Blunt Traumatic Aortic Rupture and the Aortic Response to High Speed Impact

MARK COHEN AND LYES KADEM
Blunt Traumatic Aortic Rupture (BTAR)

- In North America, approximately 19% of all auto accident fatalities are caused by BTAR.

- Second in fatalities only to Cranial Trauma, BTAR is a condition characterized by the rupture of the aorta and subsequent internal haemorrhaging due to high-speed impacts.

- Due to the difficulty in diagnosing this condition, patients who have been in auto accidents and who seem otherwise healthy, may die days after the fact.

- While the general cause for BTAR is understood to be high-speed impact, the physiological causes are scarcely understood due to the clinical and ethical constraints of human testing for such a condition.

- As such, we have no definitive answer to the mechanism of action of BTAR, though we do have a few theories.
  - Aortic Stretching
  - Shearing and Bending stresses due to aortic flexing over the pulmonary artery.
  - Aortic “water hammer” effect
  - Osseous Pinch

Source: Branchereau and Jacobs, Vascular Emergencies
OSCAR

- Hoses
- Festooning
- Water Reservoir
- Water Pump
- Inlet
- Outlet
- Aorta
- OSCAR
The System

Signal generation and acquisition using LabView

3D Printed Rib Cage

Aorta with Pressure Probe
Test Parameters

- **Pulsatile Flow – Normal Pressure** (120/80 mmHg)
- **Pulsatile Flow – High Pressure** (160/120 mmHg)
- **Pulsatile Flow – Low Pressure** (90/50 mmHg)
- **Continuous Flow – Normal Pressure** (115 mmHg)
- **No Flow** (gauge pressure 0 mmHg)
Test Procedure
A similar acceleration profile was observed for all tests (±2g).
Results – Pressure Probe in the Descending Aorta

- The waveform shows a pressure spike to 250 mmHg at the moment of impact, and then a return to normal after approximately 4 seconds.
Results – Pressure Probe in the Ascending Aorta

- The waveform shows a pressure spike to 326.34 mmHg at the moment of impact, and then a return to normal after approximately 4 seconds.

![Normal Pressure Waveform - Peak at Diastole](image)

- Maximum Pressure: 326.34 mmHg
- Average Pressure Between 2nd and 3rd Peaks: 150.53 mmHg
Results – Pressure Comparison

Comparison of Pressure Waveforms – Impact at Diastole

- Normal Pressure Profile
- High Pressure Profile
- Low Pressure Profile
The results below show the maximum pressure at impact, and the difference between the maximum pressure at impact and the steady state values for systolic/diastolic pressure.

<table>
<thead>
<tr>
<th>Test</th>
<th>Max Pressure</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>Max-S.S. Systole Mean</th>
<th>Std. Dev.</th>
<th>Max-S.S. Diastole Mean</th>
<th>Std. Dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal Pressure - Impact at Diastole</td>
<td>326</td>
<td>312</td>
<td>24</td>
<td>196</td>
<td>183</td>
<td>266</td>
<td>233</td>
</tr>
<tr>
<td>Normal Pressure - Impact at Systole</td>
<td>298</td>
<td></td>
<td></td>
<td>175</td>
<td>15</td>
<td>224</td>
<td>21</td>
</tr>
<tr>
<td>High Pressure - Impact at Diastole</td>
<td>334</td>
<td></td>
<td></td>
<td>168</td>
<td></td>
<td>216</td>
<td></td>
</tr>
<tr>
<td>High Pressure - Impact at Systole</td>
<td>336</td>
<td></td>
<td></td>
<td>170</td>
<td></td>
<td>217</td>
<td></td>
</tr>
<tr>
<td>Low Pressure - Impact at Diastole</td>
<td>274</td>
<td></td>
<td></td>
<td>182</td>
<td></td>
<td>224</td>
<td></td>
</tr>
<tr>
<td>Low Pressure - Impact at Systole</td>
<td>304</td>
<td></td>
<td></td>
<td>206</td>
<td></td>
<td>252</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Test</th>
<th>Max Pressure</th>
<th>Max-Avg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous Flow - 115mmHg</td>
<td>310</td>
<td>195</td>
</tr>
<tr>
<td>No Flow</td>
<td>217</td>
<td>217</td>
</tr>
</tbody>
</table>
Results – No Flow vs. Normal Flow Peaks

<table>
<thead>
<tr>
<th>Test</th>
<th>Impact Peak</th>
<th>Secondary Peak</th>
<th>Tertiary Peak</th>
<th>Mean</th>
<th>Std. Dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>326</td>
<td>181</td>
<td>190</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No Flow</td>
<td>217</td>
<td>74</td>
<td>88</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Δ(Normal-No Flow)</td>
<td>109</td>
<td>107</td>
<td>102</td>
<td>106</td>
<td>3.73</td>
</tr>
</tbody>
</table>

Max Pressure (no flow): 217.10 mmHg
Max Pressure (normal): 326.34 mmHg
Normal Pressure Waveform - Impact at Diastole
Discussion

- Pressure Loss During Acceleration Phase
- Change in Hydrostatic Pressure and Convective Acceleration
- Pressure Differential Due to Aortic Volume
- Peak at High Pressure

A Wiggers diagram, showing the cardiac cycle events occurring in the left side of the heart. (Wikipedia)
What’s Next?

- Continued Testing to Have a Larger Sample Size
- Particle Image Velocimetry
  - Straight Tube Aortae
    - Modification to Allow for Different Aorta Placements
  - Deformation Measurements
Thank You