Changes in the subendocardial viability ratio in patients with atherosclerotic coronary heart disease

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Research Article

Keywords: subendocardial viability ratio, atherosclerotic coronary heart disease, coronary angiography, SYNTAX score

Posted Date: November 4th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-2198417/v1

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Abstract

Background

The subendocardial viability ratio (SEVR) is a pulse wave analysis parameter that reflects coronary perfusion noninvasively. Coronary angiography is the gold-standard modality for assessing the involvement of the coronary artery in patients with atherosclerotic coronary heart disease (CHD). Changes in SEVR in patients with CHD have not been elucidated. Therefore, the aim of the present study was to analyze changes in SEVR in patients with atherosclerotic CHD.

Methods

We enrolled 243 patients with atherosclerotic CHD who had visited our hospital from July 1, 2021, to January 30, 2022. Inclusion criteria were: clinical diagnosis of atherosclerotic CHD and availability of the SYNTAX score derived by coronary angiography. The patients were further divided into the control (n = 100), low stenosis (n = 107), and high stenosis (n = 36) groups, with SYNTAX scores of 0, ≤ 22, and > 22, respectively. Pressure waveforms were obtained with a high-fidelity tonometer within the outspread supply route for SEVR calculation before coronary angiography. SEVR was measured and compared among the three groups.

Results

Atherosclerosis-related data, including the ankle–brachial index (ABI), pulse pressure, heart rate (75 beats/min)-corrected aortic augmentation index (Alx@75), brachial–ankle pulse wave velocity (BaPWV), and SEVR, differed significantly among the three groups. SEVR was significantly lower in the high stenosis group (1.02 ± 0.14) than in the control (1.13 ± 0.20) and low stenosis (1.12 ± 0.21) groups (p < 0.05). However, SEVR was lower in the low stenosis group than in the control group, although without statistical significance. In patients with CHD, the SYNTAX score correlated positively with age (r = 0.375, p = 0.001) and Alx@75 (r = 0.226, p = 0.007) and negatively with ABI (r = −0.255, p = 0.002) and SEVR (r = −0.18, p = 0.029).

Conclusions

In this study, the SEVR, ABI, and Alx@75 correlated well with atherosclerotic CHD. A decrease in SEVR measurements represents an increase in coronary artery stenosis.

Thus, SEVR calculation could be used as a noninvasive method for the detection of CHD.

Background
Cardiovascular diseases (CVDs), mainly ischemic heart disease and stroke, are leading causes of mortality and disability worldwide [1]. In China, they were the leading cause of death in 2018, accounting for 46.66% and 43.81% of all deaths in rural and urban areas, respectively. Approximately 330 million people suffer from CVDs, approximately 11.39 million of whom have coronary heart disease (CHD). Further, the incidence of CHD is growing every year [2]. The degree of coronary ischemia should be determined early through noninvasive methods. Currently, our understanding of CHD depends mostly on an anatomical approach undertaken with intrusive angiography [3]. A safe, accurate, reproducible, low-cost, noninvasive test is required to measure the degree of myocardial ischemia that would correlate strongly with the severity of coronary stenosis. Noninvasive detection of myocardial ischemia includes direct detection of coronary stenosis, such as using coronary computed tomography angiography, and indirect detection of the degree and location of myocardial ischemia, such as using the treadmill test, cardiac radionuclide imaging, and cardiac magnetic resonance imaging. Berg et al. defined the term “subendocardial viability ratio” (SEVR) and confirmed the sensitivity of subendocardial cardio myocytes to the balance of myocardial oxygen supply [4]. SEVR reflects cardiac perfusion and coronary microcirculation. It is closely related to the incidence rate and morbidity of cardiovascular events in chronic kidney disease, rheumatoid arthritis, diabetes, and peripheral arterial disease (PAD). For example, low SEVR is associated with impaired coronary flow in patients with hypertension without severe coronary stenosis and predicts various cardiovascular events in patients with non-dialysis chronic kidney disease [5–7]. The degree of decrease in SEVR can predict the severity of lower limb perfusion injury [8]. Arterial stiffness is associated with increased or decreased noninvasive myocardial perfusion in patients with PAD [9]. Women with diabetes have significantly lower SEVR, which is related to cardiovascular risk markers and may contribute to the unfavorable cardiovascular prognosis [10]. Patients with rheumatoid arthritis have lower SEVR compared to healthy individuals. SEVR may be valuable as a predictor of myocardial perfusion in rheumatoid arthritis [11, 12].

The correlation between SEVR and the degree of coronary stenosis has been investigated. SEVR is used to evaluate the coronary reserve capacity and correlates with the severity of coronary stenosis. However, evidence of changes in SEVR is lacking in patients with CHD. The aim of the present experimental study was to investigate the correlation between SEVR and the severity of coronary stenosis based on the anatomy. We calculated SEVR using coronary angiography and divided the cohort into the experimental group comprising patients with coronary stenosis and the control group comprising those without, in order to investigate the use of SEVR in assessing the severity of coronary ischemia.

**Materials And Methods**

**Study Population**

We enrolled 243 patients from June 12 to December 31, 2021, with typical angina pectoris or angina-equivalent symptoms treated at the Department of Cardiology of the Second Affiliated Hospital of Anhui Medical University. Invasive coronary angiography was performed in patients with recurrent symptoms. Obstructive CHD was diagnosed based on coronary computed tomography angiography findings or
objective evidence of inducible ischemia on noninvasive testing. All patients were clinically diagnosed with unstable angina and prepared for elective coronary angiography. The characteristic coronary angiography feature of obstructive CHD was considered to be plaque with > 50% stenosis near the epicardial coronary artery [13].

The participants were classified into the control group without coronary stenosis (n = 100) and CHD group with > 50% coronary stenosis (n = 143). The SYNTAX score using coronary angiography was obtained for patients in the CHD group, and accordingly, the patients were divided into the low (SYNTAX score ≤ 22, n = 107) and high (SYNTAX score > 22, n = 36) stenosis subgroups. Exclusion criteria were acute myocardial infarction, aortic valve stenosis, acute or chronic infectious disease, atrial fibrillation, pregnancy or lactation, known radial or lower extremity artery occlusion, end-stage renal failure, and unsuitability for invasive coronary angiography. Patients’ current medications were continued.

The ethics committee of the Second Affiliated Hospital of Anhui Medical University approved the study protocol (YX2021-039). All patients provided informed consent. The Good Clinical Practice guidelines were followed when conducting the study. Patients’ medical histories were acquired to determine the demographic features.

On the day of hospital admission, medical histories and peripheral systolic and diastolic blood pressures (SBP and DBP, respectively) were obtained. Examinations were performed between 7 and 9 o'clock at night after a minimum of 5–10 min of undisturbed relaxation. Two skilled operators analyzed the pulse waves. Noninvasive tests were performed for atherosclerosis-related indicators, including augmentation and ankle–brachial indices (ABI, BaPWV, PP, Alx, SBP, DBP and HR respectively), and coronary artery-related indicators, including SEVR and the SYNTAX score. Patients underwent biochemical tests for kidney function, blood glucose and lipid levels, and uric acid levels in the urine sample obtained early in the morning after the day of admission.

**Hemodynamic Assessment**

**Atherosclerosis detection**

The automated, noninvasive waveform analysis equipment was used to measure ABI (arteriosclerosis detector, BX-AS-100, Hefei Zhongke Boxie Technology Co., Ltd). For the statistical analysis, the lowest ABI score was employed. BaPWV was determined by calculating the pulse transit time and the range between two points. Pulse waves were recorded using a certified noninvasive arteriosclerosis detector (BX-AS-100, Hefei Zhongke Boxie Technology Co., Ltd.). Sequential electrocardiogram-related recordings of the pulse waves at the brachial and ankle arteries were used to calculate ABI and BaPWV following at least 5 min of rest in the supine position. The conventional mercury sphygmomanometer was used to obtain the brachial blood pressure in the dominant arm as part of the laboratory protocol for consecutive readings. The difference between SBP and DBP was used to calculate the peripheral pulse pressure (PP).
AIx was calculated as the difference between the first and second systolic peaks of the central artery waveform, represented as a percentage of the central PP. In addition, it was adjusted to a standard heart rate of 75 bpm (AIx@75) owing to the strong influence of the heart rate [14].

**Cardiovascular function test**

SEVR, a measure of myocardial oxygen supply and request, was calculated using the pulse wave analysis performed with cardiovascular function test instrument (IIM-CFTI-100, Institute of Intelligent Machines, Hefei, China) as a rate of the diastolic and systolic pressure time indices. Before coronary angiography, pressure waveforms from the radial artery were recorded to calculate SEVR. Lower SEVRs were considered to represent an unfavorable correlation between the myocardial supply and demand [15]. Considering that the physiological SEVR is ≥ 1.3, SEVR < 1.3 was considered to be a reliable predictor of cardiovascular events [6, 16].

**Invasive Coronary Angiography and SYNTAX Score**

Coronary angiography was performed on patients with typical angina pectoris or angina-equivalent symptoms and a clinical diagnosis of CHD or unstable angina. Unstable angina was defined as the absence of myocardial ischemia at rest or during mild exercise [13]. Coronary angiography helps determine whether or not angina is due to myocardial ischemia after coronary stenosis. Depending on the lesion's form and the individual's risk profile, the subsequent treatment for the lesion may involve percutaneous coronary intervention during the same procedure or coronary artery bypass grafting.

The SYNTAX score is a comprehensive, integrated angiographic scoring system, determined by the patient's coronary artery anatomy and lesion characteristics. It is clinically used to grade the severity of anatomic lesions in CHD, with higher scores indicating more complex coronary artery lesions [17]. It quantifies the severity of coronary artery lesions and guides revascularization strategies and predicts the long-term prognosis of patients with left main artery or multiple vessel lesions [18, 19]. A coronary vessel was included in the calculation when its diameter was ≥ 1.5 mm, and the SYNTAX score was calculated when ≥ 50% of the coronary lumen was obstructed, with ≤ 22 points indicating a low score and > 22 points indicating a high score [20].

**Statistical Analysis**

Unless otherwise stated, the results are expressed as mean ± standard deviation. For inter-group comparisons, the one- or two-way analysis of variance was performed, followed by the Bonferroni test for the post-hoc analysis. To evaluate the association between SEVR and the SYNTAX score in patients with CHD, a Pearson's correlation analysis was performed. A p-value < 0.05 was considered to indicate statistical significance.

**Results**

**Basic Characteristics of the Study Population**
Table 1 demonstrates the clinical characteristics of the patients. We enrolled 234 patients, aged 63.37 ± 10.04 (range: 32–84) years. The triglyceride, blood urea nitrogen, or uric acid level (p = 0.315, 0.359, and 0.353, respectively) did not differ among the three groups. Compared to patients without CHD, patients with CHD showed a higher incidence of abnormal clinical indicators, including age (p = 0.001) and cholesterol (p = 0.035), low-density-lipoprotein cholesterol (p = 0.045), high-density-lipoprotein cholesterol (p = 0.002), and creatinine (p = 0.010) levels. The SYNTAX scores were 0, ≤ 22, and > 22 in 100, 107, and 36 patients, respectively.

Table 1
Comparison of basic indicators among the three groups

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Control (n = 100)</th>
<th>Low stenosis (n = 107)</th>
<th>High stenosis (n = 36)</th>
<th>F-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>59.67 ± 10.37</td>
<td>64.60 ± 9.33</td>
<td>70.00 ± 6.28</td>
<td>17.56</td>
<td>0.001</td>
</tr>
<tr>
<td>CHOL (mmol/L)</td>
<td>4.71 ± 1.08</td>
<td>4.31 ± 1.03</td>
<td>4.48 ± 1.23</td>
<td>3.39</td>
<td>0.035</td>
</tr>
<tr>
<td>TG (mmol/L)</td>
<td>1.65 ± 0.96</td>
<td>1.68 ± 1.11</td>
<td>1.40 ± 0.48</td>
<td>1.16</td>
<td>0.315</td>
</tr>
<tr>
<td>LDL-C (mmol/L)</td>
<td>2.83 ± 0.77</td>
<td>2.58 ± 0.76</td>
<td>2.58 ± 0.94</td>
<td>3.88</td>
<td>0.045</td>
</tr>
<tr>
<td>HDL-C (mmol/L)</td>
<td>1.24 ± 0.34</td>
<td>1.11 ± 0.25</td>
<td>1.09 ± 0.13</td>
<td>6.57</td>
<td>0.002</td>
</tr>
<tr>
<td>CRE (µmol/L)</td>
<td>70.66 ± 19.17</td>
<td>76.07 ± 17.72</td>
<td>81.33 ± 22.52</td>
<td>4.68</td>
<td>0.010</td>
</tr>
<tr>
<td>BUN (mmol/L)</td>
<td>5.89 ± 1.91</td>
<td>5.90 ± 1.95</td>
<td>6.41 ± 2.23</td>
<td>1.02</td>
<td>0.359</td>
</tr>
<tr>
<td>UA (µmol/L)</td>
<td>313.30 ± 85.02</td>
<td>332.11 ± 87.06</td>
<td>361.58 ± 97.71</td>
<td>1.04</td>
<td>0.353</td>
</tr>
</tbody>
</table>

CHOL: cholesterol; TG: triacylglycerol; LDL-C: low-density-lipoprotein cholesterol; HDL-C: high-density-lipoprotein cholesterol; CRE: creatinine; BUN: blood urea nitrogen; UA: uric acid. A p-value < 0.05 indicates statistical significance and is expressed in bold font.

Atherosclerosis-Related Data

Table 2 shows the atherosclerosis-related data of the patients. The ABI, BaPWV, PP, Alx@75, or SEVR were significantly different among the three groups (p = 0.001, 0.001, 0.045, 0.018, and 0.016, respectively). Further, the SBP, DBP, or heart rate (p = 0.173, 0.976, and 0.210, respectively) did not differ significantly among the three groups.
Table 2
Comparison of atherosclerosis-related data among the three groups

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Control (n = 100)</th>
<th>Low stenosis (n = 107)</th>
<th>High stenosis (n = 36)</th>
<th>F-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABI</td>
<td>1.22 ± 0.72</td>
<td>1.16 ± 0.99</td>
<td>1.12 ± 0.09</td>
<td>21.56</td>
<td>0.001</td>
</tr>
<tr>
<td>BaPWV (m/s)</td>
<td>14.97 ± 2.43</td>
<td>16.48 ± 3.34</td>
<td>16.55 ± 2.28</td>
<td>8.41</td>
<td>0.001</td>
</tr>
<tr>
<td>PP (mmHg)</td>
<td>52.23 ± 12.34</td>
<td>56.08 ± 12.93</td>
<td>56.83 ± 11.32</td>
<td>3.14</td>
<td>0.045</td>
</tr>
<tr>
<td>Alx@75 (%)</td>
<td>0.80 ± 0.12</td>
<td>0.83 ± 0.13</td>
<td>0.86 ± 0.13</td>
<td>4.090</td>
<td>0.018</td>
</tr>
<tr>
<td>SEVR (%)</td>
<td>1.13 ± 0.20</td>
<td>1.12 ± 0.21</td>
<td>1.02 ± 0.14</td>
<td>4.195</td>
<td>0.016</td>
</tr>
<tr>
<td>SBP (mmHg)</td>
<td>130.50 ± 15.72</td>
<td>134.32 ± 17.79</td>
<td>135.50 ± 18.77</td>
<td>1.76</td>
<td>0.173</td>
</tr>
<tr>
<td>DBP (mmHg)</td>
<td>78.27 ± 10.07</td>
<td>78.24 ± 9.48</td>
<td>78.66 ± 13.36</td>
<td>0.024</td>
<td>0.976</td>
</tr>
<tr>
<td>HR (beats/minute)</td>
<td>71.61 ± 9.54</td>
<td>70.82 ± 10.12</td>
<td>68.25 ± 9.24</td>
<td>1.57</td>
<td>0.210</td>
</tr>
</tbody>
</table>

ABI: ankle–brachial index; BaPWV: brachial–ankle pulse wave velocity; PP: pulse pressure; Alx@75: heart rate-corrected aortic augmentation index; SEVR: subendocardial viability ratio; SBP: systolic blood pressure; DBP: diastolic blood pressure; HR: heart rate. A p-value < 0.05 indicates statistical significance and is expressed in bold font.

Differences in SEVR among the Three Groups

The high stenosis group had a significantly lower SEVR compared to the control and low stenosis groups (1.02 ± 0.14 vs. 1.13 ± 0.20, p = 0.006, and 1.02 ± 0.14 vs. 1.12 ± 0.21, p = 0.009). The low stenosis and control groups did not differ in SEVR (1.12 ± 0.21 vs. 1.13 ± 0.20, p = 0.862). Table 3 and Fig. 1.

Table 3
Comparison of Subendocardial Viability Ratio (SEVR) among the three groups

<table>
<thead>
<tr>
<th></th>
<th>Control (n = 100)</th>
<th>Low stenosis (n = 107)</th>
<th>High stenosis (n = 36)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEVR (%)</td>
<td>1.13 ± 0.20</td>
<td>1.12 ± 0.21</td>
<td>1.02 ± 0.14</td>
<td>0.862</td>
</tr>
<tr>
<td></td>
<td>1.13 ± 0.20</td>
<td></td>
<td>1.02 ± 0.14</td>
<td>0.006</td>
</tr>
<tr>
<td></td>
<td>1.12 ± 0.21</td>
<td>1.02 ± 0.14</td>
<td></td>
<td>0.009</td>
</tr>
</tbody>
</table>

Correlation Analysis of Various Parameters with the SYNTAX Score in Patients with CHD

Table 4 shows the influence of variables associated with the SYNTAX score in patients with CHD after stepwise selection. In patients with CHD, the SYNTAX score correlated positively with age (r = 0.375, p =
0.001, Fig. 2A) and Alx@75 (\( r = 0.226, p = 0.007 \), Fig. 2C) and negatively with ABI \( (r = -0.255, p = 0.002, \) Fig. 2B) and SEVR \( (r = -0.18, p = 0.029, \) Fig. 2D). None of the other parameters correlated with the SYNTAX score.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>CHD (n = 143)</th>
<th>Estimate</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>65.96 ± 8.95</td>
<td>0.375</td>
<td>0.001</td>
</tr>
<tr>
<td>CHOL (mmol/L)</td>
<td>4.35 ± 1.08</td>
<td>0.115</td>
<td>0.171</td>
</tr>
<tr>
<td>TG (mmol/L)</td>
<td>1.61 ± 0.99</td>
<td>-0.126</td>
<td>0.133</td>
</tr>
<tr>
<td>LDL-C (mmol/L)</td>
<td>2.58 ± 0.81</td>
<td>0.032</td>
<td>0.701</td>
</tr>
<tr>
<td>HDL-C (mmol/L)</td>
<td>1.11 ± 0.23</td>
<td>-0.002</td>
<td>0.983</td>
</tr>
<tr>
<td>CRE (µmol/L)</td>
<td>77.39 ± 19.09</td>
<td>0.153</td>
<td>0.068</td>
</tr>
<tr>
<td>BUN (mmol/L)</td>
<td>6.03 ± 2.03</td>
<td>0.131</td>
<td>0.119</td>
</tr>
<tr>
<td>UA (µmol/L)</td>
<td>322.74 ± 92.32</td>
<td>-0.136</td>
<td>0.105</td>
</tr>
<tr>
<td>ABI</td>
<td>1.15 ± 0.09</td>
<td>-0.255</td>
<td>0.002</td>
</tr>
<tr>
<td>BaPWV (m/s)</td>
<td>16.50 ± 3.10</td>
<td>-0.025</td>
<td>0.770</td>
</tr>
<tr>
<td>PP (mmHg)</td>
<td>56.27 ± 12.51</td>
<td>0.051</td>
<td>0.549</td>
</tr>
<tr>
<td>Alx@75 (%)</td>
<td>0.8879 ± 0.1976</td>
<td>0.226</td>
<td>0.007</td>
</tr>
<tr>
<td>SBP (mmHg)</td>
<td>134.62 ± 17.98</td>
<td>0.039</td>
<td>0.642</td>
</tr>
<tr>
<td>DBP (mmHg)</td>
<td>78.34 ± 10.34</td>
<td>0.007</td>
<td>0.935</td>
</tr>
<tr>
<td>HR (beats/minute)</td>
<td>70.17 ± 9.94</td>
<td>-0.107</td>
<td>0.203</td>
</tr>
<tr>
<td>ED (ms)</td>
<td>0.4106 ± 0.0420</td>
<td>-0.021</td>
<td>0.805</td>
</tr>
<tr>
<td>SEVR</td>
<td>1.10 ± 0.20</td>
<td>-0.182</td>
<td>0.029</td>
</tr>
</tbody>
</table>

CHD: coronary heart disease; CHOL: cholesterol; TG: triglycerides; LDL-C: low-density-lipoprotein cholesterol; HDL-C: high-density-lipoprotein cholesterol; CRE: creatinine; BUN: blood urea nitrogen; UA: uric acid; ABI: ankle–brachial index; BaPWV: brachial–ankle pulse wave velocity; PP: pulse pressure; Alx@75: heart rate-corrected augmentation index; SBP: systolic blood pressure; DBP: diastolic blood pressure; HR: heart rate; ED: ejection duration; SEVR: subendocardial viability ratio. A \( p \)-value < 0.05 indicates statistical significance and is expressed in bold font.

**DISCUSSION**

In the present study, atherosclerosis-related data, including ABI, BaPWV, PP, and Alx@75, differed significantly among the three groups. With aggravation of coronary artery stenosis, indicators of
arteriosclerosis included decreased ABI and SEVR and increased BaPWV, PP, and Alx@75. Atherosclerosis is an independent cardiovascular risk factor and a predictor of all-cause cardiovascular mortality in many diseases [21, 22]. The gold-standard noninvasive method to measure central arterial stiffness is the pulse wave velocity test [23, 24]. Currently, age is generally accepted as an independent risk factor for coronary atherosclerosis. Many clinical trials have confirmed the correlation between the aforementioned indicators and CVD. Indicators commonly used to evaluate the degree of atherosclerosis include SBP, PP, Alx@75, ABI, and BaPWV. PP may be a major determinant of small-artery disease, which usually manifests as expanded arterial stiffness. PP and SBP are independent risk factors for CHD. Brachial PP is an independent risk factor for CHD [25, 26]. Alx is an indirect marker of arterial stiffness [27, 28]. Weber et al. found that a higher Alx correlated with a higher risk of CHD [29]. The aortic Alx values were significantly higher in the CHD group than in the control group [30]. The pulse wave velocity is an independent predictor of cardiovascular events after adjusting for risk factors of CHD. However, a recent study has shown that BaPWV predicts total mortality but not CVD incidence [31]. In this study, BaPWV showed an increasing trend with aggravation of coronary artery stenosis but no correlation with the SYNTAX score in patients with CHD. These results suggested that the carotid–femoral pulse wave velocity is better than BaPWV in representing the degree of central atherosclerosis. Our findings were consistent with those of Tritakis et al., whose multivariate analysis showed that decreased coronary flow reserve correlated negatively with Alx [32]. Age-related arterial stiffness is more common in the aorta than in the peripheral arteries [33]. ABI measurements are used in clinical practice to diagnose PAD. An ABI of 0.9 indicates the existence of PAD and is associated with an independent risk of cardiovascular events [34]. In patients with CHD, arteriosclerosis increases the post-systolic load of the left ventricle, resulting in increased oxygen demand. Coronary stenosis diminishes diastolic coronary artery perfusion pressure and oxygen delivery. This imbalance in oxygen supply and demand between the coronary artery and the myocardium leads to subendocardial ischemia. In the present study, ABI was low in patients with CHD and associated with high SYNTAX scores. However, it remained within the normal range and not was not consistent with PAD. Even slight changes in ABI affect the evolution of arteriosclerotic lesions. The ABI, BaPWV, and Alx are arterial stiffness parameters. Therefore, this method may not determine the severity of CAD. Arterial elasticity measures can identify an increased cardiovascular risk; nonetheless, CAD should only be confirmed using additional techniques [35]. Therefore, we used a more representative indicator of coronary ischemia, i.e., SEVR.

SEVR is a noninvasive method to assess myocardial perfusion and the prognostic value of CVD [36]. It is significantly low in patients with zero- and three-vessel CHD[s [37]. In this study, it was lower in the high stenosis group than in the control and low stenosis groups classified according to the SYNTAX score. Further, it was lower in the low stenosis group than in the control group, although without statistical significance. The severity of atherosclerotic CHD lesions correlates with low SEVR. In addition, the link between SEVR and the SYNTAX score persists even after accounting for numerous conventional risk factors of atherosclerosis, including cholesterol and low-density-lipoprotein cholesterol levels, SBP, and the heart rate. Patients with CHD showed a negative correlation between SEVR and the SYNTAX score. Severe coronary stenosis is accompanied by a gradual decrease in SEVR. The coronary arteries are
located in the outer membrane of the heart. As coronary artery stenosis increases, subendocardial myocardial ischemia gradually worsens, and the SEVR decreases proportionally.

The severity of coronary atherosclerosis is inherently linked to age. In patients with more frequent unfavorable cardiovascular events, the low SEVR and ABI and high Alx are mostly linked to the systemic nature of atherosclerosis and the concurrent existence of atherosclerosis in various arterial regions. In this regard, at the time of chest pain consultation, patients with apparently decreased SEVR show a significantly higher chance of coronary stenosis than those with normal SEVR. Significant decline in SEVR is a hallmark of myocardial ischemia. As a preliminary screening method for CHD, SEVR has advantages of accessibility, repeatability, and low cost.

In the present study, even in the participants with normal coronary arteries, SEVR was lower than 1.3, suggesting an association with the presence of other diseases, such as hypertension and diabetes simultaneously. Thus, the presence of comorbidities other than CHD affects SEVR. Further, patients with severe coronary stenosis had lower SEVR, possibly because of more significant subendocardial myocardial ischemia in the presence of severe coronary stenosis. Many clinical tests can represent subendocardial myocardial ischemia, including cardiac magnetic resonance and myocardial nuclear examinations, but they require higher financial and physical costs. This study validates a non-invasive, inexpensive and convenient means of detecting the severity of coronary heart disease.

This study has some limitations. Many clinical tests reveal subendocardial myocardial ischemia, including cardiac magnetic resonance imaging and myocardial nuclear scanning. SEVR is superior to both these tests for noninvasive testing.

**Conclusion**

The results of this study suggested that in patients with typical chest pain and a significant decrease in SEVR measured by noninvasive methods, anatomical coronary stenosis can be considered, and treatment related to CHD can be started as early as possible. SEVR calculation could be used as a noninvasive method for the detection of CHD.

**Abbreviations**

CHD: coronary heart disease; CVDs: cardiovascular diseases; PAD: peripheral arterial disease; CHOL: cholesterol; TG: triacylglycerol; LDL-C: low-density-lipoprotein cholesterol; HDL-C: high-density-lipoprotein cholesterol; CRE: creatinine; BUN: blood urea nitrogen; UA: uric acid. ABI: ankle–brachial index; BaPWV: brachial–ankle pulse wave velocity; PP: pulse pressure; Alx@75: heart rate-corrected aortic augmentation index; SBP: systolic blood pressure; DBP: diastolic blood pressure; HR: heart rate; SEVR: subendocardial viability ratio.

**Declarations**
Ethics Approval and Consent to Participate

This study was complied with the Declaration of Helsinki and approved by the Institutional Ethical Committee of the Second Affiliated Hospital of Anhui Medical University approved the study Protocol (YX2021-039). Participation of patients in this study was entirely voluntary and confidential. Each participant was asked to sign a written informed consent before data collection. All methods were performed in accordance with the relevant guidelines and regulations (Declaration of Helsinki).

Consent for Publication

Not applicable.

Availability of Data and Materials

Data used and analyzed during the current study are available from corresponding author on reasonable request.

Competing Interests

The authors declare that they have no competing interests.

Funding

The present study was supported by The Second Affiliated Hospital of Anhui Medical University - Hefei Institute of Intelligent Machinery, Chinese Academy of Sciences “Joint Research Fund for Prevention and Control of Chronic Diseases”(MBLHJJ202007).

Authors’ Contributions

TTF and BLX conceived the study, ZQY, ZW, QW acquired the data, YT NJZ and MLL methodology, drafting revising the manuscript. TTF performed statistical analyses, drafted and wrote the manuscript. BLX revised the manuscript. All authors read and approved the final manuscript.

Acknowledgements

The authors would like to thank all patients who were volunteered to participate in this study. The authors also would like to thank Institute of Intelligence, Chinese Academy of Sciences for all their help

References


Figures
Figure 1

Comparison of SEVR among the three groups. SEVR: subendocardial viability ratio
Figure 2

Pearson's correlation among age (A), ABI (B), Alx@75 (C), SEVR (D), and SYNTAX score in patients with CHD