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The effect of innate compliance on the performance of a counterpulsation device

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Heart Failure

Heart failure is the inability to provide enough blood perfusion to peripheral organs.

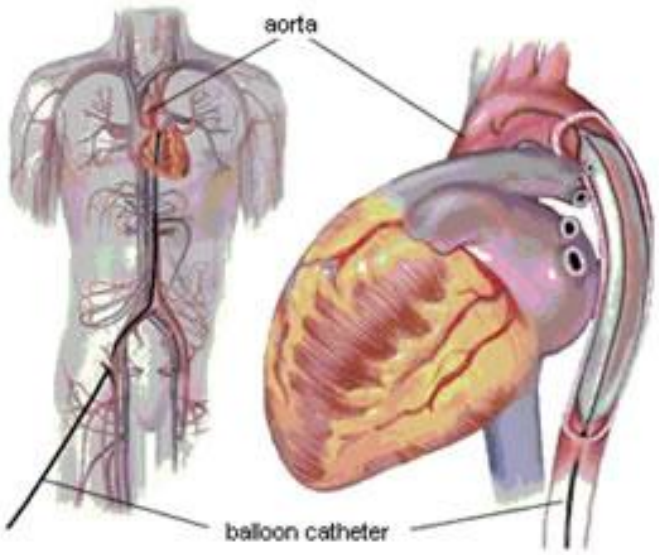
The heart treatment ranges from lifestyle adjustment to heart transplantation

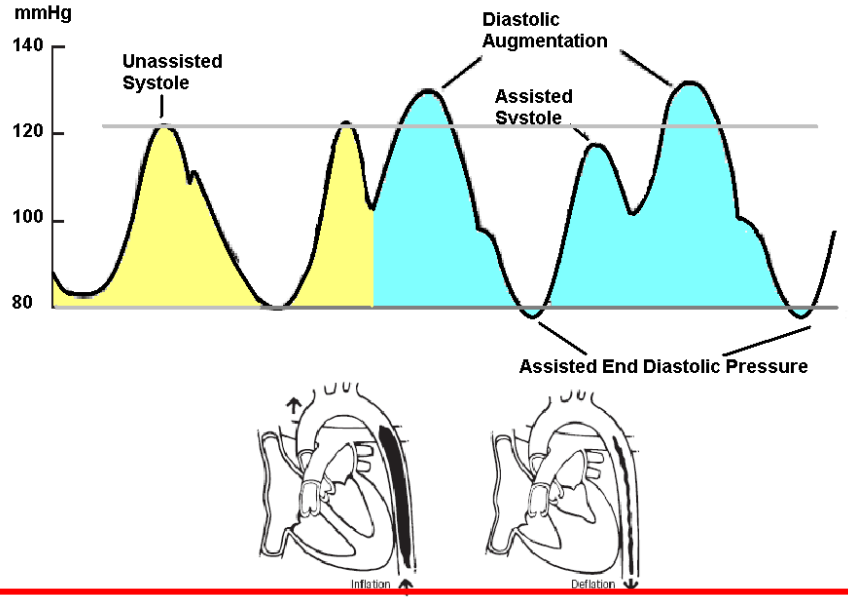
Heart transplantation is the gold standard, but lack of donor hamper the effort.

Mechanical heart assist devices are the alternative for end-stage heart failure patients

Intra Aortic Balloon Pump (IABP)

- A mechanical heart asssit device.
- It is a volume displacement left ventricular assist device (LVAD).
- A short duration assist device
- Work using counterpulsation technique
- Places at descending aorta





The advantages of IABP are

1. Increasing cardiac output
2. Increasing left coronary artery flowrate
3. Decreasing afterload i.e. resistance to blood at start of systole, making heart work less to eject blood.

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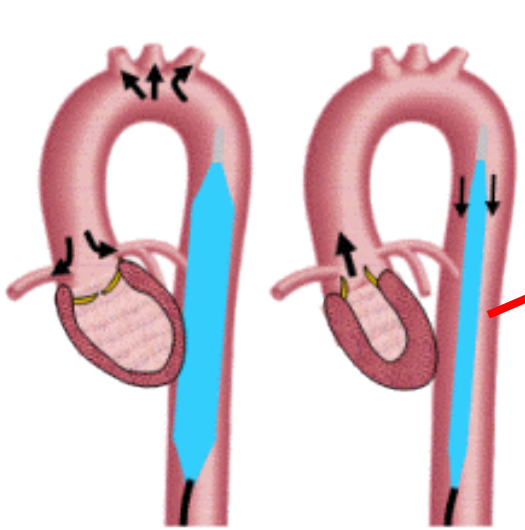
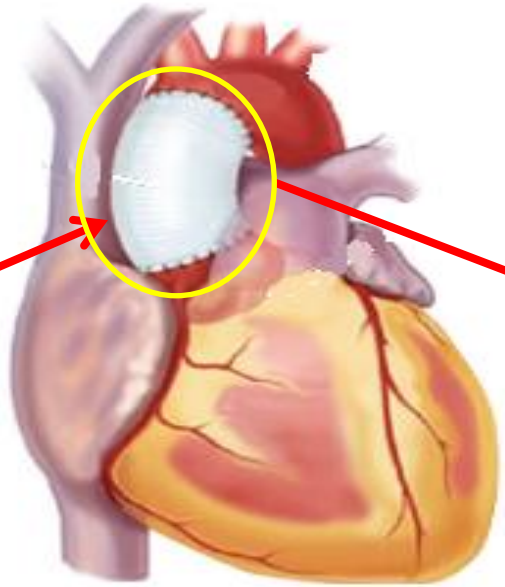
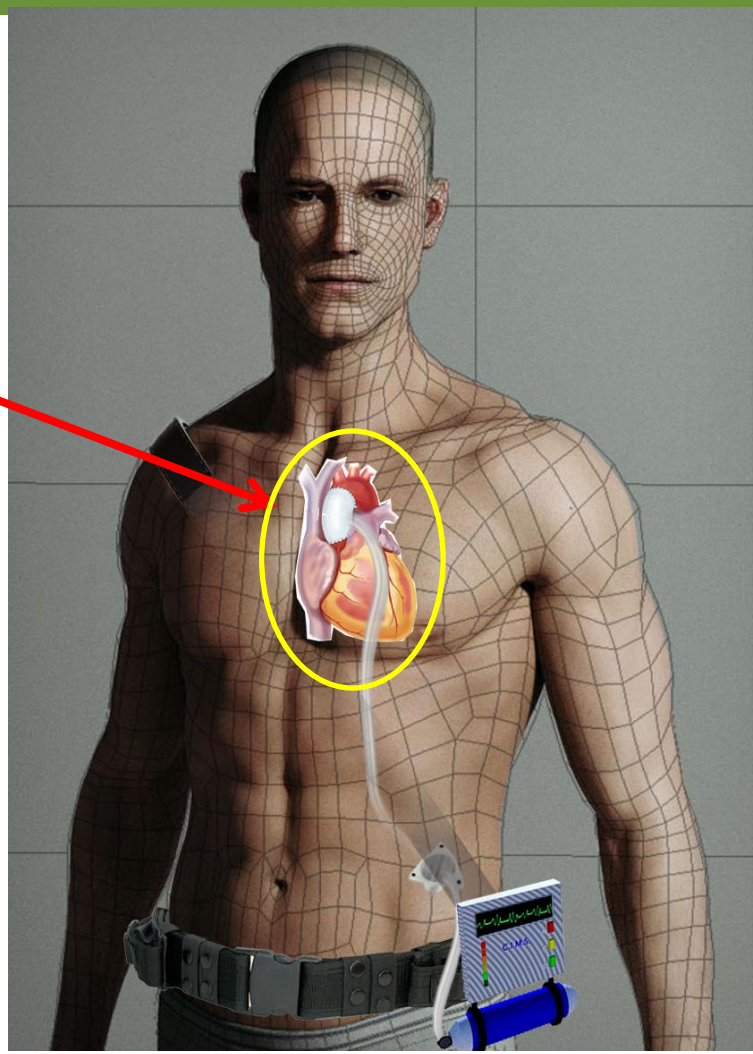
From IABP to…



IABP at descending aorta



permanent balloon pump at ascending aorta



CIMS modality treatment devices

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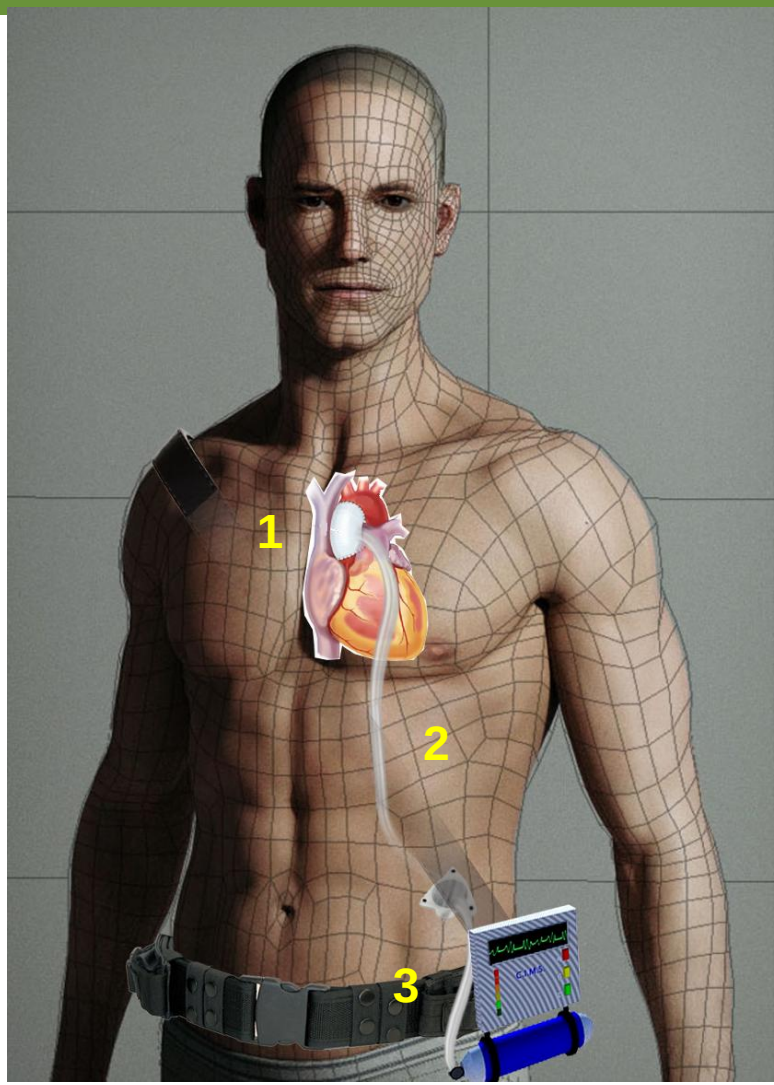
Chronic Intermittent Mechanical Support (CIMS)

- An implantable LVAD
- Consists of:
  1. Balloon pump
  2. Percutaneous driveline
  3. Ambulatory control console

- The target patient cohort for CIMS are those in later stages of HF i.e. Stage D/Class III (IV) and ineligible for heart transplantation

- The aims of this study are
  - To develop an in-vitro CIMS balloon pump prototype
  - To determine the level of augmentation
  - To quantify the reduction of aortic end diastolic pressure i.e. resistance to blood ejection



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Experiments: Material

- Two in-vitro versions of the CIMS balloon pump were made using rapid prototype machine.
  1. A straight body balloon pump
  2. A compliant body balloon pump

- Silicone cylindrical membrane was used as inner lining. The extended port is where the Helium gas enters/exit and inflate/deflate the balloon pump

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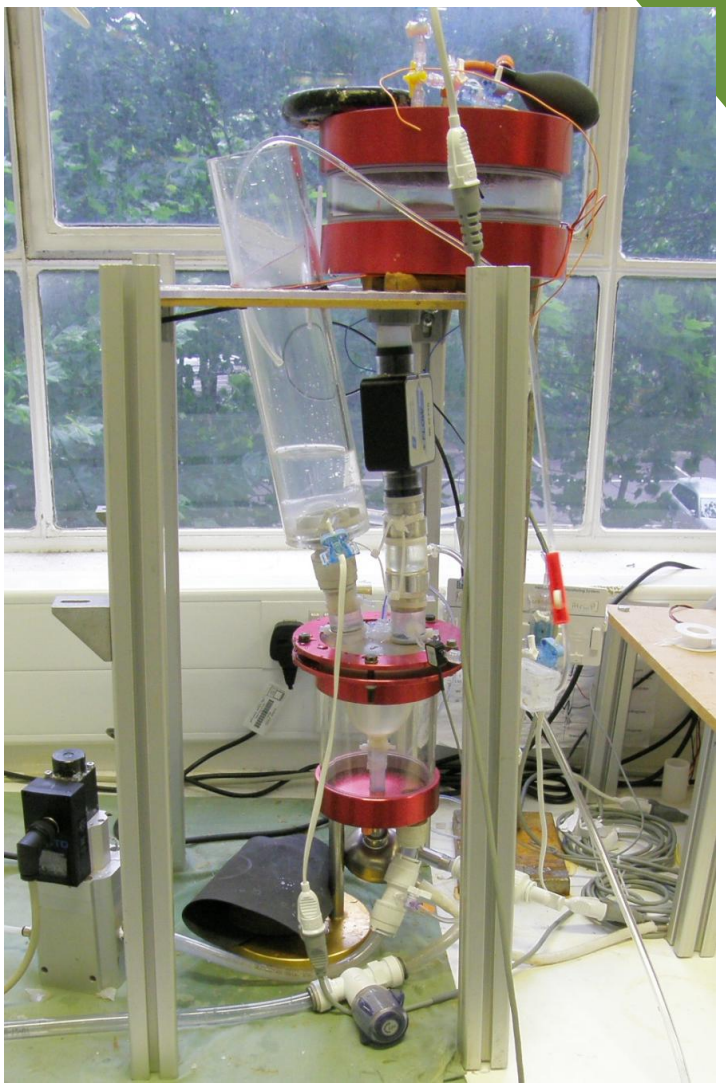
Mock Circulatory Loop

- Human mock circulatory loop is the best place to test out the haemodynamics response of in-vitro device
- Ranges in complexity and accurateness.
- The mock loop is capable of simulating both systemic and left coronary artery circulation
- From normal resting condition to heart failure.
- Able to simulate various vasculature stiffness level (soft,stiff)



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Experiment

- As per this study's aims, important response outputs are

  1. Cardiac output (main artery flowrate)
  2. Left coronary artery flowrate
  3. Aortic end diastolic pressure (measure of resistance)

- The factors manipulated are
  - Compliance of the balloon pump
  - Vasculature compliance/stiffness

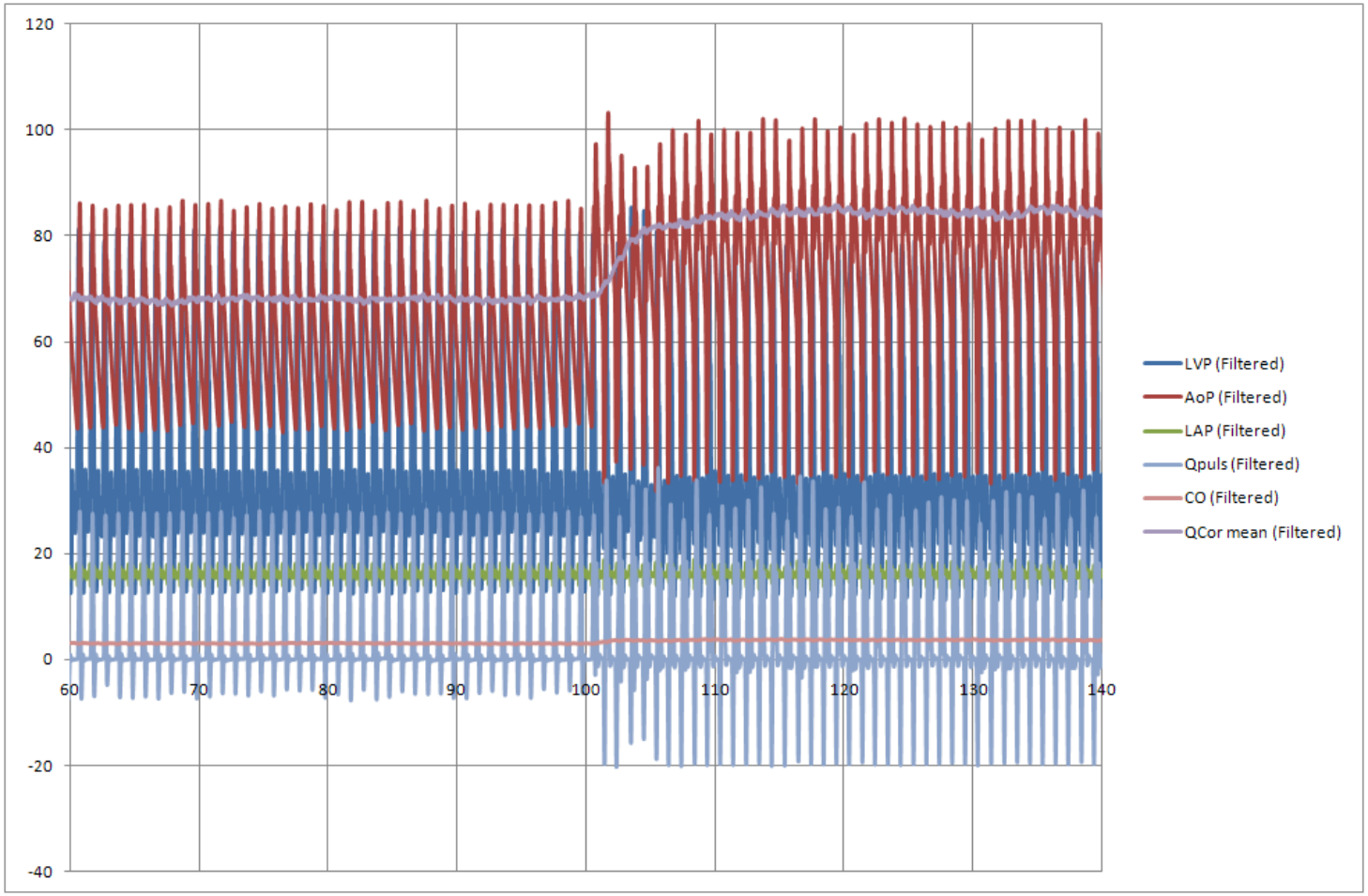
- The question is what is influence between those factors to response output

- 2^k factorial designs were used to design the experimental procedures and ANOVA was used as the statistical analysis tool.

Experimental procedure

- With in-vitro balloon pump fixed in the mock loop, the mock loop is set to run in heart failure mode with two level of vasculature stiffness.
- Three replicates were done with randomized order for all factors involved.
- Result for each response output is the percentage increase of assisted run against non-assisted run.

RESULT



Flowrate and Pressures recorded

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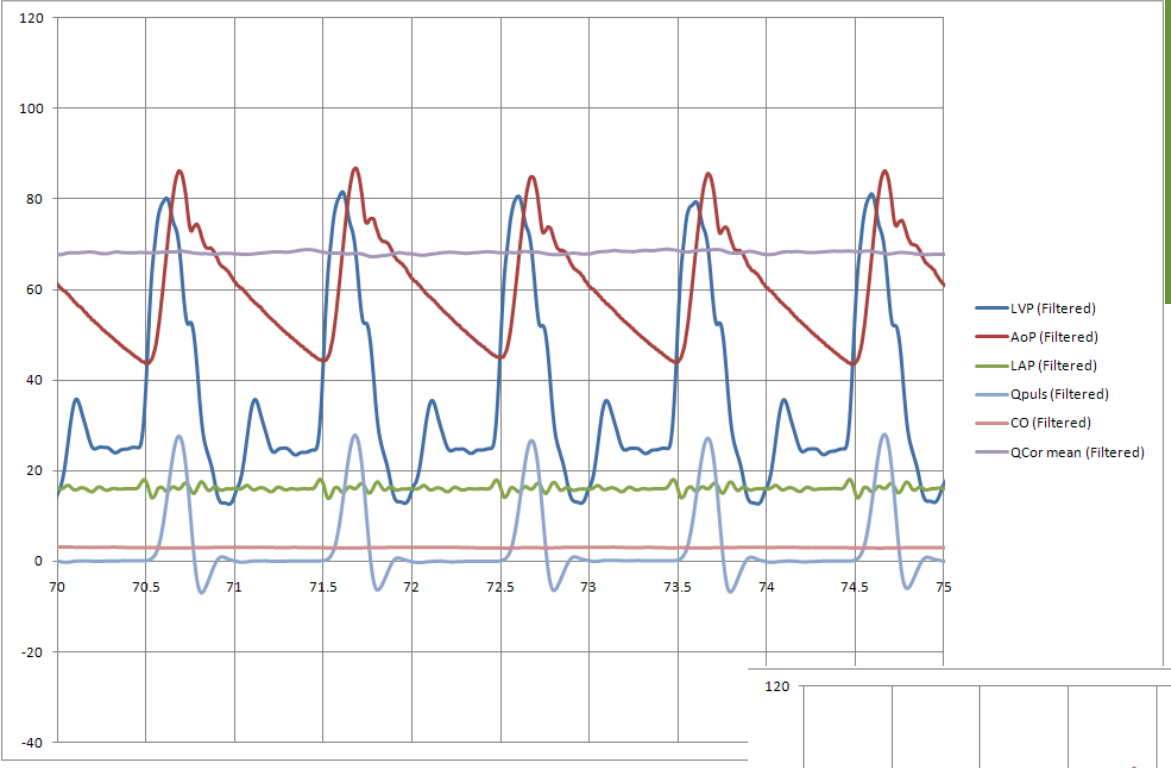
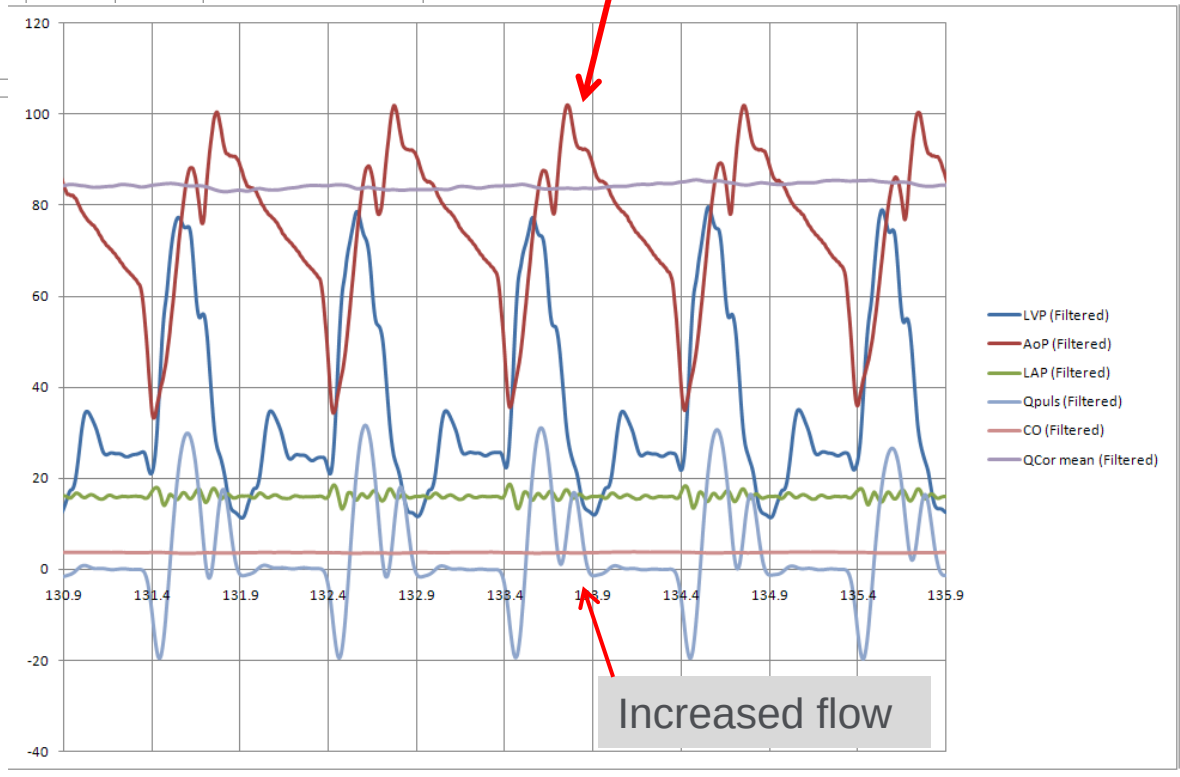


Non-assisted flow

Increased diastolic pressure



Assisted Flow

Increased flow

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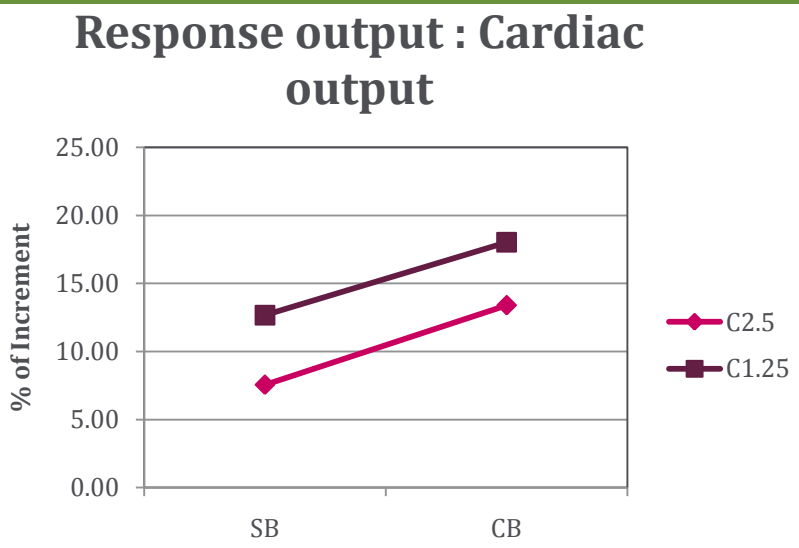
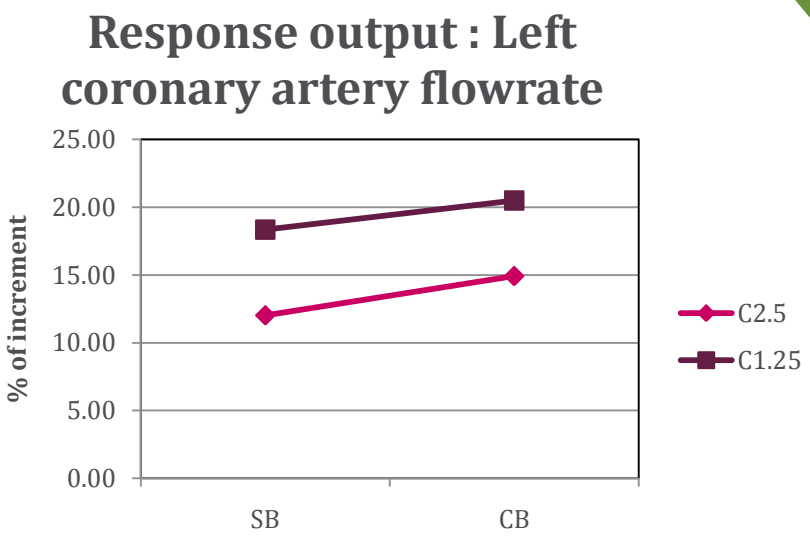
Results



Source of Variation	P-value
Vasculature compliance	p < 0.001
Balloon compliance	p < 0.001
Interaction	0.43601



Source of Variation	P-value
Vasculature compliance	p < 0.001
Balloon compliance	p < 0.001
Interaction	0.18576

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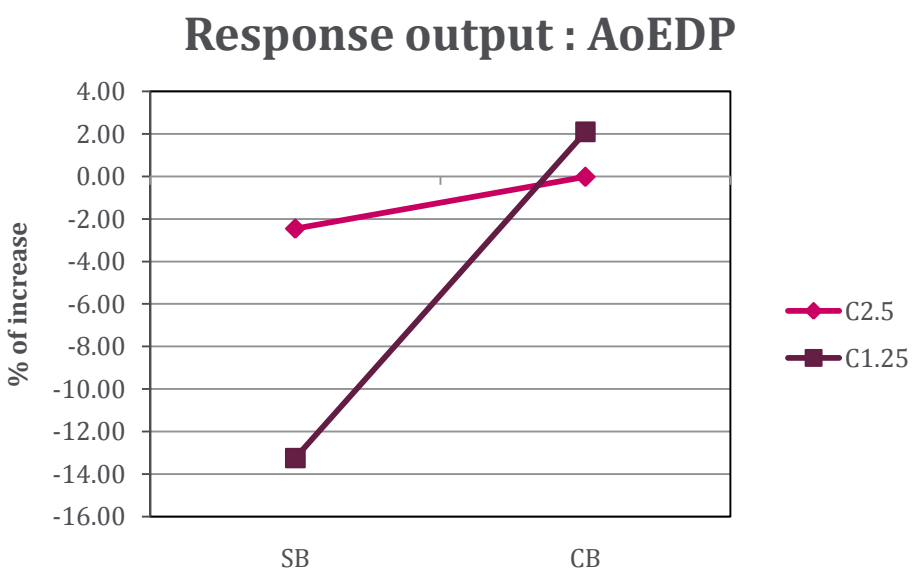
Result

- For reduction of blood resistance, the result is not so straightforward as CO and QcorMean due to the interaction between factors.

- But, we can say that the best reduction is given by straight body balloon pump at stiffer vasculature



Source of Variation	P-value
Vasculature compliance	$p < 0.001$
Balloon compliance	$p < 0.001$
Interaction	$p < 0.001$

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Conclusion

- CIMS balloon pump using counterpulsation delivers a respectable diastolic augmentation on both cardiac output to peripheral and left coronary artery flowrate to heart cells.
- The degree of augmentation differs depending on the level of balloon compliance and vasculature stiffness
- In general, compliant body and stiffer vasculature yielded higher percentage of flow augmentation
- However, the straight body balloon pump reduced blood resistance the best
- For older HF patient, CIMS device might be better suited, since with aging vascular is stiffening.

Future Work

- In-vivo version prototype.
- Comparison between CIMS balloon pump and IABP
- Development of other part of CIMS modality treatment i.e. driver console
- Clinical trial

Thank You

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