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Virtual Stenting for Carotid Stenosis with Elastic Artery Wall Modeling

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Introduction

Internal carotid artery stenosis (Fig. 1) is a major cause of cerebral ischemia, and increasing degrees of stenosis are associated with an increasing stroke risk [1]. There are two surgical treatment alternatives to heal carotids. One option is endarterectomy (CEA) where vessels are opened to remove the atheromatous plaque substance.

An alternative is stenting (CAS). Here, a stent is deployed in the stenotic region of the artery to reconstruct the original lumen and scaffold vulnerable plaque (Fig. 2). The stent is inserted by a catheter through a small cut in the femoral artery, mostly under local anesthesia. To plan operation, precise determination of the stenosis morphology based on computed tomography angiography (CTA) is often required.

CAS is less stressful on the patient than CEA and is suit-able for most of high risk patients who are not eligible for CEA. Clinical studies [2, 3] have shown that the results of CAS are comparable to CEA. To further improve CAS, pre-interventional simulation of stent expansion is useful, e.g. to analyze the conformity of stent and vessel wall.

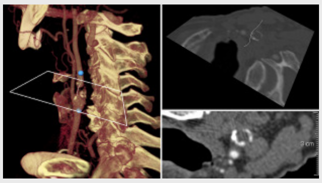

Fig. 1. Left: Carotid stenosis with centerline (white) between two seed points (blue). Right: MPR CT slices belonging to the white box on the left side. Additionally, the centerline is drawn on the upper right image (white).

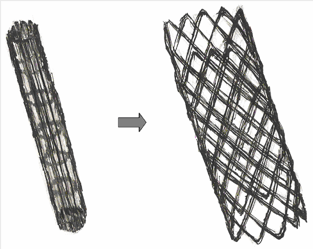

Fig. 2. Left image: Folded non bifurcated tube stent (I-Stent). Right image: Unfolded tube stent.

Methods

The presented methods are based on our previous approaches [4, 5]. Additionally, the simulation includes an explicit model of the vessel wall. It is reconstructed from CTA data and deformed according to properties of physical material using 3D Active Contours Methods (ACM) [6]. Before virtual stenting can be performed, CTA data has to be pre-processed by segmenting the carotids. This is realized by a seed point-based region growing algorithm that classifies artery voxels by their intensity values. Seed points for region growing are given by a start- and endpoint. Subsequently, the vessel's centerline is determined by a skeletonization algorithm [7], and a distance image D is calculated. The centerline is used to create an initial wall contour mesh (Fig. 3, left). After this geometrical construction, the initial wall contour is deformed by a 3D ACM and expanded to the distance transformation D (Fig. 3, middle). Next, the stent model is created by a geometrical method – similar to the initial wall contour. However, ray length is shorter to ensure that the initial stent fits completely into the wall mesh (Fig. 3, right). This model reflects the unexpanded stent after insertion on the catheter. Finally, the initial stent is expanded under the influence of internal and external forces, whereby simultaneous deformations of the stent and the vessel wall occur.

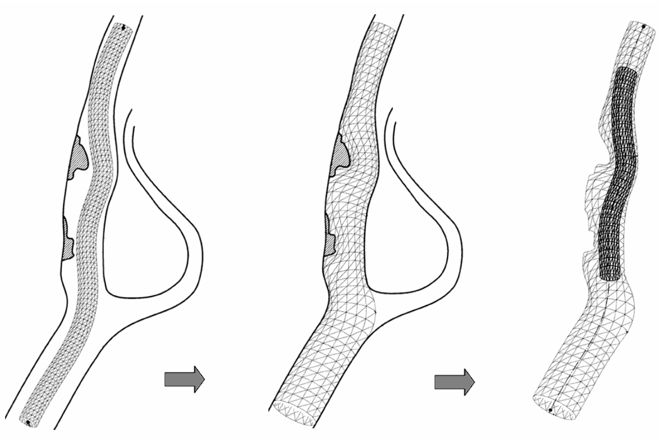

Fig. 3. Principle steps of modeling an elastic artery wall for stent simulation. The initial artery wall inside the vessel is shown on the left side. Segmented artery wall after the initial artery wall has been expanded to the distance transformation (middle). Initial stent that has been constructed inside the flexible artery wall (right).

Results

The presented stent simulation has been implemented in C++ within the MeVisLab platform (see http://www.mevislab.de).

The computing time for a simulation was less than one minute on a PC with an Intel Pentium 4 CPU of 3 GHz, 3.4 GB RAM, and Windows XP Professional.

In Figure 4, strong external forces were chosen for the stent. Thus, the stent model has expanded to its maximum diameter and therefore widened the artery wall model. Compared with pre- and post-operative angiographic images of stented carotid stenosis (Fig. 5), our approach shows promising results for being able to predict the wall appearance and the stent shape.

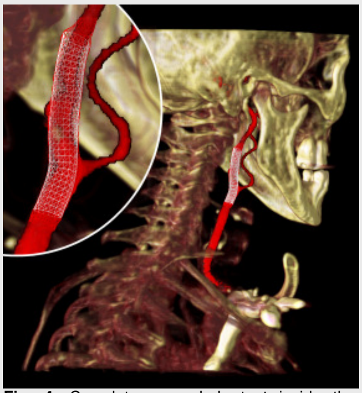

Fig. 4. Complete expanded stent inside the artery wall model. Due to the strong internal forces of the stent model, the artery wall is widened in the stenosis area and smoothed in the bifurcation of the artery.

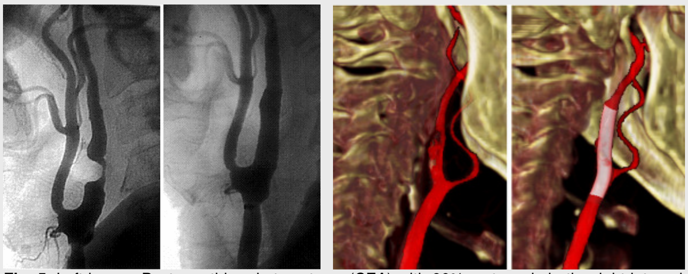

Fig. 5. Left image: Post carotid endarterectomy (CEA) with 90% restenosis in the right internal carotid artery. Second image from the left: Result of the post carotid artery stenting [8]. Second image from the right: Carotid stenosis. Right image: Simulation result of our method with an elastic artery wall.

Conclusions

We presented a fast and practical method for virtual stenting of carotid stenosis. In contrast to our previous work [5], the stent simulation in this paper uses an explicit model of an elastic artery wall. Furthermore, our approach has few user interactions for creating a stent and wall model. Only start- and endpoints of the stenosis and the stent position have to be defined.

In the future, we intend to compare our method with a simulation that is based on the finite element method (FEM) [9] and evaluate it with pre- and postoperative CTA data.

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