3-D FINITE ELEMENT MODELS OF ARTERIAL CLAMPING WITH FLUID-STRUCTURE INTERACTIONS - A STEP TOWARD SIMULATING CARDIOVASCULAR SURGERY

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INTRODUCTION

Patient-specific computational modeling can be a useful component of pre-operative planning of cardiovascular surgeries such as those of valves and arteries. The deformation and stress analysis could also provide valuable insights into the tissue injury mechanisms.[1] The objective of this study was to simulate clamping of the aorta, a particularly challenging step, as it is computationally demanding and involves contact between rigid clamps and flexible aorta, contact within the artery walls, large deformations in tissues, and fluid-structure interactions (FSI).

METHODS

The models were created using Finite Element Analysis as well as Computer Aided Design packages. The aorta was modeled as a soft, non-linear material and the clamp was modeled as rigid. The soft tissue material was modeled using a custom in-house subroutine.[2,3] The fluid was modeled as Newtonian, incompressible and transient flow. For validation purpose, ascending porcine aortas were dissected from fresh unfixed hearts and clamped with actual surgical clamps. The external deformation profiles of the pinched aorta were imaged and compared with those of the simulations.

RESULTS AND DISCUSSION

Clamping of the aorta was simulated, producing occlusion of blood flow. The deformation profile of the simulated aorta matched well with that of the real tissue (see Figure 1), indicating that our material model and the simulation were reasonable. The computed deformation profile and stress distributions within the aorta, with and without the internal fluid, indicated significant difference between the two simulations, suggesting the importance of FSI in surgical modeling. The flow fields within the aorta were also computed (see Figure 2).

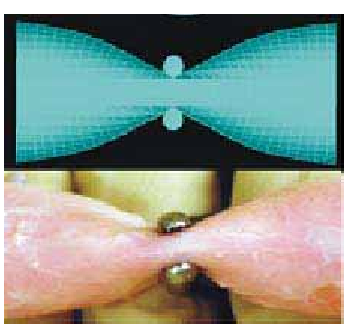

Figure 1. The simulated clamp test showing the deformed profile of the aorta that can be matched to real experiment data of the same deformation.

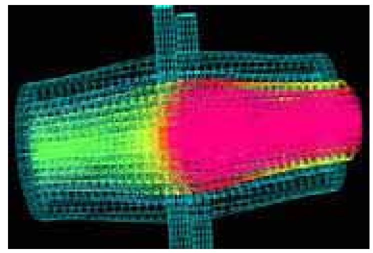

Figure 2. Top view of the fluid flow fields within the aorta during the clamping process; the colors correspond to magnitudes of flow velocities.

CONCLUSIONS

Clamping of a fluid-filled aorta, an important first step towards simulating of surgical procedures, was successfully modeled. The simulation was compared with actual aortic clamping, and deformation profiles of the simulations matched the experiment. The techniques developed in this project are applicable to valve FSI models and further surgery simulations. This model could also be linked with systemic Matlab simulations to have even more realistic modeling.

REFERENCES

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