and further large-scale studies are needed to reveal the clinical implications of using ELCo in patients with AS.

Conclusions
In 21% of patients with “severe” AS diagnosed by Doppler echocardiography, the ELCo value indicated moderate rather than severe AS (>1.0 cm²). These patients had a significantly lower incidence of symptoms related to AS than patients who had ELCo ≤1.0 cm². ELCo, which can be calculated non-invasively from the echocardiogram, might be a useful measure for quantifying the severity of AS.

References


