Establishing a Coronary Artery Anomaly Phantom Flow Loop to Assess Hemodynamic Relevance under Stress Conditions

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Introduction

Coronary artery anomalies are rare diseases, often linked to abnormal sinus origins of Valsalva.[1] If this malformation has an intramural segment, it may be compressed and cause ischemia. This condition can go undetected and is linked to sudden cardiac death in young athletes. Sometimes symptoms of fatigue during light exercise lead to a CT scan and reveal the malformation. The relevance of the malformation is performed by a minimally invasive intervention. In the clinical study NARCO, those assessments and the patient specific anatomy are collected. To goal of this project was, to build a flow-loop that can replicate the hemodynamic conditions from those study patients, to then perform the assessment on artificial copies(phantoms) of those patients' anatomy.

Materials and Methods

Development of the flow-loop began with a reverse-engineering phase on the pump simulating the heart. Several elements influence the hemodynamic of the system, such as the "Windelkessel Effect" in the compliance chamber, the pump flow profile, the systemic resistance. Most of these elements were designed by leveraging additive manufacturing (FDM & SLA), whilst optimizing flow to achieve the required high cardiac output of up to 15 L/min.

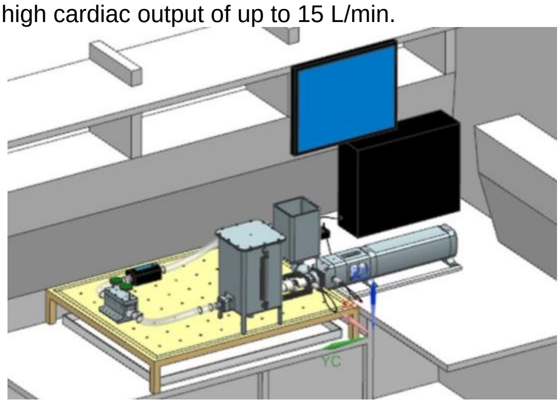

Fig. 1 CAD of the h-CO Flow-loop assembly, containing: Pump, phantom, compliance chamber, flow probe, and the left atrium.

The same devices used for patient diagnostics in clinics were also used with our setup and standardized coronary anomaly phantom (made from Agilus30Clear by PolyJet printing). The diagnostics consisted of fractional flow reserve measurement with the "PressureWire™ X Guidewire" and OCT "CoroFlow‡ Cardiovascular System" from "Abbott". Based on the NARCO trial, 3 hemodynamic conditions were defined to be replicated, rest, Adenosine and Stress.

Results

For the three conditions, the target pressures were 120 (rest), 110 (Adenosine) and 140 (stress) for systolic pressure and 65 [mmHg] for diastolic pressure. For each condition, a total of 3x400 cycles were performed, i.e., a total of 1200 per conditions. The results in [mmHg] are 120.09 ±0.50 & 64.912 ±0.518, 109.87 ±0.24 & 64.816 ±0.288, and 139.86 ±0.94 & 64.624 ±0.832 respectively. For FFR, the following results were obtained 0.97, 0.97, and 0.89 respectively.

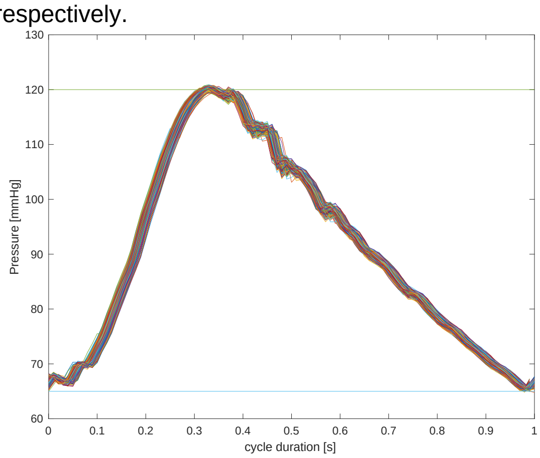

Fig. 2 Superposition of cycle curves for a sample simulating 400 heartbeats at 60 BPM with a standardized coronary anomaly phantom and set to reproduce the typical values at rest of patients suffering from anomalous coronary artery origin.

Discussion

The reproduction of the three conditions closely matches patient database values and, show minimal dispersion. However lower, the FFR under stress is still within the range considered acceptable, as it is the case for most of those patients. Nonetheless, the promising results further investigation with patient-specific phantoms and parameters, are needed to investigate the potential for further the assessment of clinical relevance of those anomalies.

References

[1] P. Angelini, 'Normal and anomalous coronary arteries: Definitions and classification', *Am Heart J*, vol. 117, no. 2, pp. 418–434, 1989, doi: 10.1016/0002-8703(89)90789-8.

Acknowledgements

I would like to thank all the heartcore engineers for their welcome and support throughout these months.