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Simulation of bifurcated stent grafts to treat abdominal aortic aneurysms (AAA)

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Introduction

- An aneurysm is a dilation of a blood vessel.
- AAA:
  - Aneurysm of abdominal aorta, usually extending to the iliac bifurcation
  - When reaching a critical diameter above 55 millimeters the risk of rupture increases dramatically
- Two possibilities to treat an AAA with a graft before rupture occurs (Fig. 1):
  - Endovascular surgery
  - Open surgery
- Endovascular treatment is done by deploying a bifurcated stent graft (Y-stent graft), which splints and eliminates the aneurysm.
- Open surgery is very stressful on the patient and not eligible for everyone, e.g. risk patients.

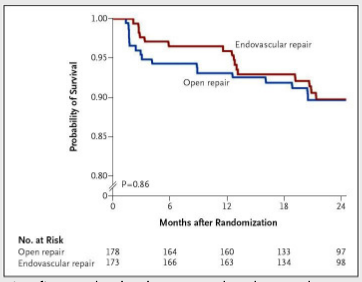

Fig. 1. Mortality rate after randomized open- and endovascular surgery (DREAM) [1]

Methods

Preprocessing

- The affected artery is segmented with a region growing method that starts at user-defined seed points [2].
- A skeletonization algorithm determines the three vessel centerlines (aorta, right and left iliac) by iterative erosion of the segmentation mask [2].

ACM

- Starting with these centerlines an initial bifurcated stent graft is constructed with a given radius.
- After this pure geometrical bifurcated stent graft construction [3], the bifurcated stent graft is deformed by using an active contours (ACM) method.
- The ACM method minimizes the following energy functional and bases on [4, 5]:

$$E = \int_{t=0}^{1} \int_{s=0}^{1} E_{int}(v(s,t)) + E_{ext}(v(s,t))\,ds\,dt$$

Bifurcated (Stent) Model

- For stent simulation the physical attributes of the virtual bifurcated stent graft are simulated by internal and external forces.
- The internal forces act in horizontal, vertical and diagonal directions:

$$E_{int} = w_1 \frac{\partial v(s,t)}{\partial s} + w_2 \frac{\partial v(s,t)}{\partial t} + w_3 \frac{\partial^2 v(s,t)}{\partial s^2} + w_4 \frac{\partial^2 v(s,t)}{\partial t^2} + w_5 \frac{\partial^2 v(s,t)}{\partial s \partial t}$$

- At branching points a neighborhood must be defined, enough to calculate the derivations up to degree four (Fig. 2)
- The external forces simulate the resistance of the vessel wall and the balloon that is used to expand the bifurcated stent graft:

$$E_{ext} = w_{vesselWall} \cdot D(x,y,z) + w_{balloon} \cdot F_{balloon}$$

$$F_{balloon} = \begin{cases} F_{pressure}(R-r) & if \|r\| < \|R\| \\ 0 & otherwise \end{cases}$$

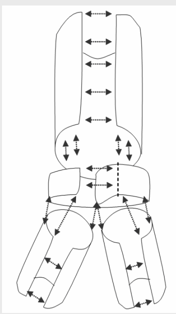

Fig. 2. Internal forces

Measurements

- For measuring the dimensions of the AAA the internal forces lose their influence.
- Thus the bifurcated stent expands to completely fit to the vessel walls
- From this geometric model of the AAA the relevant sizes for choosing a bifurcated stent can be measured easily (Fig. 3, 4):
  - Aortic diameter at proximal implantation site (a)
  - Aortic diameter – 15 mm inferior to proximal implantation site (b)
  - Maximum aneurysm diameter (c)
  - Minimum diameter of distal neck (d)
  - Right common iliac diameter (e)
  - Left common iliac diameter (f)

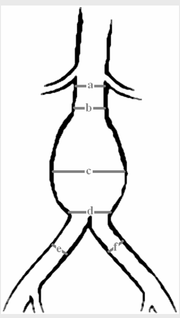

Fig. 3. Critical values

Results

- The method presented in this paper was implemented in C++ in the MeVisLab environment.
- Results were applied to CTA with variations in anatomy and location of the pathology.
- The ACM method for simulating bifurcated stent grafts provided good results.
- The material properties of the stent grafts were simulated suitably and the fit to the vessel wall was realistic (Fig. 5).
- For testing we used two kinds of CT data:
  - CT scans acquired during clinical routine
  - Artificially generated CT abdominal aortic aneurysm data

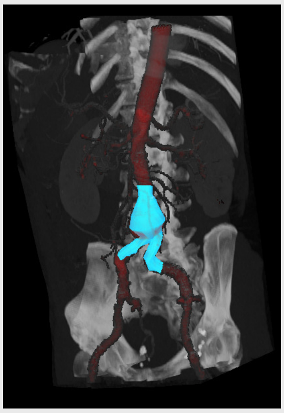

Fig. 4. Segmentation

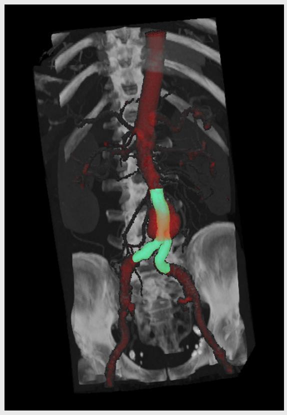

Fig. 5. Simulation

- Performance evaluation on an Intel Xeon CPU, 3 GHz, 3 GB RAM, Windows XP Professional 2002:
  - Using a CT dataset with 512*512*385 voxels and a stent graft consisting of 624 surface vertices, the calculation of the inverse stiffness matrix took about 80 seconds in our implementation
  - An iterative expansion step within the ACM method took less than one second

Conclusion

We segmented various abdominal aortic aneurysms and measured their dimensions. With these measured values we constructed and visualized bifurcated stent grafts in the CT-Data. The method provides realistic results for the simulation of bifurcated stent grafts. Based on this simulation, physicians are supported in choosing a bifurcated stent graft before an intervention. This is very important because a bifurcated stent graft which has not the exact dimensions could shift or cover an artery branch.

References

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