Virtual Surgical Modification and Fluid Structure Interaction
CFD Simulation for Planning Tetralogy of Fallot Repair
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BACKGROUND

TOF is a condition where the right ventricle of the heart pumps blood into the pulmonary artery, which is not oxygenated. This results in decreased oxygen levels to the body's tissues. The usual surgery for TOF involves a tetralogy repair, which involves cutting away a segment of the right ventricle, the pulmonary valve, and the pulmonary artery to create an arteriovenous fistula. This allows for the blood to flow more efficiently to the lungs, improving oxygenation. The surgery is usually done in the first few years of life and involves significant medical and surgical procedures.

INTRODUCTION

TOF is a complex congenital heart defect that affects the heart's structure and function. The deformations in the heart caused by TOF require careful planning and simulation to ensure a successful repair. CFD simulations can help in understanding the fluid dynamics in the heart and optimizing the surgical approach.

METHODS

1. Patient Data Acquisition
   - TOF patient was imaged pre-operatively using a GE LightSpeed VCT CT scanner at St. Joseph's Hospital & Medical Center.
   - Image data for 10 cardiac phases equally spaced over 0.06 s intervals over the heart cycle were acquired.

2. Segmentation & Reconstruction
   - Each of the ten cardiac phases for the patient were segmented & reconstructed into 3D models with Mimics software.
   - Reconstructed 3D models from Mimics were smoothened using Geomagic Studio in order to make it easier to run CFD simulations.

3. Fluid Structure Interaction (FSI)-based Computational Fluid Dynamics simulation
   - Ansys Workbench was used to perform an FSI simulation of the main pulmonary artery.
   - Material properties used in Ansys Mechanical for the pulmonary artery wall were:
     - Young's Modulus: 48,574 kPa, Density: 1030 Kg/m³, Poisson's ratio: 0.49, Wall Thickness: 1mm.
     - A Quad dominant mesh was created in Ansys Mechanical with 153,784 elements.
     - An Ansys Fluent mesh with a hexahedral core and tetrahedral surface mesh was created with 192,667 nodes, corresponding to 704,497 mesh elements.
     - A patient specific, scaled input waveform was used as a pulsatile velocity inlet to the Ansys Fluent model.

RESULTS

1. Peak Flow Velocities
   - Peak flow velocities in the Main Pulmonary Artery (MPA) were recorded at 3.67 m/sec which are very similar with the post-operative data from transthoracic ECHO.

2. MPA pressure
   - Peak pressure values at systole in the MPA region were recorded at 38 mmHg and were similar to the value that was by performing transthoracic ECHO post-operatively.

3. Vessel Wall Deformations
   - Fluid Structure Interaction based CFD simulations enabled us to estimate the wall deformations associated with fluid flow at peak systole, 0.11 sec into the heart cycle.
   - We observed deformations between 0.06 mm to 0.6 mm on the various surfaces of the vessel wall.
   - Wall deformations fell short by 30% of the actual values estimated by 3D reconstruction of the various phases of the heart cycle.

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REFERENCES