AN INTEGRATED SOFTWARE SYSTEM FOR PREOPERATIVELY EVALUATING AORTO-FEMORAL RECONSTRUCTION PROCEDURES

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INTRODUCTION

Traditionally, engineers have constructed and tested physical prototypes to create new devices and improve on existing designs. The current paradigm in planning treatment for patients with vascular disease is similar to traditional prototyping found in engineering. Specifically, a surgeon will select a procedure for a particular patient based on past experience for patients with a similar state of disease. The experience gained from this patient will be selectively used when treating the next patient with similar symptoms. In this fashion, the surgeon is using a "build and test" approach where the design of a particular procedure is iteratively improved.

In this work, a surgical planning system was developed enabling a vascular surgeon to create and test alternative operative plans prior to surgery for a given patient. Hemodynamic (i.e. blood flow) simulations were performed for the operative plans for two aorto-femoral bypass (AFB) patients and compared with actual postoperative data. The information that can be obtained from hemodynamic simulation (e.g. wall shear stress) may be clinically relevant to future vascular surgeons planning surgical interventions.

The work presented differs from previously published related work [1-3] in that geometric models for actual aorto-femoral reconstruction patients were created preoperatively in a clinically relevant time frame. In addition, prior to this work no system existed that enabled a surgeon to create surgical plans to be evaluated prior to surgery.

METHODS

Previously, over 15 separate programs and scripts were required to create patient-specific geometric models from medical imaging data and perform hemodynamic simulations. A modular software architecture was developed (see Figure 1) to allow the use of best-in-class component technology and create a single application capable of surgical planning. The figure shows three distinctive parts: a front-end integration environment, a data repository for an abstract data exchange between modules, and modules roughly corresponding to the major tasks in the process. An integrated system was developed utilizing the architecture shown in Figure 1 that enabled a vascular surgeon and a technician to go from medical imaging data to analysis results (see [4]).

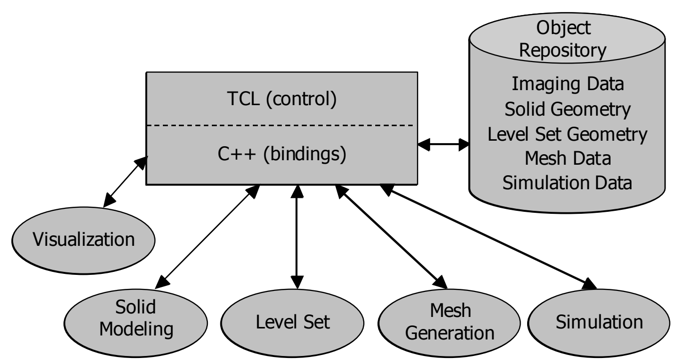

Figure 1. Modular software architecture.

RESULTS

A case study of a patient who underwent an aorto-fermoral reconstruction is discussed here. An additional case study is detailed in [4].

Case Study

A 67 year-old female with rest pain and calf claudication at 20 feet with a past medical history significant for peripheral vascular disease (ankle brachial index 0.50 bilaterally), chronic obstructive pulmonary disease, nicotine abuse, and cerebral vascular occlusive disease (60% carotid stenosis) was studied. Noninvasive imaging was consistent with atherosclerotic occlusive disease of the iliac and femoral arteries bilaterally. Imaging data was acquired preoperatively (Figure 2) to obtain geometric information (using MRA) and quantify volumetric flow (using PCMRI) in the aorto-iliac-femoral system. Approximately two weeks after the acquisition of the preoperative data the patient underwent an end-to-side aorto-femoral reconstruction.

Postoperative image data was acquired approximately 6 months after the operation (Figure 2). The patient at that time was symptom free (i.e. felt better than before the operation), although diagnostic imaging and testing indicated a progression of the disease. There was mild narrowing of the profunda femoris arteries distally and the external iliac arteries that were bypassed had occluded completely.

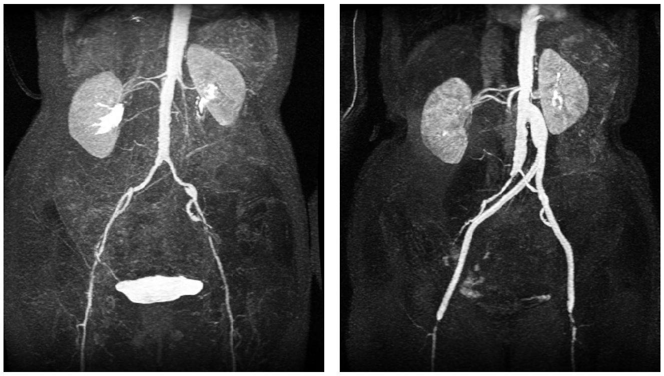

Figure 2. MIP of preoperative (left) and postoperative (right) MRA data for case study.

Surgical Planning

Figure 3 shows two different surgical plans for this case study. Using the system developed in this work, a vascular surgeon created the geometric model shown on the left side of the Figure 3. The plan was created in the same graphics window with the volumetric image data, which provided additional anatomic context for planning the location of the graft. The geometric model on the right was created using the postoperative image data as a guide to create a plan similar to the outcome of the actual operation.

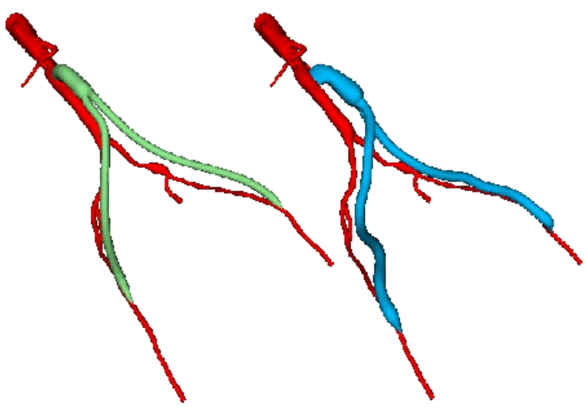

Figure 3. Two different surgical plans.

Simulation Results

Unstructured tetrahedral meshes were automatically created from the geometric models discussed above. The boundary conditions used in the present work were prescribed from imaging data (i.e. PCMRI) and represent a state of rest. Hemodynamic simulations were performed by solving the incompressible Navier-Stokes equations using stabilized finite-element methods. Note the vessel walls were assumed rigid and blood was modeled as a Newtonian fluid.

Clinically relevant quantities of interest were then calculated and visualized including volumetric flow distributions, velocity profiles, and scalar clearance time for each proposed surgical procedure. For this case study, the simulation results indicate extremely low (retrograde) flow in the external iliac arteries during resting conditions. The simulated low flow in the external iliac arteries (an order of magnitude lower than the preoperative flow rates) could explain the clinically observed occlusion postoperatively (see Figure 2). In addition, wall shear stress (shown in Figure 4) is of interest because of its theorized role in atherosclerosis.

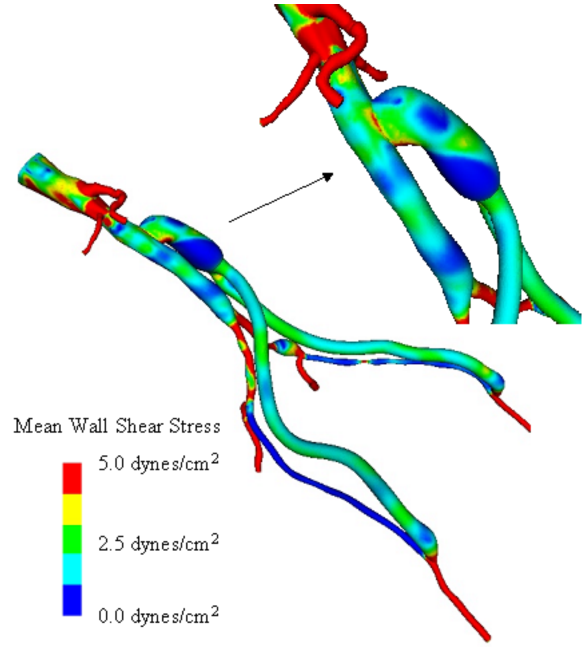

Figure 4. Mean wall shear stress for one surgical plan.

DISCUSSION

The results presented may be consistent with clinically relevant phenomena such as postoperative occlusion of the external iliac arteries. However, simulation during exercise conditions is likely required to differentiate between similar procedures. To this end, boundary conditions are currently being developed to utilize preoperatively acquired physiologic information to simulate exercise conditions. In addition, relaxation of the rigid-wall assumption used in this work may in the future yield more realistic pressure solutions.

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REFERENCES

1. C.A. Taylor, "A Computational Framework for Investigating Hemodynamic Factors in Vascular Adaptation and Disease," PhD Dissertation, Stanford University, August 1996.
2. C.A. Taylor *et. al.*, "Predictive Medicine: Computational Techniques in Therapeutic Decision-Making," Computer Aided Surgery, Volume 4, pages 231-247, 1999.
3. N.M. Wilson *et. al*., "A Software Framework for Creating Patient Specific Geometric Models from Medical Imaging Data for Simulation Based Medical Planning of Vascular Surgery," Proceedings of MICCAI, pages 449-456, 2001.
4. N.M. Wilson, "Geometric Algorithms and Software Architecture for Computational Prototyping: Applications in Vascular Surgery and MEMS," PhD Dissertation, Stanford University, December 2002.