Design and numerical simulation for the development of an expandable paediatric heart valve

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Objectives: Early implant failure in paediatrics with congenital heart valve lesions can be caused by patient-prosthesis mismatch which leads to obstructive blood flow, inflammatory tissue growth and early calcification. There is a clinical need for an expandable prosthetic heart valve that is mimetic to somatic growth to reduce the risk of implant failure and ultimately reduce the need for revision surgeries in paediatrics.

Methods: The aortic valve has well established parameters ratios including leaflet and coaptation height, commissure length and free edge angle, which will be used as the basis for designing an expandable valve. Using software package Ansys Mechanical APDL, a polymeric paediatric aortic valve was modelled in the closed position having a taut free edge that angles variably in relation to diameter, whilst maintaining valve parameter ratios.

Results: Finite element analysis and computational fluid dynamics were carried using ANSYS 19R2 across a full systemic cardiac cycle to determine valve competence and identify haemodynamic stresses. Blood was modelled during a systolic cardiac cycle as pulsatile and the K-epsilon turbulent and Carraeu models applied for non-Newtonian blood flow. The leaflets have a thickness of 200 µm and were assigned silicone anisotropic material properties.

Discussions: Varying the leaflet free edge angle with diameter enables the valve to remain taut whilst closed and prevent leaflet buckling when compressed into a smaller diameter. Early results from the computational fluid dynamic studies have shown reasonably low transvalvular pressure gradients at the smallest diameter (12 mm) and low localised regions of stress.

Conclusions: Parametric design modelling can be successfully used to design a novel heart valve with leaflet positions that vary with diameter whilst respecting established valve parameter ratios. Work is ongoing to optimise the design of these leaflets for the growing paediatric environment.

Keywords: numerical simulation, paediatric heart valve, expandable prosthetic heart valve