

Quantitative Imaging in CTA for Endovascular Repair Planning and Follow-up of Aortic Aneurysms

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Abstract: CTA-based quantitative imaging applications play an important role in the endovascular repair of different types of aortic aneurysms, both for endograft selection or design and post-interventional follow-up.

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OCIS codes: (100.2960) Image analysis; (100.5010) Pattern recognition

1. Introduction

Aortic aneurysms are focal dilations of the aorta occurring primarily in elderly Caucasian males. If not treated, they tend to grow and rupture with a high risk of mortality. Abdominal aortic aneurysms (AAAs) are the most common, occurring between the infrarenal and iliac arteries. Thoracic aortic aneurysms (TAAs) are about three times less common. Most aortic aneurysms are asymptomatic and many are discovered incidentally during unrelated imaging examinations.

Open surgical repair by anastomosis of a synthetic conduit has been performed since the 1950s without major changes. Endovascular Aneurysm Repair (EVAR) was developed in the 1990s involving the deployment and fixation of a stent-graft inside the aorta via catheter to exclude the aneurysm wall from the blood circulation. For correctly excluded aneurysms, this decreases the pressure exerted on the aortic wall, leading to a reduction in size over time and decreasing the risk of aortic rupture. An Intraluminal Thrombus (ILT) is formed in the majority of AAAs. Advantages of EVAR surgery include reduction in recovery time and better 1-year survival rates. The technique is evolving rapidly, allowing endovascular management of complex aneurysms, for example with fenestrated endografts (f-EVAR).

Computerized Tomography Angiography imaging is the gold standard for pre-operative planning and prognosis of aortic aneurysms. High quality imaging that may be obtained with current technology is essential for diagnosis, EVAR candidate selection, endograft sizing and planning. Pre-operative planning software is especially important for cases with complicated anatomies, especially when fenestrated endografts, where holes for subsidiary arteries have to be designed precisely.

One of the post-EVAR complications are endoleaks which are defined as persistent flow into the aneurysm sac due to incorrect sealing, endograft defects or breakdown or retrograde blood flow from collateral vessels. It may lead to recurrent aneurysm growth and possibly rupture requiring re-intervention. Lifelong surveillance is thus required after EVAR, usually performed with CTA imaging after 1,3 and 6 months and then yearly. It has been demonstrated that volumetry correlates better with aneurysm size than largest diameter quantification, but it requires a segmentation of the thrombus, which is very cumbersome for routine and difficult to obtain automatically due to lack of contrast in the thrombus region. Specialized imaging applications are required in order to perform complex tasks such as volumetric quantification or visual assessment of the evolution of the aneurysm, which may provide decision support for the re-intervention of patients whose evolution is negative.

We present some of the developments we performed in the field of CTA-based quantitative image analysis of aortic aneurysm EVAR planning and follow-up, explaining the advantages and results obtained, current needs and future directions in this field.

2. Pre-operative EVAR Planning

Once a patient is eligible for EVAR, an endograft selection must be made based on patient-specific anatomy obtained from the CTA. This process requires a prior vascular image analysis and a workflow for quantification for endograft that may depend on the stent of choice.

This is the basis of our *eVida Aorta* (eMedica S.L.) EVAR planning application, developed using open source software such as the Insight Toolkit and Visualization Toolkit. Currently the application, at its validation stage, is designed only for AAAs only, but we are already working in an extension to TAAs. The design is based on the indications of Mariano de Blas M.D. and Jose María Egaña M.D., respectively heads of the Radiology and Surgery departments at Donostia Hospital (San Sebastián, Spain) which is a reference team with a large experience in the endovascular treatment of aortic aneurysms.

2.1 Vascular Image Analysis

We consider at least the following vascular image analysis steps:

- **Lumen segmentation:** automated lumen segmentation is diffculted by non-uniform contrast arrival due to the length of the vessels. Currently we use an adaptive region growing algorithm with a single user-selected seed for this task.
- **3D reconstruction:** a 3D surface model of the aorta lumen covering the aneurysm area and some relevant subsidiary arteries is obtained from the 3D mask after reconstruction.
- **Centerline extraction and smoothing:** tries to obtain the medial axis of the extracted aorta and branches and it is the basis of most of the subsequent analysis and quantifications. We use a distance-map-based homotopic thinning algorithm for this task.
- **Vessel graph creation:** a vessel graph [1] may be required to analyze the topological structure and properties of the extracted vessel tree. It will also be the basis of some operations such as spurious branch pruning or identifying branches.

In our application, most of these processes are performed through a segmentation and vascular analysis wizard, allowing the surgeons to control some parameters of the process and visualize some intermediate results.

2.1 Vascular Quantification for Endograft Sizing and Design

Once the vascular analysis is performed, diameter and length measurements can be performed on the basis of the extracted centerline and normal sections. Length estimation requires obtaining lengths along paths through the vessel graph. Most of the process is performed in 3D, showing the obtained model of the aorta and branches, centerlines, 3D MPR planes of the original volume and several interactive tools. We consider three types of workflow modes to guide the surgeon through the selection and design process:

- *Standard (endograft) mode:* it is used for the specification of non-fenestrated endograft, when the patient is eligible usually when the aortic geometry is not too complicated and there is free infrarenal space for the fixation of the device. The application guides the surgeon for interactively measuring the diameters of the aortic neck, bifurcation and iliac arteries and lengths between corresponding points.
- *Fenestrated (endograft) mode:* for fenestrated endografts, the standard diameters and lengths are taken plus some additional measurements corresponding to fenestrations (holes designed in the endograft for subsidiary branches). These correspond to the diameter and clock position at the fenestration and aortic diameter at the center of the fenestration for the Celiac Trunk, Superior Mesenteric Artery and Left and Right Renal Arteries.
- *Fenestrated (endograft) mode:* the surgeon is allowed to perform and record length and diameter measurements at the desired locations and in the desired order.

Although some parts of the system are highly automated, special emphasis was made in allowing the surgeon to supervise the whole process. Reference point selection and final diameter selection are currently not automated. In any case, it is important to provide the surgeon with the ability of taking the final decision, by allowing to correct the suggested measurement via interactive tools.

3. Post-EVAR Follow-up

Obtaining a 3D model and volumetry of the aneurysm requires a segmentation of the thrombus. This segmentation is very challenging since the thrombus is not enhanced by the contrast media and sometimes its boundary cannot be distinguished from adjacent structures. Our developments in this area have focused in two main approaches:

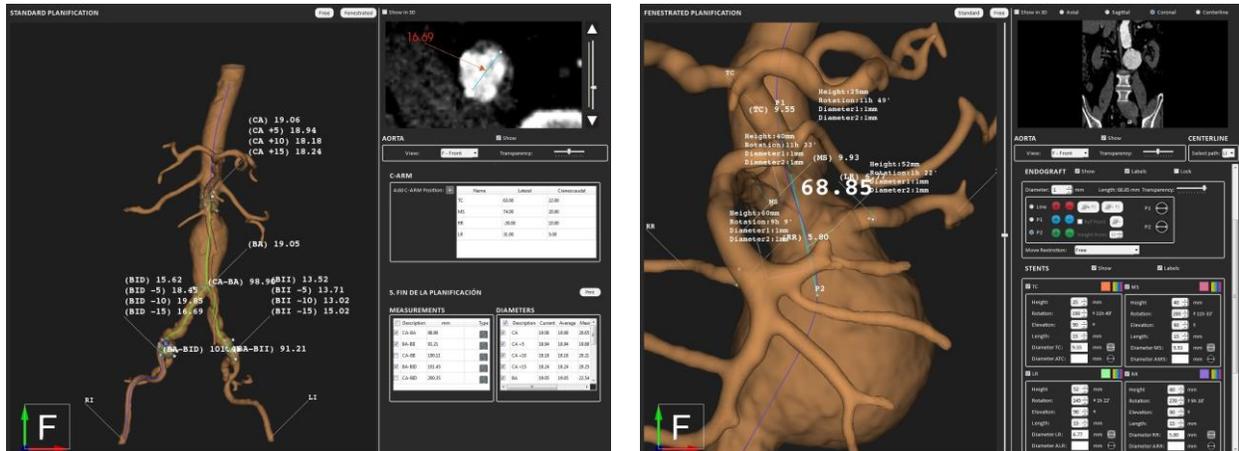


Fig. 1. eVida Aorta (eMedica S.L.) tool showing workflow for standard (left) and fenestrated (right) endografts.

- Radial model [2]: it is a fast segmentation approach designed for simple parameter setting and possible manual correction. The segmentation is based on a priori knowledge of the location and appearance of the aneurysm. An initial contour is corrected for discontinuities and some 3D coherence is imposed on the final model.
- Classification with active learning [3]: thrombus segmentation is considered a classification problem where a Random Forest (RF) supervised classifier is used. Active Learning is a strategy that tries to obtain the most accurate classification and greater generalization using the smallest possible training set by requesting the user to label only the pixels whose uncertainty is greater.

We also developed registration methods comparing the geometrical shape and location of the thrombus for different series of follow-up scans [4]. By registering the aorta lumen along scans, which is assumed to be stable, and then co-registering the obtained thrombi segmentations, we are able to assess the displacement and deformation of the aneurysm sac. The process is a series of consecutive affine, coarse deformable (B-spline based) and fine deformable registration algorithms. Besides direct visual feedback, co-registration of the thrombus of the aneurysm sac provides quantitative values that may be used to provide some criteria for decision support and that may be used to build predictive models of the evolution of the aneurysm based on similarity measurements.

Another possibility is to study the content of the aneurysm sac for possible endoleaks, either by direct segmentation and quantification [2] or by texture analysis [5]. This may provide insight into the sources of sealing problems for difficult cases, or to predict possible outcomes.

4. Conclusions

Medical image analysis tools such as those described in this article may provide quantitative information that is important for the diagnosis, prognosis, EVAR endograft sizing and design and post-operative follow-up, and allow to perform increasingly complex procedures reducing the risk of problems during and after the intervention.

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