3D-Printed Peristaltic Pump for Fontan Patients - Flow Rate Characterisation

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Introduction

The Fontan procedure is a life saving surgical intervention primarily performed on children with single-ventricle heart defects, where the blood from lower body is redirected to the lungs bypassing the heart. This procedure improves the oxygenation of blood without the missing chamber of the heart.

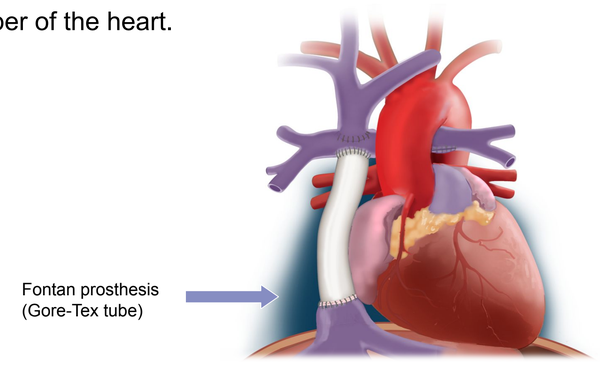

Figure 1: Gore-Tex tube rerouting blood flow from lower body directly to lungs bypassing the heart [1]

To further enhance the blood flow and oxygenation, a peristaltic pump could support the Fontan prosthesis (Gore-Tex tube). A Peristaltic pump with five actuators is designed which can transport non-Newtonian fluids like blood without harm.

The flow rate of the peristaltic pump for different actuation settings is characterised to investigate sufficient fluid transport using peristaltic pumping principles.

Methods

- A 3D printed peristaltic pump with five actuators is used for characterisation with water as test fluid to study fluid transport
- The flow rates of two pump designs (with and without spine) are compared under different actuation settings
- The pumps are characterised for the actuation times 30ms, 50ms, 75ms and actuation pattern with and without pause after one cycle of actuation

Design

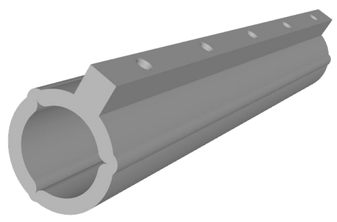

Figure 2 a: Pump design without spine

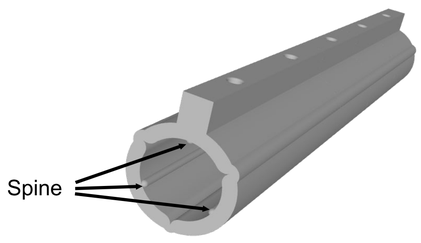

Figure 2 b: Pump design with spine

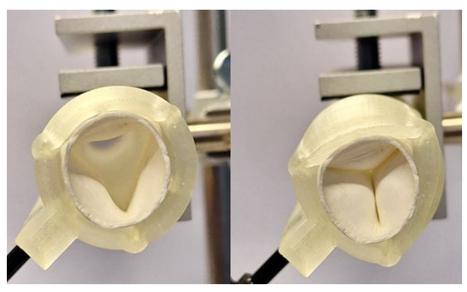

Figure 3: (left) Unpressurized state - open (right) Pressurized state - occluded

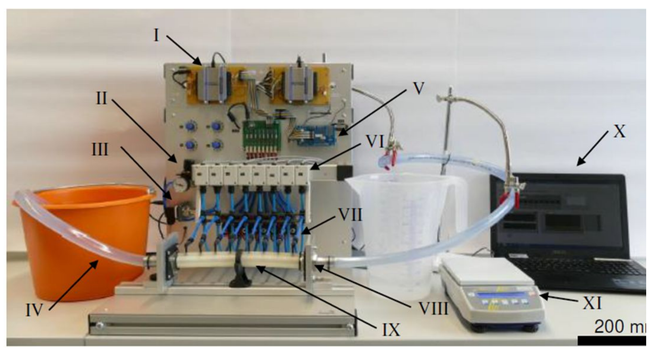

Figure 4: Test bench setup for the operation of the pump [2]

Test bench Description:

From figure 4, I: Data acquisition devices. II: Throttle valve for setting the system pressure with a gauge. III: System air pressure sensor. IV: Fluid circuit consisting of containers, peristaltic pump, and clear tubes. V: Microcontroller to program the peristaltic patterns and actuation duration. VI: Pressure sensors of single ring actuators. VII: Solenoid valve for single elements. VIII: Connection plate for the peristaltic pump with adapters. IX: Peristaltic pump). X: Measurement laptop. XI: Scale for weighing delivered media. [2]

Characterisation

The two pumps **Pump 1 (without spine)** and **Pump 2 (with spine)** are characterised for the following settings:

Pressure applied to the actuators: based on **full occlusion** for the respective actuation time
Actuation time for each actuator: **30 ms** and **50 ms** for each O or **I** state
Actuation pattern:

IOOOO
OIOOO
OOIOO
OOOIO
OOOOI

IOOOO
OIOOO
OOIOO
OOOIO
OOOOI
OOOOO ← Pause

O: Unpressurized state (open)
I: Pressurized state (occluded)

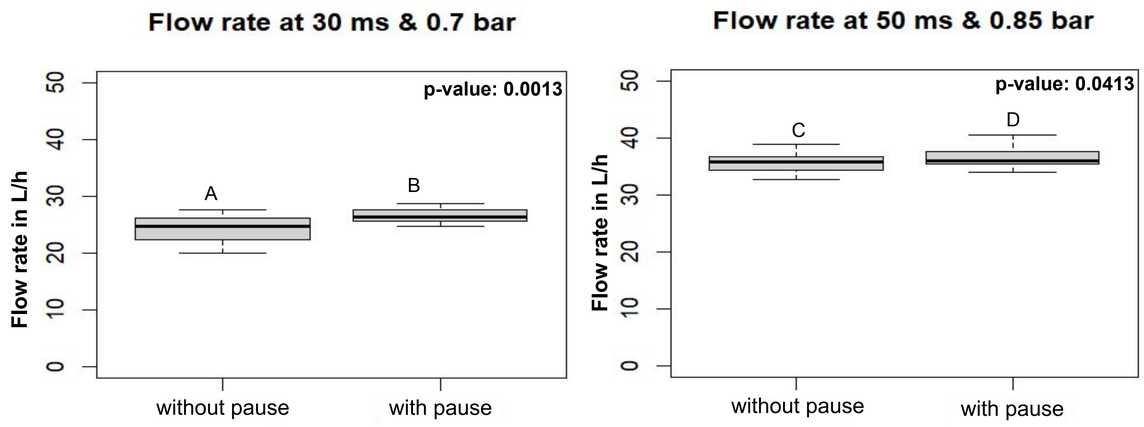

Figure 5: Flow rate characterisation of Pump 1 - without spine with actuation patterns without and with pause

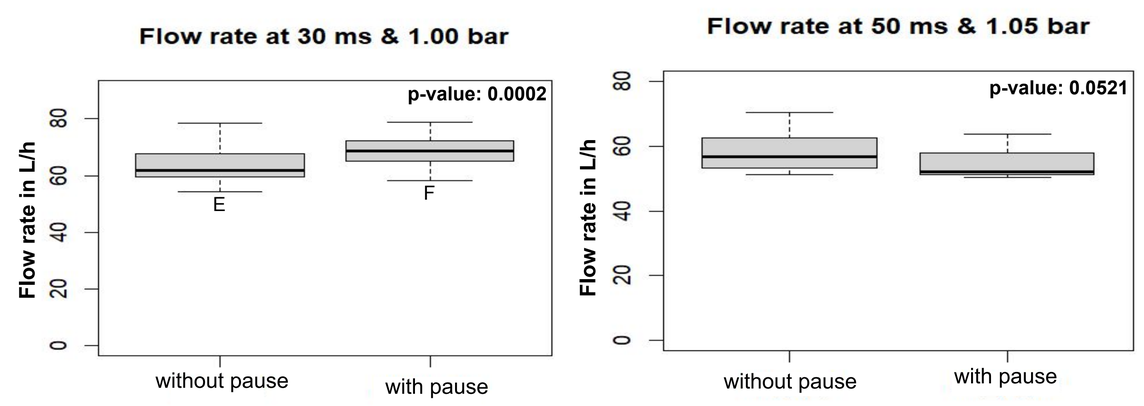

Figure 6: Flow rate characterisation of Pump 2 - with spine with actuation patterns without and with pause

The capital letters in the plots are significance levels; different letters correspond to a significant difference in the achieved volume flow with p-values below 0.05.
The flow rate for 25 runs is plotted for two actuation patterns in Figure 5 and 6. Overall, with a pause in the actuation pattern and a spine in the design which helps complete occlusion during pressurized state, a higher flow rate can be achieved

Conclusion

The characterisation results highlight that it is possible to transport fluids through the Fontan stent with a peristaltic pump. With an improved flow across the Fontan stent, the low flow issue arising from the use of a Fontan stent could be mitigated. Our research is the first step towards this goal. To reach it we must further improve the system and possibly find another actuation principle for in body use. In the future this has the potential to open up new possibilities in patient treatment and quality of life.

References

1. © LUMC Leiden University Medical Center
2. Daniel Bellin, Development and characterization of a 3D-printed biomimetic peristaltic pump (3BPP) for fluids and solids

Acknowledgements

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Further information

Esser, F., Krüger, F., Masselter, T., Speck, T. (2019). Characterization of Biomimetic Peristaltic Pumping System Based on Flexible Silicone Soft Robotic Actuators as an Alternative for Technical Pumps. In: Martinez-Hernandez, U., et al. Biomimetic and Biohybrid Systems. Living Machines 2019. Lecture Notes in Computer Science(), vol 11556. Springer, Cham. https://doi.org/10.1007/978-3-030-24741-6_9

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