Université Concordia University

Laboratory Cardiovascular Fluid Dynamics (LCFD)

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

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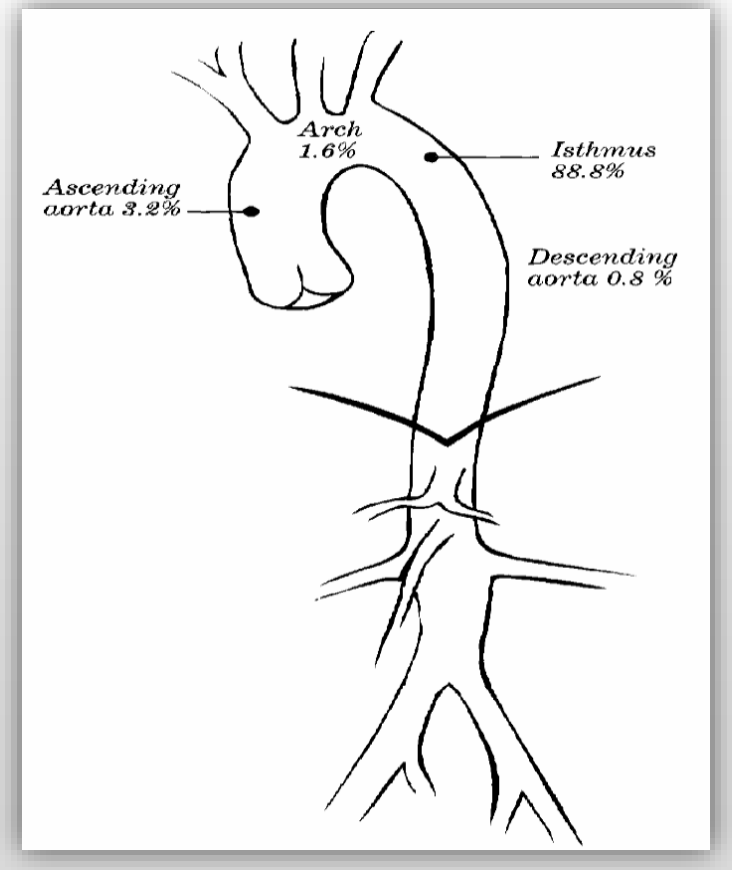
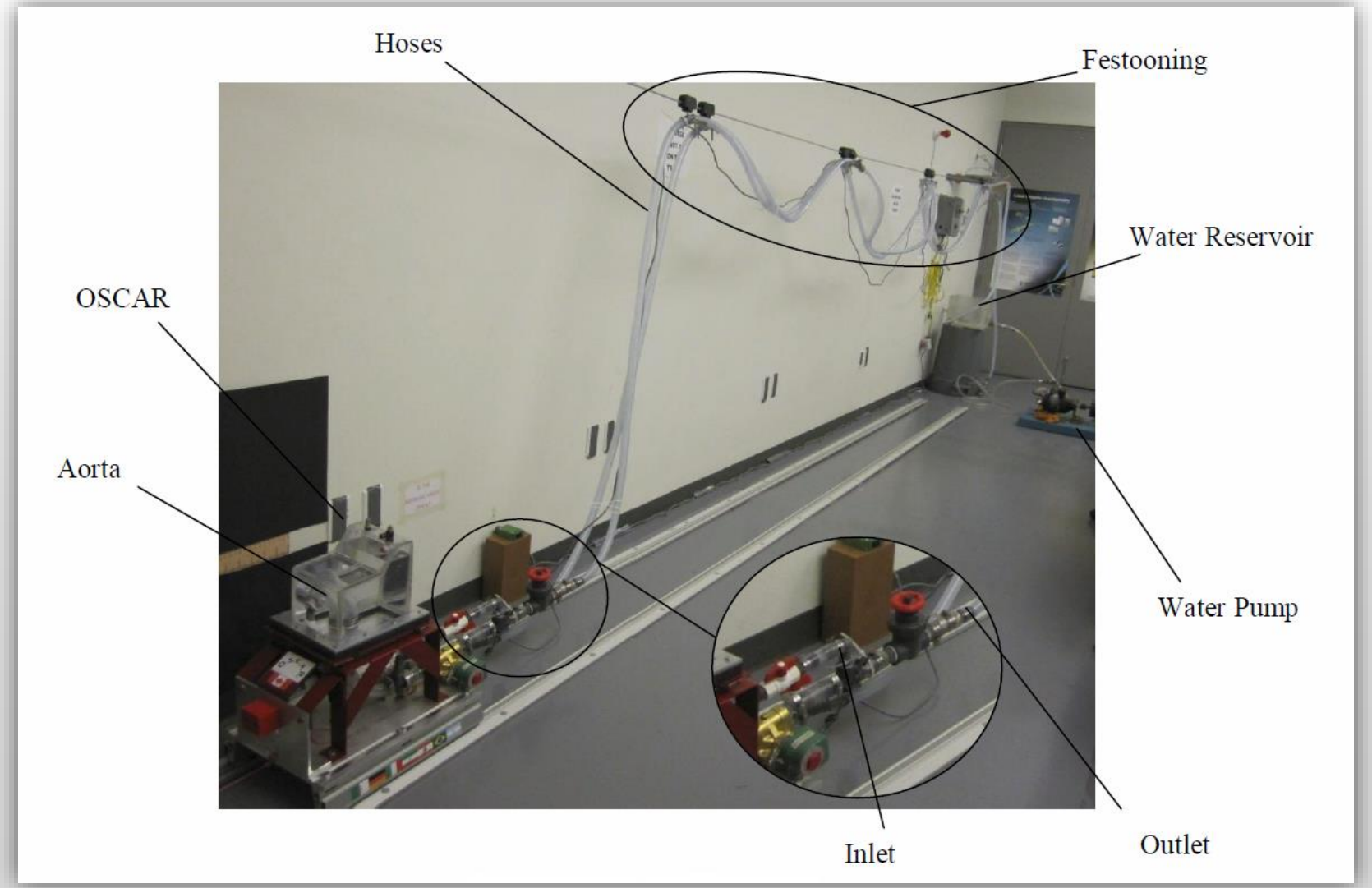
Blunt Traumatic Aortic Rupture (BTAR)

- 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



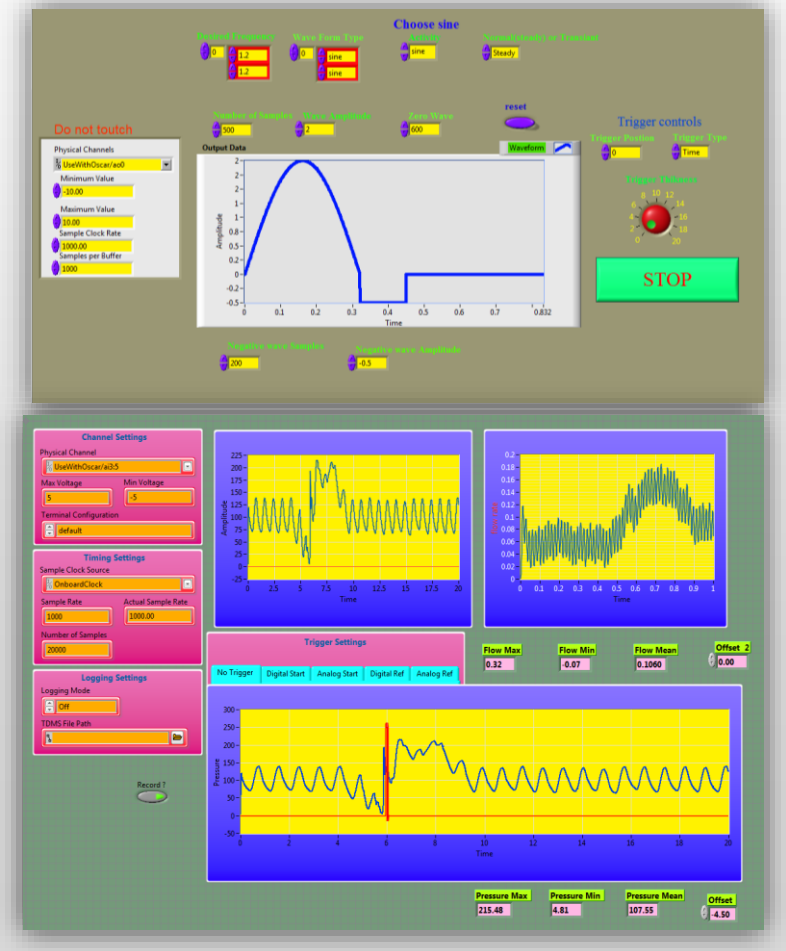
Source: Branchereau and Jacobs, Vascular Emergencies

OSCAR


Hoses
Festooning
Water Reservoir
OSCAR
Aorta
Water Pump
Inlet
Outlet

The System

Signal generation and acquisition using LabView

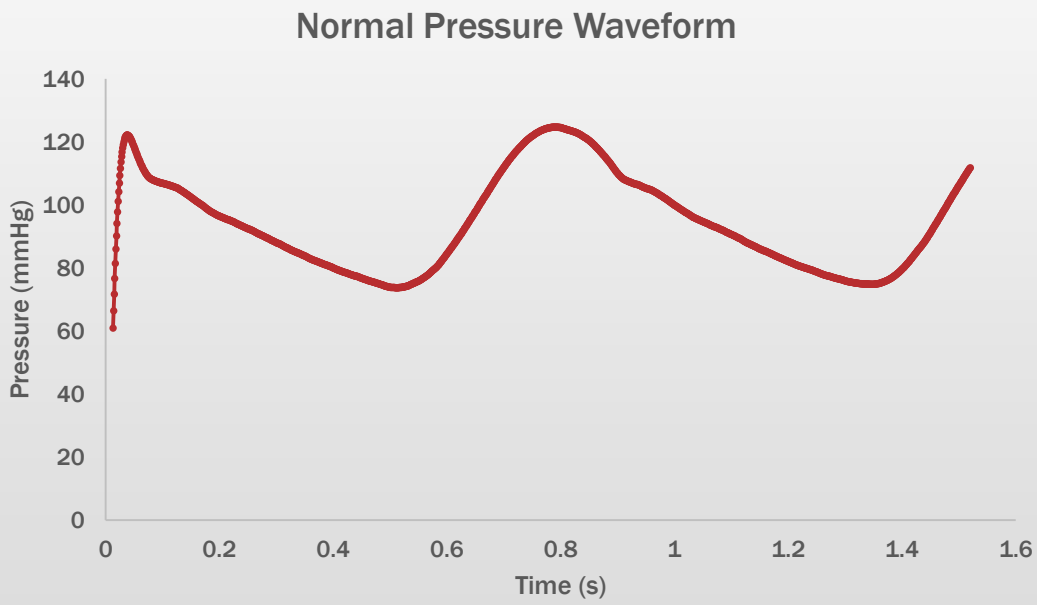


3D Printed Rib Cage

Aorta with Pressure Probe

Test Parameters

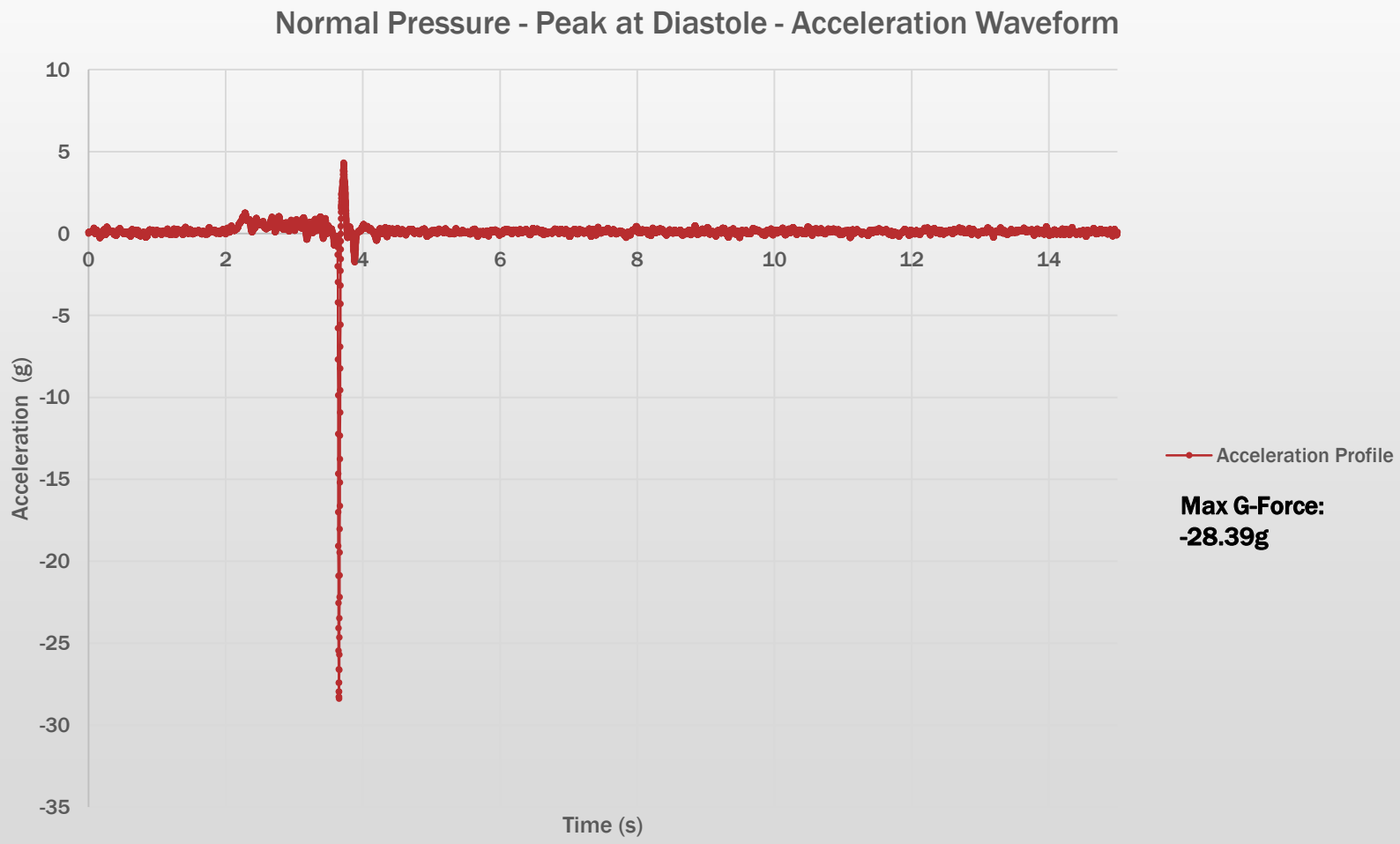
- Pulsatile Flow – Normal Pressure (120/80 mmHg)
- Pulsatile Flow – High Pressure (160/120 mmHg)
- Pulsatile Flow – Low Pressure (90/50 mmHg)
- Continuous Flow – Normal Pressure (115 mmHg)
- No Flow (gauge pressure 0 mmHg)



Test Procedure

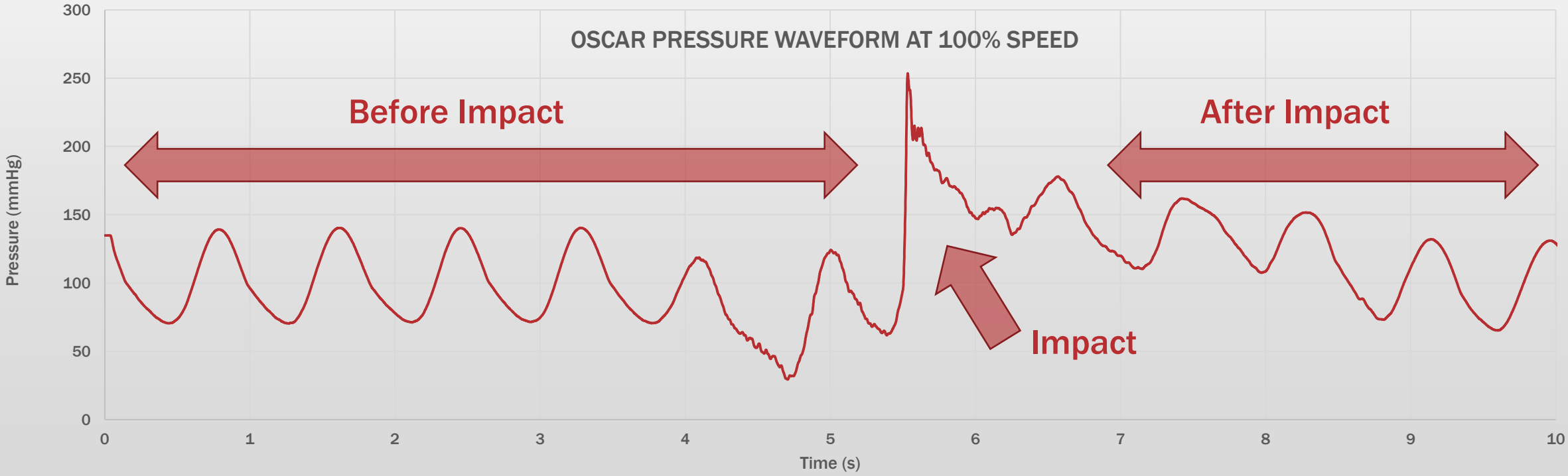
Acceleration Profile

A similar acceleration profile was observed for all tests (±2g).



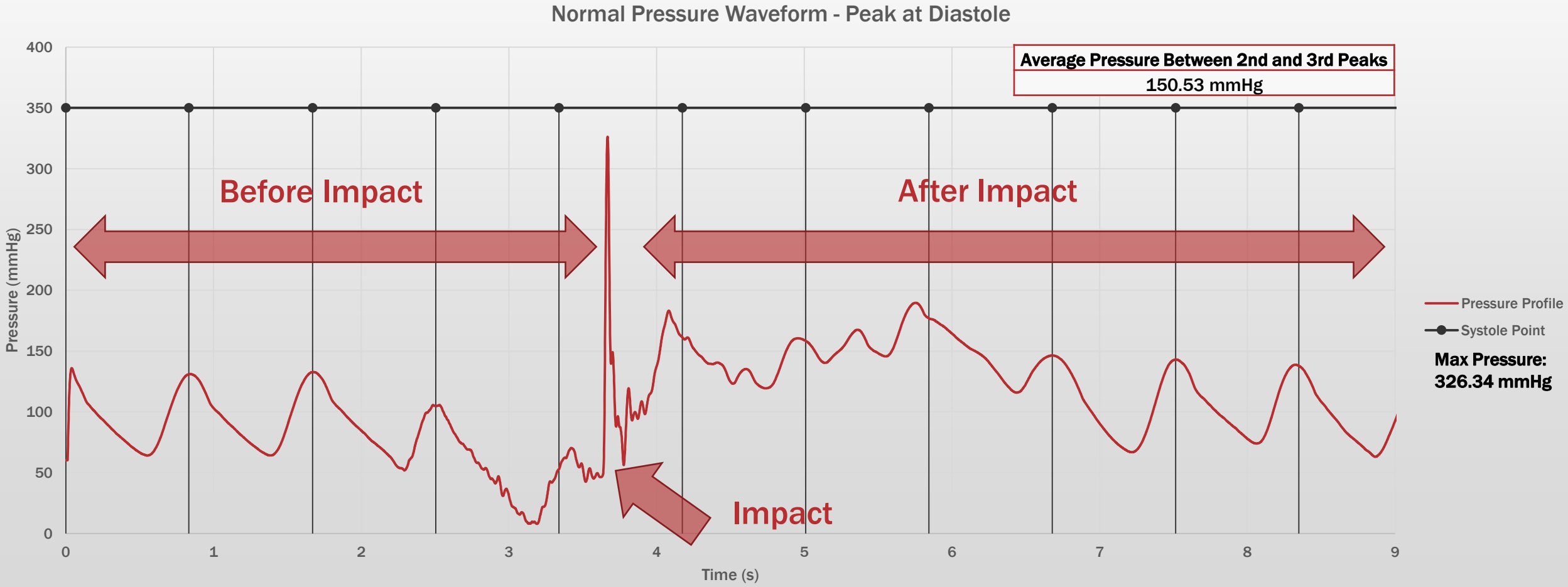
Results – Pressure Probe in the Descending Aorta

- The waveform shows a pressure spike to 250 mmHg at the moment of impact, and then a return to normal after approximately 4 seconds.

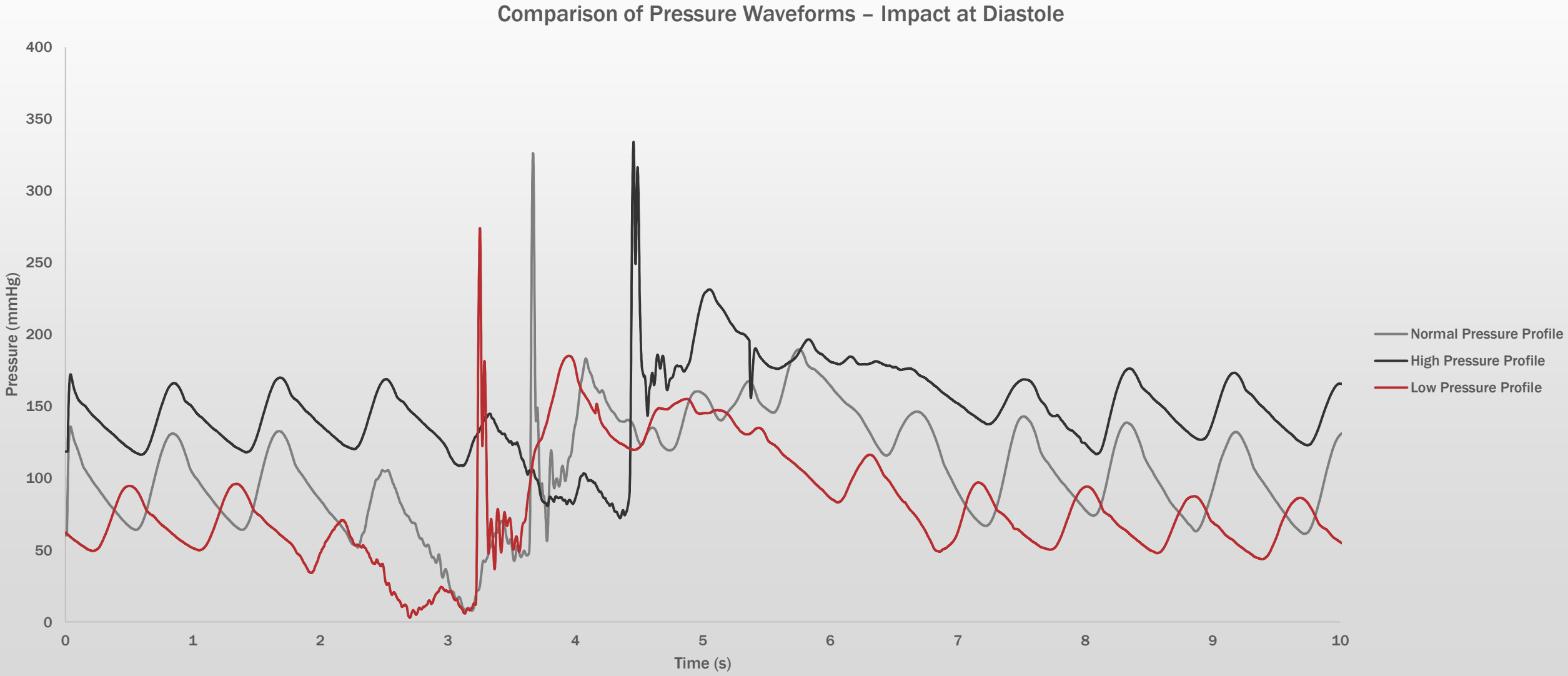


Results – Pressure Probe in the Ascending Aorta

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



Results – Pressure Comparison



Results

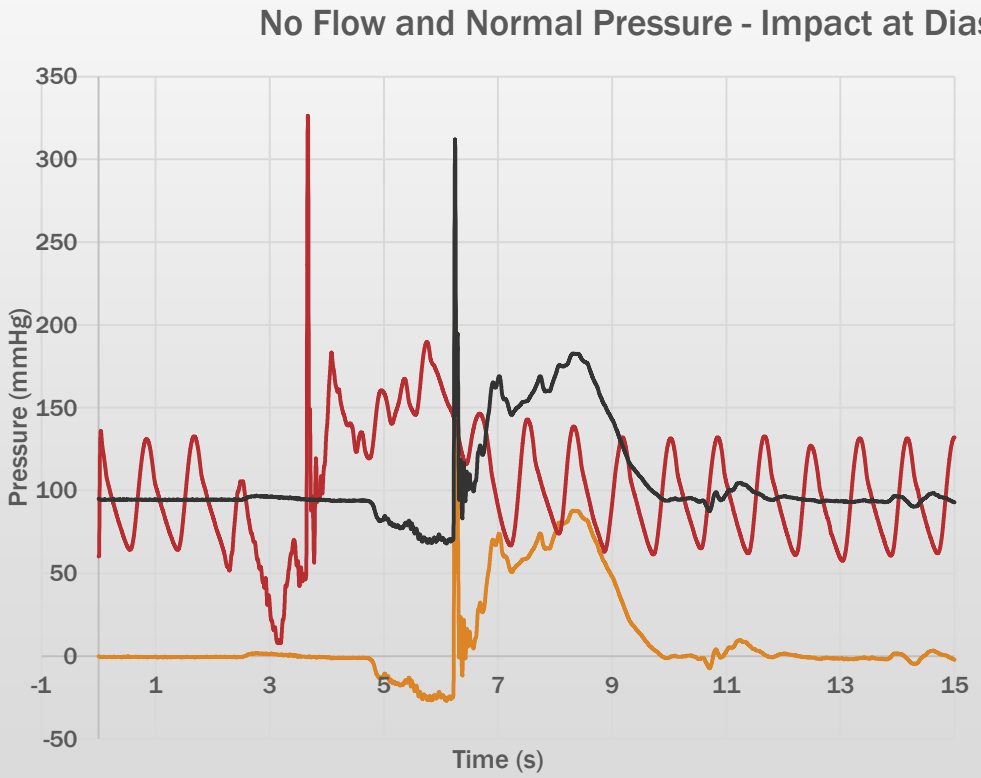
- The results below show the maximum pressure at impact, and the difference between the maximum pressure at impact and the steady state values for systolic/diastolic pressure.

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

Test	Max Pressure	Max-Avg
Continuous Flow - 115mmHg	310	195
No Flow	217	217

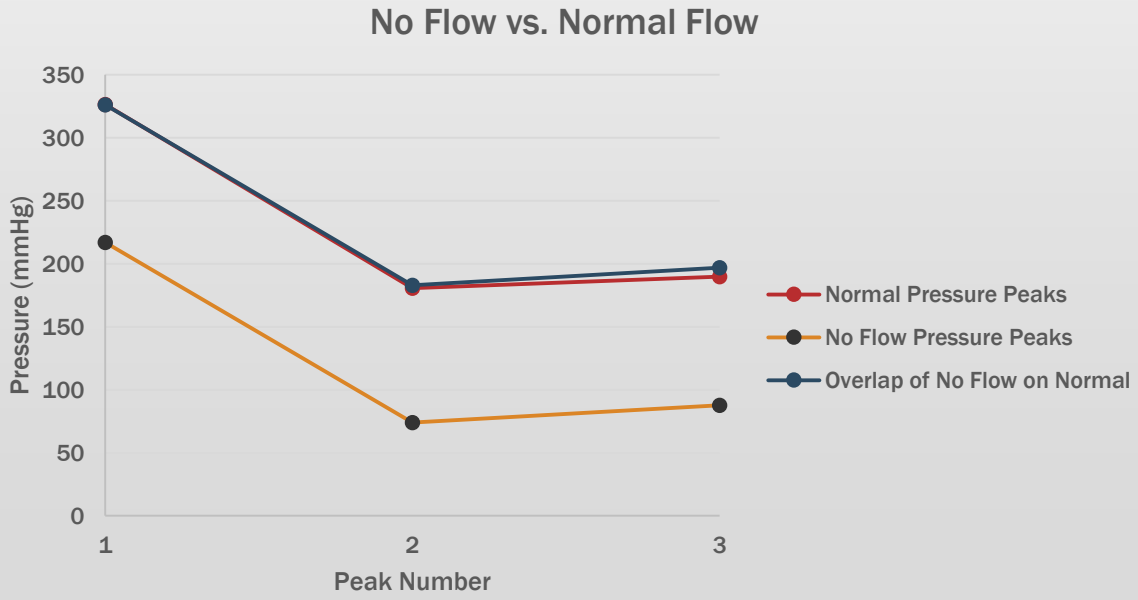
Results – No Flow vs. Normal Flow Peaks

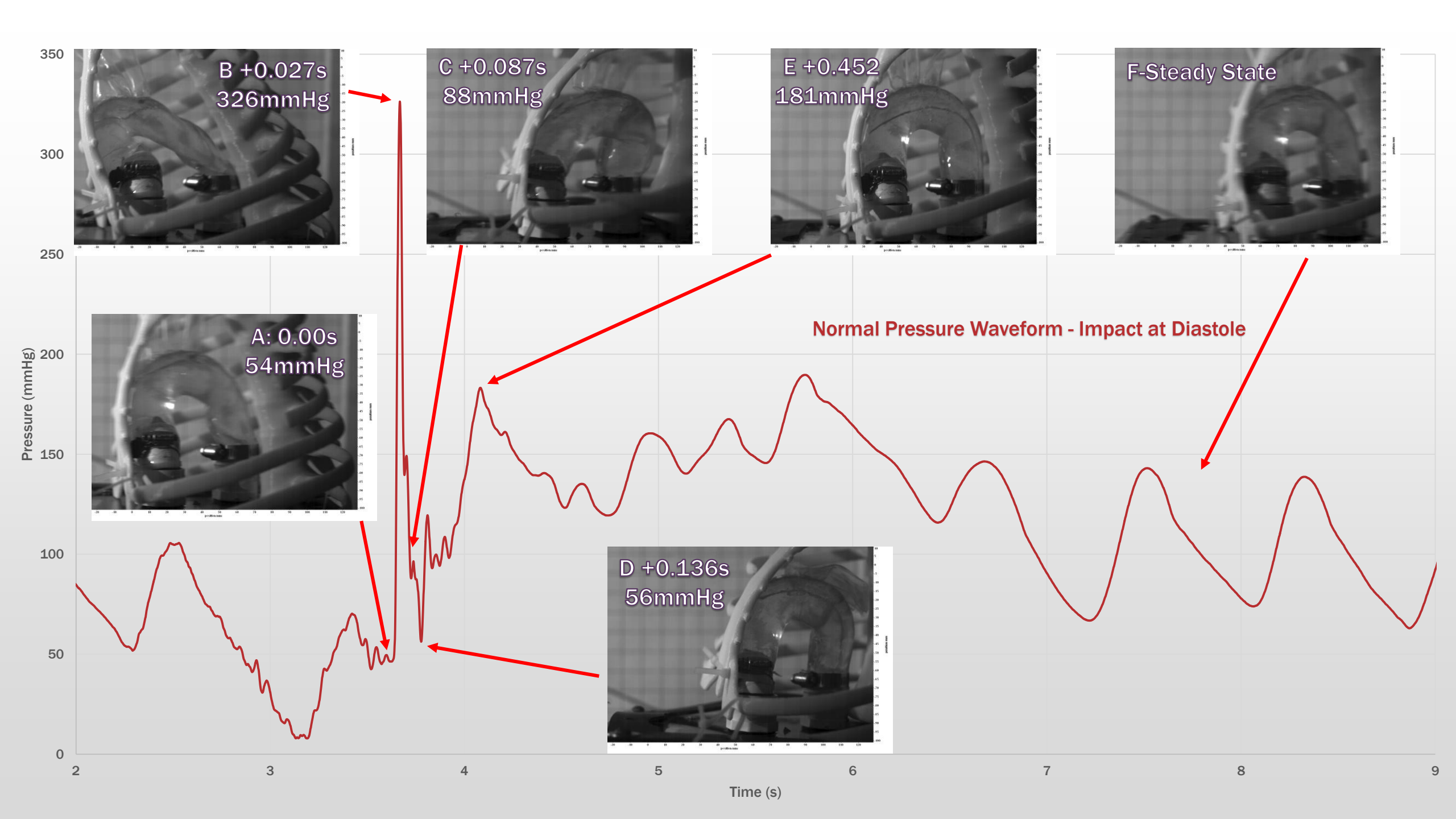
Test	Impact Peak	Secondary Peak	Tertiary Peak	Mean	Std. Dev.
Normal	326	181	190		
No Flow	217	74	88		
Δ(Normal-No Flow)	109	107	102	106	3.73



Max Pressure (no flow): 217.10 mmHg

Max Pressure (normal): 326.34 mmHg



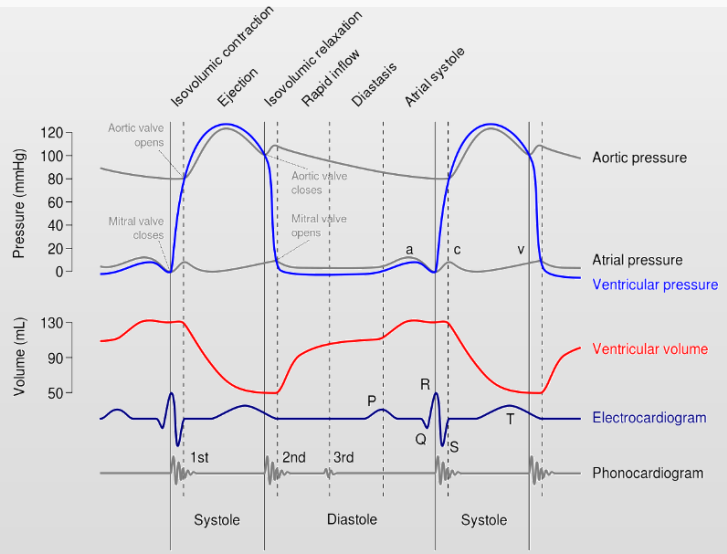

B +0.027s
326mmHg
C +0.087s
88mmHg
E +0.452
181mmHg
F-Steady State
A: 0.00s
54mmHg
D +0.136s
56mmHg
Normal Pressure Waveform - Impact at Diastole
Pressure (mmHg)
350
300
250
200
150
100
50
0
2
3
4
5
6
7
8
9
Time (s)

Discussion

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

$$\underbrace{\rho\left(\underbrace{\frac{\partial \mathbf{v}}{\partial t}}_{\text{Unsteady acceleration}} + \underbrace{\mathbf{v}\cdot\nabla\mathbf{v}}_{\text{Convective acceleration}}\right)}_{\text{Inertia (per volume)}} = \underbrace{\underbrace{-\nabla p}_{\text{Pressure gradient}} + \underbrace{\mu\nabla^2\mathbf{v}}_{\text{Viscosity}} + \underbrace{\mathbf{f}}_{\text{Other body forces}}}_{\text{Divergence of stress}}$$

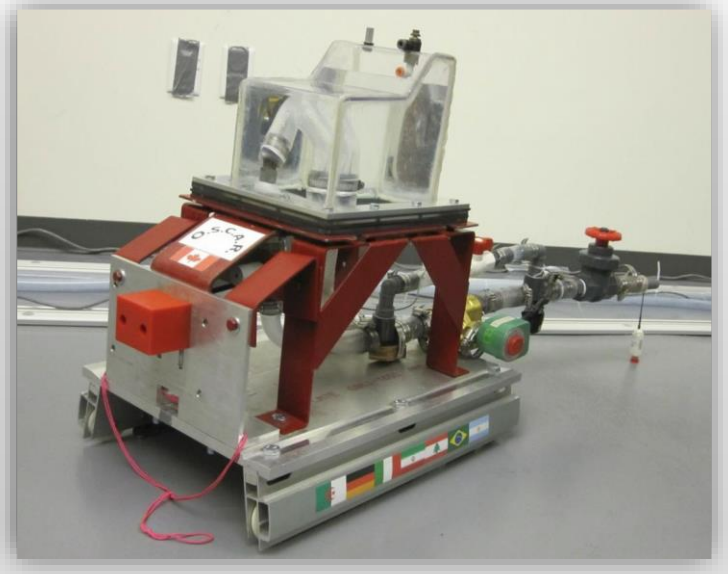
(Wikipedia)



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