A COMPUTATIONAL FRAMEWORK FOR MODELLING PATCH-AUGMENTED AORTIC ARCH RECONSTRUCTION

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Introduction

Hypoplastic left heart syndrome (HLHS) is a congenital heart defect characterized by an underdeveloped aortic arch and left ventricle. To survive these conditions, the underdeveloped aortic arch needs to be surgically enlarged and connected to the right ventricle. At the same time, a shunt is created to provide blood flow to the pulmonary arteries [1].

Given the highly non-linear mechanical behavior of native aortic tissue and available patch materials, it remains challenging for clinicians to predict the shape of the reconstructed aortic arch [2]. The shape of the aortic arch is vital for ventricular function and avoiding (long-term) complications [3].

To accurately predict the reconstructed aortic arch geometry, we present a flexible computational framework that allows us to study the effect of patch size, shape, and insertion location on the pressurized shape of the reconstructed neo-aorta.

Methods

We built a finite element framework replicating the surgical reconstruction of the hypoplastic aortic arch in HLHS patients. More specifically, we integrate the non-linear elastic behavior of the aorta and the patch, model surgical reconstruction, and simulate the pressurization of the reconstructed aorta.

Third-degree B-splines are used to describe the geometry of the aorta and the patch. This parametric description enables the geometries to be easily adapted and changed. Tetrahedral meshes are generated, and the model equations describing static equilibrium are solved using second-order Lagrange elements.

The geometry of the surgical cut of the aorta is described by level set functions. The resulting surfaces exposed by the surgical cut are used to model patch insertion. Insertion of the patch into the aorta is simulated by constraining the distance between the surface of the surgical cut and the patch to zero. We use a strain energy function that accounts for the anisotropic hyperelastic behavior of the mechanical behavior of the native aortic and patch tissues [4]. Finally, we simulate pressurization using a Neumann boundary condition on the internal surface of the aorta and on one side of the patch.

Results

Reconstruction of aortic arch is modeled here using an idealized geometry for the aorta and different patches. Figure 1 shows the aorta and the patches, before and after the reconstruction. The inserted patch enlarges the aorta but can lead to mechanical instability due to geometric or mechanical variation. The anisotropic hyperelastic behavior of the tissue plays an important role in the final shape.

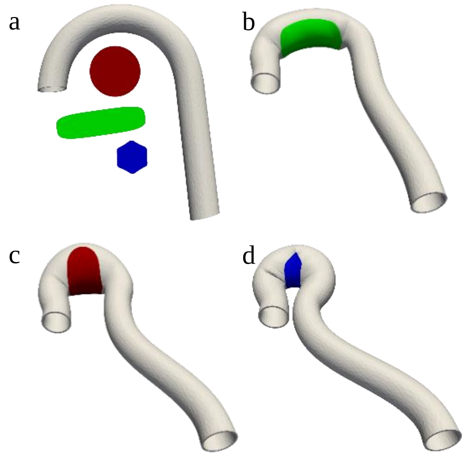

Figure 1: (a) An idealized aorta and three patches. (b, c, d) The reconstructed aorta with an inserted patch after pressurization.

Discussion

The framework presented here models the shape of the reconstructed aorta after pressurization. The final shape is highly dependent on the insertion location, the shape, and the material properties of the patch. These are important design variables to ensure adequate circulation, as well as to avoid complications, such as rupture or blockages. A large mismatch in mechanical properties between the patch and the aorta can lead to buckling and other mechanical failures [5].

Accurately predicting the final shape of the reconstructed aorta after pressurization is extremely complex. Using this framework, the shape of the reconstructed aorta during the cardiac cycle can be predicted. We aim to optimize the shape and insertion location of the patch with respect to post-surgical blood flow and oxygen delivery. The optimized patch can then be used to inform clinicians during this challenging surgery.

References

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