IN VITRO CHARACTERISATION OF MODIFIED MICRO VASCULAR PLUGS AS PULMONARY FLOW RESTRICTORS

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Introduction

Hypoplastic Left Heart Syndrome denotes a severe congenital heart disease with high mortality rates due to pulmonary overperfusion and reduced systemic flow. In recent studies, patients who were not eligible for the initial surgical procedure benefitted from the implantation of a modified Micro Vascular Plug (MVP) (Medtronic®) as a pulmonary blood flow restrictor [1]. Due to its high level of unpredictability in its in situ behaviour [2], a steady in vitro setup was used to hydraulically characterise the MVP in different vessel diameters and compliances.

Methods

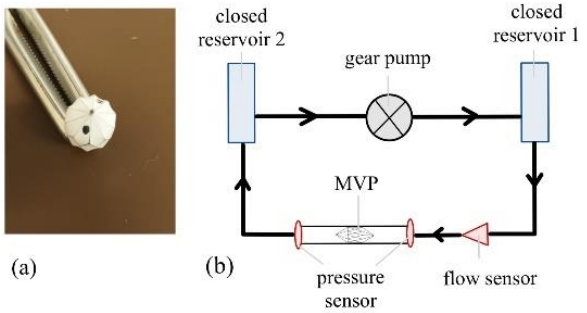

Figure 1: (a) Picture of a modified MVP-7Q with two fenestrations (∅2 mm). (b) Schematic drawing of the in vitro experimental setup for measuring pressure drop across the device at steady flow rate from 0-2 L/min.

The pressure drops over a single and a double hole perforated MVP (∅ 9.2 mm unconstrained) were investigated in a steady circulatory loop. The perforations were performed with an injection needle and expanded by the placement and inflation of a 2 mm balloon catheter (Fig.1a). A water-glycerol mixture was prepared to reach a target viscosity of 4.5 cP at room temperature of 25 °C. The pressure drop across the MVP was measured for volume flow rates between 0 to 2 L/min with an increment of 0.1 L/min every 60 seconds. The pressure drop value was averaged over the stable range of measured values. During the tests, different vessel diameters and compliances (inner diameters: 4.8, 5, 6 and 6 mm, the latter with a higher compliance) were used.

Results

The pressure drop increases with smaller vessel diameters (6<5<4.8 mm) and lower compliance (6 mm comp. < 6 mm). Two distinct relationships of the pressure drop on the flow rate can be observed: quadratic at low-volume flow rates and almost linear at high-volume flow rates.

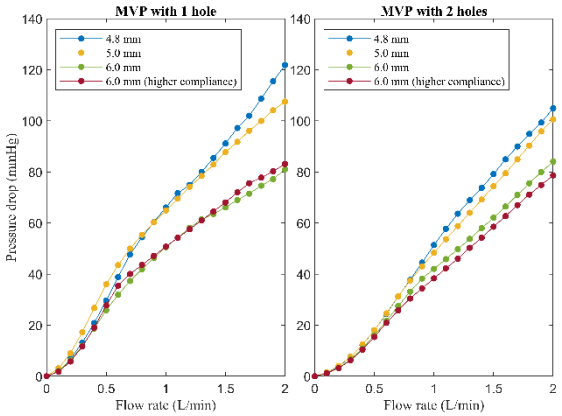

Figure 2: Average pressure drop curves across MVP for flow rates ranging from 0-2 L/min. Influence of perforation choice, tube size and compliance.

A single hole in the MVP causes a higher pressure drop as compared to two holes. For low-volume flow rates, the percentage difference is about 67%.

Discussion

Tailoring the hydraulic resistance of the MVP to the patients´ cardiovascular condition may improve hemodynamics and patient outcome considerably. We showed that the number of holes significantly affects the hydraulic resistive behaviour of the MVP especially at lower volume flow rates. This finding may be attributable to the flow distribution: At low-volume flow rates (0-0.6 L/min), the differences in the pressure drop between the two groups is explained by the perforation choice (predominant flow proportion passes through the holes). At higher volume flow rates (1.6-2 L/min), the collapse of the MVP leads to a reduction of the effective fenestration size. Therefore, the vessel diameters are primarily causing the differences in pressure drop as para-device flow increases.

References

1. Kizilski et al, Cardiovasc. Eng. Technol., 14:640–654, 2023.
2. Nageotte et al, Pediatr Cardiol., 42(6):1410-1415, 2021.