Assessment of Aortic Valvular Stenosis from the Aortic Pressure Pulse

By Djavad T. Arani, M.D., and Richard A. Carleton, M.D.

SUMMARY
In a search for an indirect estimate of severity, data from 40 patients with pure aortic stenosis have been analyzed. Calculated aortic valvular areas ranged from 0.5 cm² to 2.4 cm². Both aortic systolic upstroke time and the rate of aortic pressure rise were significantly altered by aortic stenosis; neither permitted reliable estimates of severity of the stenosis. An estimate of arterial compliance, stroke volume divided by pulse pressure, has been used in conjunction with the first derivative of rising aortic pressure to obtain an index of aortic stenosis. This index correlates well with calculated aortic valvular area (r = 0.912) and permits estimates of the severity of aortic stenosis when the left ventricle cannot be entered.

Additional Indexing Words:
Aortic valve area
Arterial pressure
Bundle-branch block
Arterial compliance
Cardiac output
Stroke volume

Severe valvular aortic stenosis is now a surgically correctible lesion; accordingly, it is mandatory to establish the existence and assess the severity of the stenosis preoperatively. The most direct approach to assessment of the aortic valve is retrograde left heart catheterization from a peripheral artery. This, however, is commonly a technically difficult procedure in the face of severe calcific aortic stenosis. The catheter has failed to traverse the aortic valve 31 times in a group of 86 patients with aortic stenosis. An alternative approach, the transseptal technique is easily accomplished but carries a greater risk to the patient. In our series of 70 transseptal procedures, the pericardium has been entered on five occasions, three of which resulted in cardiac tamponade. In one additional case, an uncommon complication occurred in which the transseptal needle broke.

Several efforts have been made in the past to assess the severity of aortic stenosis from the peripheral arterial pressure pulse, and from the central aortic pressure pulse. These analyses have often permitted the detection of aortic stenosis, but none has yielded criteria from which the approximate severity of the aortic stenosis could be assessed. It is the purpose of this report to present an analysis of the central aortic pressure pulse which appears to provide a meaningful estimate of the severity of aortic stenosis as estimated from calculated aortic valvular areas.

Methods
Data from 40 patients with aortic stenosis have been analyzed. The age of the patients varied from 19 to 71 years, with an average of 52 years; four patients were less than 30 years of age. In these four patients, the diagnosis was considered to be congenital heart disease with aortic stenosis. Thirty-six patients were considered to have calcific aortic stenosis of unknown etiology. Thirty-one patients were male. Each patient had the typical murmur of valvular aortic stenosis. Most had palpable, electrocardiographic, and roentgenographic evidence of left ventricular enlargement. All had normal sinus rhythm. None had disease of other valves, and none had detected aortic regurgitation.

From the Section of Cardio-Respiratory Diseases, Division of Medicine, Presbyterian-St. Luke’s Hospital, and the Department of Medicine, University of Illinois College of Medicine, Chicago, Illinois.

Work supported in part by Grant C66-46 from the Chicago Heart Association and in part by Grant HE-09923-01 from the U. S. Public Health Service.
Data also were analyzed from 12 subjects, who were considered to have normal hearts after no cause could be identified for their soft systolic ejection murmurs. None had an aortic valvular pressure gradient.

Right and retrograde left heart catheterizations were performed on each subject. The retrograde arterial catheterizations were performed from the right brachial artery. The catheter could not be passed across the aortic valve in nine patients; left ventricular pressures were obtained by the transseptal route in these patients. Left ventricular and aortic pressures were measured simultaneously in 24 patients. The pressure differential across the aortic valve was measured at the time of a slow continuous withdrawal of the catheter across the aortic valve in 16 patients. Aortic pressures were recorded less than 2 cm above the aortic valve. Brachial arterial pressures were measured with the same catheter approximately 10 cm from the antecubital fossa. Cardiac output was measured by the Fick principle, using methods previously described from this laboratory.7 at the time of measurement of the aortic valve pressure gradient in each patient. The pressures were recorded with equisensitive strain gauges and an optical galvonometer-photographic paper system. This system is critically damped at 18 to 22 cycles per second. The paper speed was 75 mm per second in 18 patients, and 25 mm per second in 22 patients.

Ten cardiac cycles were analyzed for each measurement. The mean pressure gradients were measured with a compensating polar planimeter. Aortic valve areas were calculated by using the standard hydraulic equation as modified by the Gorlins.8 The first derivative of the rising aortic pressure was measured by calculating the slope of a line drawn tangential to the pressure pulse in the segment between the onset of rising pressure and the anacrotic notch.

The pressure response of the arterial tree to changes in volume is a complex phenomenon. The response is modified by the wall characteristics of the arterial tree, by the increment in volume with each heart beat, by the rate of outflow through the systemic capillary bed, by the velocity of blood flow, and, importantly, in aortic stenosis by the rate of arterial tree filling during ventricular systole. One of these important characteristics may be expressed as the compliance of the arterial tree. During ventricular systole, the change in arterial volume approximates the stroke volume and the change in pressure approximates the pulse pressure. Thus, an approximation of arterial tree compliance is represented by the ratio of stroke volume to central pulse pressure. For this reason, an index has been obtained by multiplying the first derivative of the central aortic pressure pulse by this ratio.

The systolic upstroke time was measured between the first and the last instant of increase in aortic systolic pressure. The systolic ejection period was measured from the left ventricular pressure tracing as the time between the instant at which left ventricular pressure reached aortic diastolic pressure, and during its descent, the instant at which it reached the level of the incisura in the aortic pressure.

The significance of the data was tested by means of regression analysis.9

Results

The data obtained are presented in table 1. Three studies were conducted in the presence of left bundle-branch block. This conduction defect within the ventricles has previously been shown to be associated with a reduced rate of central aortic pressure rise in the presence of aortic stenosis.10 The data from these patients has not been included in any statistical analyses.

Analysis of the present data indicates that systolic upstroke time and, less strikingly, systolic ejection period are prolonged by

![Figure 1](https://example.com/figure1.png)

*Figure 1*  
Rate of rise in aortic pressure obtained in 40 patients with aortic stenosis and in 12 individuals with normal hearts. The means and standard deviations are shown.
Table 1
Data from Twelve Normal Individuals and from Forty Patients with Aortic Valvular Stenosis

<table>
<thead>
<tr>
<th>Study no.</th>
<th>Age (yr) &amp; sex</th>
<th>Heart rate (beats/min)</th>
<th>Systolic ejection periods (sec)</th>
<th>Systolic upstroke time (sec)</th>
<th>Aortic pressure (mm Hg)</th>
<th>Stroke volume (ml/beat)</th>
<th>Aorta Brachial artery dp/dt (mm Hg/sec)</th>
<th>Index of stenosis*</th>
<th>Mean aortic gradient (mm Hg)</th>
<th>Aortic valve area (cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>63-158</td>
<td>26 M</td>
<td>74</td>
<td>0.30</td>
<td>0.14</td>
<td>121</td>
<td>86</td>
<td>113</td>
<td>662</td>
<td>1087</td>
<td>2137</td>
</tr>
<tr>
<td>64-220</td>
<td>29 F</td>
<td>60</td>
<td>0.35</td>
<td>0.26</td>
<td>153</td>
<td>91</td>
<td>100</td>
<td>501</td>
<td>1079</td>
<td>806</td>
</tr>
<tr>
<td>64-302</td>
<td>18 M</td>
<td>70</td>
<td>0.30</td>
<td>0.17</td>
<td>131</td>
<td>90</td>
<td>115</td>
<td>738</td>
<td>1430</td>
<td>2069</td>
</tr>
<tr>
<td>64-312</td>
<td>16 F</td>
<td>90</td>
<td>0.28</td>
<td>0.10</td>
<td>103</td>
<td>77</td>
<td>63</td>
<td>461</td>
<td>846</td>
<td>1117</td>
</tr>
<tr>
<td>65-45</td>
<td>8 M</td>
<td>88</td>
<td>0.28</td>
<td>0.16</td>
<td>91</td>
<td>63</td>
<td>43</td>
<td>490</td>
<td>1091</td>
<td>752</td>
</tr>
<tr>
<td>65-85</td>
<td>16 M</td>
<td>88</td>
<td>0.25</td>
<td>0.11</td>
<td>102</td>
<td>78</td>
<td>78</td>
<td>506</td>
<td>643</td>
<td>1644</td>
</tr>
<tr>
<td>65-170</td>
<td>13 F</td>
<td>87</td>
<td>0.25</td>
<td>0.12</td>
<td>107</td>
<td>76</td>
<td>85</td>
<td>508</td>
<td>643</td>
<td>1392</td>
</tr>
<tr>
<td>65-207</td>
<td>11 M</td>
<td>80</td>
<td>0.26</td>
<td>0.17</td>
<td>99</td>
<td>72</td>
<td>112</td>
<td>776</td>
<td>1556</td>
<td>3218</td>
</tr>
<tr>
<td>66-24</td>
<td>23 M</td>
<td>79</td>
<td>0.25</td>
<td>0.14</td>
<td>134</td>
<td>98</td>
<td>88</td>
<td>659</td>
<td>865</td>
<td>1610</td>
</tr>
<tr>
<td>66-189</td>
<td>14 M</td>
<td>72</td>
<td>0.29</td>
<td>0.16</td>
<td>106</td>
<td>67</td>
<td>123</td>
<td>762</td>
<td>2286</td>
<td></td>
</tr>
<tr>
<td>66-224</td>
<td>17 M</td>
<td>60</td>
<td>0.28</td>
<td>0.12</td>
<td>121</td>
<td>80</td>
<td>120</td>
<td>708</td>
<td>852</td>
<td>2071</td>
</tr>
<tr>
<td>66-231</td>
<td>31 F</td>
<td>87</td>
<td>0.26</td>
<td>0.18</td>
<td>111</td>
<td>81</td>
<td>62</td>
<td>517</td>
<td>1013</td>
<td>1068</td>
</tr>
<tr>
<td>62-223</td>
<td>62 F</td>
<td>113</td>
<td>0.20</td>
<td>0.18</td>
<td>133</td>
<td>79</td>
<td>27</td>
<td>328</td>
<td>164</td>
<td>43</td>
</tr>
<tr>
<td>62-317</td>
<td>43 M</td>
<td>70</td>
<td>0.33</td>
<td>0.26</td>
<td>116</td>
<td>67</td>
<td>108</td>
<td>185</td>
<td>407</td>
<td>61</td>
</tr>
<tr>
<td>63-27</td>
<td>29 M</td>
<td>95</td>
<td>0.30</td>
<td>0.29</td>
<td>129</td>
<td>73</td>
<td>58</td>
<td>222</td>
<td>230</td>
<td>74</td>
</tr>
<tr>
<td>63-36</td>
<td>46 M</td>
<td>84</td>
<td>0.28</td>
<td>0.24</td>
<td>148</td>
<td>76</td>
<td>55</td>
<td>311</td>
<td>493</td>
<td>237</td>
</tr>
<tr>
<td>63-185</td>
<td>59 M</td>
<td>68</td>
<td>0.31</td>
<td>0.29</td>
<td>85</td>
<td>48</td>
<td>56</td>
<td>277</td>
<td>419</td>
<td>60</td>
</tr>
<tr>
<td>63-254</td>
<td>50 M</td>
<td>73</td>
<td>0.31</td>
<td>0.28</td>
<td>78</td>
<td>55</td>
<td>76</td>
<td>101</td>
<td>334</td>
<td>50</td>
</tr>
<tr>
<td>63-274</td>
<td>62 M</td>
<td>66</td>
<td>0.30</td>
<td>0.28</td>
<td>141</td>
<td>74</td>
<td>66</td>
<td>238</td>
<td>234</td>
<td>69</td>
</tr>
<tr>
<td>63-278</td>
<td>50 M</td>
<td>78</td>
<td>0.33</td>
<td>0.30</td>
<td>98</td>
<td>68</td>
<td>80</td>
<td>116</td>
<td>286</td>
<td>309</td>
</tr>
<tr>
<td>63-348</td>
<td>51 F</td>
<td>86</td>
<td>0.24</td>
<td>0.18</td>
<td>105</td>
<td>54</td>
<td>88</td>
<td>393</td>
<td>1080</td>
<td>678</td>
</tr>
<tr>
<td>63-407</td>
<td>63 M</td>
<td>74</td>
<td>0.32</td>
<td>0.28</td>
<td>121</td>
<td>65</td>
<td>58</td>
<td>260</td>
<td>410</td>
<td>269</td>
</tr>
<tr>
<td>64-5</td>
<td>26 F</td>
<td>100</td>
<td>0.24</td>
<td>0.19</td>
<td>117</td>
<td>76</td>
<td>49</td>
<td>477</td>
<td>490</td>
<td>570</td>
</tr>
<tr>
<td>64-20</td>
<td>59 M</td>
<td>83</td>
<td>0.24</td>
<td>0.22</td>
<td>130</td>
<td>93</td>
<td>49</td>
<td>206</td>
<td>510</td>
<td>273</td>
</tr>
<tr>
<td>64-48</td>
<td>55 M</td>
<td>72</td>
<td>0.27</td>
<td>0.24</td>
<td>150</td>
<td>87</td>
<td>72</td>
<td>332</td>
<td>590</td>
<td>379</td>
</tr>
<tr>
<td>64-169</td>
<td>61 M</td>
<td>84</td>
<td>0.24</td>
<td>0.23</td>
<td>142</td>
<td>78</td>
<td>48</td>
<td>397</td>
<td>510</td>
<td>298</td>
</tr>
<tr>
<td>64-272</td>
<td>58 M</td>
<td>60</td>
<td>0.31</td>
<td>0.26</td>
<td>124</td>
<td>60</td>
<td>83</td>
<td>464</td>
<td>160</td>
<td>601</td>
</tr>
<tr>
<td>64-300</td>
<td>58 M</td>
<td>78</td>
<td>0.33</td>
<td>0.27</td>
<td>95</td>
<td>55</td>
<td>76</td>
<td>150</td>
<td>253</td>
<td>285</td>
</tr>
<tr>
<td>64-304</td>
<td>66 F</td>
<td>48</td>
<td>0.37</td>
<td>0.30</td>
<td>112</td>
<td>52</td>
<td>83</td>
<td>270</td>
<td>373</td>
<td>373</td>
</tr>
<tr>
<td>65-23</td>
<td>54 M</td>
<td>90</td>
<td>0.31</td>
<td>0.30</td>
<td>94</td>
<td>61</td>
<td>77</td>
<td>138</td>
<td>322</td>
<td>114</td>
</tr>
<tr>
<td>65-98</td>
<td>47 M</td>
<td>50</td>
<td>0.38</td>
<td>0.31</td>
<td>153</td>
<td>64</td>
<td>74</td>
<td>315</td>
<td>261</td>
<td>122</td>
</tr>
<tr>
<td>65-194</td>
<td>39 M</td>
<td>84</td>
<td>0.26</td>
<td>0.23</td>
<td>123</td>
<td>83</td>
<td>78</td>
<td>440</td>
<td>860</td>
<td>23</td>
</tr>
<tr>
<td>65-208</td>
<td>60 M</td>
<td>99</td>
<td>0.28</td>
<td>0.23</td>
<td>99</td>
<td>67</td>
<td>35</td>
<td>253</td>
<td>484</td>
<td>275</td>
</tr>
<tr>
<td>65-215</td>
<td>58 M</td>
<td>72</td>
<td>0.30</td>
<td>0.23</td>
<td>112</td>
<td>66</td>
<td>37</td>
<td>212</td>
<td>443</td>
<td>170</td>
</tr>
<tr>
<td>65-248</td>
<td>50 M</td>
<td>66</td>
<td>0.34</td>
<td>0.28</td>
<td>117</td>
<td>58</td>
<td>77</td>
<td>262</td>
<td>360</td>
<td>342</td>
</tr>
</tbody>
</table>
AORTIC VALVULAR STENOSIS

severe aortic stenosis. However, the relationship does not yield any meaningful index of the severity of aortic stenosis. The position of the anacrotic notch on the arterial upstroke also failed to provide useful information concerning the severity of aortic stenosis.

The first derivative of aortic pressure (dp/dt) is slowed by aortic stenosis. However, the range of aortic dp/dt in patients with aortic stenosis is large and, as is shown in figure 1, overlaps the range encountered in individuals without aortic stenosis. The mean and standard error of the aortic dp/dt in the patients with aortic stenosis (316 ± 20.5 mm Hg) were significantly different from the mean value and se obtained from the normal subjects (582 ± 28.3 mm Hg). However, the variability in aortic dp/dt is large, even in patients with severe (arbitrarily taken as calculated valve areas of less than 1.0 cm²) aortic stenosis. The relationship between calculated aortic valve area and aortic dp/dt in these 40 patients is displayed in figure 2. Although aortic dp/dt usually permits the detection of aortic stenosis, it is evident that no meaningful prediction of severity can be made.

![Figure 2](http://circ.ahajournals.org/)

First derivative of rising aortic pressure plotted against calculated aortic valvular area, demonstrating the wide variability of dp/dt for any range of valve area. The three studies conducted in the presence of left bundle-branch block are indicated by open circles.
The brachial arterial pressure pulse has also been analyzed for its diagnostic value in 21 of these patients with aortic stenosis. The expected pulse contour transformation occurred in each case with transmission from the aorta to the brachial arteries. As was the case with aortic pressure, however, no measure of severity of aortic stenosis could be found.

Two examples of patients with severe aortic stenosis serve to demonstrate the effect of correcting aortic dp/dt for arterial tree compliance. Patient 63-278 had a large stroke volume, a narrow central pulse pressure, and nearly the slowest rate of aortic pressure rise. Correction for this unusual degree of arterial compliance brought the dp/dt from 116 to a modified value of 309. Conversely, patient 66-330 had a wide central pulse pressure, a slow stroke volume, and an unusually high rate of pressure rise. Correction for arterial stiffness brought the modified dp/dt to 348.

The values for the index of aortic stenosis (aortic dp/dt times stroke volume divided by aortic pulse pressure) are plotted as modified dp/dt against calculated aortic valve areas in figure 3. This relationship has a regression coefficient of +0.912. The regression line and the 95% confidence limits for the prediction of calculated aortic valve area from the modified aortic dp/dt are shown. A value for modified aortic dp/dt of less than 500 permits a conclusion that aortic valve area is less than 1.45 cm². Conversely, a value greater than 700 makes it highly unlikely that severe stenosis is present.

**Discussion**

Aortic valvular stenosis produces unique changes in the aortic pressure pulse. The detailed studies of Katz and associates of acutely induced aortic stenosis in dogs indicate that the aortic pressure is predictably modified. Their data demonstrate that the systolic ejection time, the position of the anacrotic vibration, or the rate of aortic pressure rise permits estimates of the degree of stenosis, but only when the comparison is conducted within the same animal.

The experience with aortic stenosis in man indicates a wide diversity of aortic pressure parameters for any degree of stenosis. Thus, Raber and Goldberg found no quantitatively useful information in the position of the anacrotic notch. Goldberg and co-workers and Hancock and Abelmann found that aortic stenosis could usually be detected from the systolic upstroke time, but that wide variation existed among patients. Similar results were found with the systolic ejection period by Hancock and Fleming.4 Mason and his co-workers studied the first derivative of the brachial arterial pressure in valvular aortic stenosis. Their data indicate that the diagnosis could usually be affirmed but that there was poor correlation with the severity of the stenosis.

The present study affirms that statistically significant differences exist between normal individuals and those with aortic stenosis in aortic upstroke time and in the first derivative of aortic pressure. Moreover, even after the distortion of the pressure pulse during transmission to peripheral arteries, the rate

---

*Figure 3*

The index derived from aortic dp/dt, stroke volume, and central pulse pressure (modified aortic dp/dt) is plotted against calculated aortic valve area. The least squares regression line (solid) and 95% confidence limits (dashed) are shown. The regression line for prediction of y from x is: \( y = 0.33225 + 0.001544 \times \).
of pressure rise affords a valid means of detecting aortic stenosis. However, none of these measures permits reliable assessment of the degree of stenosis.

The presence of an unusually elastic or inelastic arterial system would be expected to modify the aortic systolic pressure response to the stroke volume. Correspondingly, it has proved advantageous to adjust the rate of aortic pressure rise by an estimate of arterial tree compliance. This change produces a parameter from which the approximate aortic valve area can be predicted in the patients whose left ventricle has not been entered.

References
