Letters to the Editor

Velocity Criterion for the Onset of Vascular Murmurs

It has been shown in an interesting paper by Sacks et al. (Circ Res 29:249-256, 1971) that vascular murmurs produced in the region distal to an orifice plate implanted into the aorta of a dog occur only during systole. Furthermore, these authors found that the onset of these broad-frequency band sounds was characterized by a critical Reynolds number which decreased with increasing stenosis and which, in most instances, was well below the value of 2,000 normally associated with turbulence in unconstricted tubes. These results, together with those obtained by Chungcharoen (Am J Physiol 207:190-194, 1964) in a related study on Korotkoff sounds downstream from an externally applied pressure cuff in the carotid artery of a dog, suggest that the origin of these murmurs is pressure fluctuations existing within a turbulent region immediately distal to the stenosis and that this turbulent region is produced by the disintegration (at sufficiently high velocities) of a fluid jet formed at the constriction. It is our purpose in this letter to show that these experimental results, together with some of our own observations on flow noise in nonpulsating flow through flexible tubing with a localized constriction, are consistent with such a hydrodynamic instability mechanism and that the major criterion for the onset of vascular murmurs is the velocity existing within the stenosis. Constriction geometry, fluid viscosity, and flow conditions play only a secondary role.

An incompressible viscous flow through a constriction will generally separate immediately downstream from the constriction. Such a separation will occur at very low Reynolds numbers when the expansion in cross-sectional area distal to the constriction is rapid as is the case for a stenosis produced by the application of an external pressure cuff to an artery. Once separation has occurred, a fluid jet will be formed which has the approximate velocity and cross-sectional area existing within the narrowest portion of the constriction. As shown by Michalke and Schade (Ing Arch 33:1-23, 1963), such jets are hydrodynamically unstable to inviscid axisymmetric disturbances of the Kelvin-Helmholtz type, having an instability growth rate directly proportional to the jet velocity. As a result of this instability, the jet will disintegrate into a turbulent flow at sufficiently high velocities. It is the velocity and the pressure fluctuations in the resultant turbulent region which are responsible for the vascular murmurs detected by Sacks et al.

We have taken the experimental data of Chungcharoen and of Sacks et al. and calculated the critical velocity within the stenosis at the onset of vascular murmurs for different inner arterial diameters and different area ratios between the constricted and the unconstricted cross sections. The results are recorded in Table 1 together with some of our own observations on the onset of flow noise in polyvinyl chloride (Tygon) tubing locally constricted by sandwiching the tubing between two 5.5-cm parallel plates. In our experiments the working fluid was water, the flow was nonpulsating, and the onset of murmurs was detected by placing a stethoscope onto the tubing directly downstream from the constriction. The critical velocities shown on Table 1 are all approximately 100 cm/sec regardless of the area ratio, the fluid used, or the

<table>
<thead>
<tr>
<th>Flow conditions</th>
<th>Unconstricted diameter (cm)</th>
<th>Area ratio</th>
<th>Critical velocity (cm/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulsating blood flow through carotid artery; external pressure cuff (Chungcharoen, 1964)</td>
<td>0.30</td>
<td>0.19</td>
<td>112</td>
</tr>
<tr>
<td></td>
<td>0.28</td>
<td>0.20</td>
<td>134</td>
</tr>
<tr>
<td></td>
<td>0.25</td>
<td>0.26</td>
<td>55</td>
</tr>
<tr>
<td></td>
<td>0.21</td>
<td>0.28</td>
<td>118</td>
</tr>
<tr>
<td>Pulsating blood flow through aorta; implanted orifice plate (Sacks et al., 1971)</td>
<td>1.00</td>
<td>0.04-0.8</td>
<td>95*</td>
</tr>
<tr>
<td>Nonpulsating water flow through Tygon tubing; external pressure plates (present investigation)</td>
<td>0.98</td>
<td>0.1-0.6</td>
<td>73</td>
</tr>
<tr>
<td></td>
<td>0.67</td>
<td>0.05-0.6</td>
<td>95</td>
</tr>
<tr>
<td></td>
<td>0.32</td>
<td>0.1-0.6</td>
<td>122</td>
</tr>
<tr>
<td></td>
<td>0.19</td>
<td>0.30</td>
<td>115</td>
</tr>
</tbody>
</table>

*Based on kinematic viscosity of 0.04 cm²/sec.
pulsating or nonpulsating character of the flow. Such a result is consistent with the jet instability mechanism described above, since the instability growth rate is not a function of viscosity and since the jet cross section does not depend on the constriction geometry once separation has occurred. The critical velocity for the onset of vascular murmurs is essentially the same under pulsating and nonpulsating flow conditions: we believe that this phenomenon is due to the fact that the instability growth rate is several orders of magnitude larger than the pulse frequency. No flow noise was detected in our experiments for area ratios approaching unity even at Reynolds numbers as high as 5,000, because no fluid jet was formed under these conditions.

The preceding results clearly show that the major criterion for the onset of vascular murmurs is the critical velocity existing within the constriction. For velocities less than this critical value of approximately 100 cm/sec (as would be the case during the diastolic portion of the cardiac cycle), no sounds will be heard; however, for values greater than this critical value, vascular murmurs are readily detected. It is suggested that this velocity criterion can be used in conjunction with ultrasonic flowmeter measurements of the velocity in unconstricted arteries to determine the degree of stenosis existing locally within an artery.

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REPLY TO THE ABOVE LETTER

In my opinion, Dr. Kurzweg's thesis that instability of the jet through a stenosis is determined only by velocity in the jet is not borne out by either theory or experiment. On purely dimensional grounds, it does not seem reasonable that, in a problem involving two characteristic lengths, instability should depend only on a single quantity having the dimensions of a velocity. Furthermore, since Dr. Kurzweg's table lumps results from a wide range of area ratios without specifying any standard deviation or giving specific individual values for each experiment, it is difficult to accept these data as proof of his stated hypothesis. For example, the value of 95 cm/sec given in that table for our data is evidently based on the incorrect assumption of a constant vessel diameter of 1.00 cm. Actual calculation of the suggested critical velocity from our own data on 50 dogs shows a nearly linear dependence on orifice diameter. It appears that Dr. Kurzweg's reasoning is based on two-dimensional inviscid stability theory (which involves no characteristic length), and his experiments using two parallel plates tend to represent that case better than the real problem. The fact that Dr. Kurzweg failed to detect any sounds even at high Reynolds numbers for area ratios near unity is not surprising in view of his use of an external microphone.

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