Morphological characterization and comparison of coronary arterial trees

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Abstract. *In this work we propose the core work-flow for characterizing and comparing coronary trees from a geometrical point of view. The ultimate goal of this procedure is to develop a set of computational tools that can be used to estimate the likelihood of two heart vasculatures, and therefore be able to establish a similarity criteria between them.*

1. Introduction

Cardiovascular diseases remain as one of the top causes of death and hospitalization in western countries. Particularly in Brazil there are no registry of decreasing mortality or morbidity ratios produced by coronary arterial disease (CAD). Nevertheless, significant economic resources are dedicated to diagnostic procedures that allow early detection of CAD, before myocardial infarction or sudden death ([Mansur and Favarato 2012, Schoenenberger and Erne 2009]).

The usual noninvasive procedures for detection of myocardial ischemia involve functional studies, e.g. exercise test, stress echocardiography or thallium scan. Depending on the outcomes of these studies, it may be necessary to perform an invasive coronary angiography, which is considered to be the gold standard. The pros/cons of these procedures are discussed in [Beslic and Kucukalic-Selimovic 2011]. In the last decade, improvement of CT technology allow the acquisition of high quality images of the heart, [Sun 2010]. The coronary computed tomography angiography (CCTA) has gain popularity as a new (noninvasive) diagnostic tool and is now a common practice in hospitals worldwide.

Over the past decades, increasing efforts have been dedicated towards the development of predictors for myocardial infarction, derived from hemodynamics and anatomical variables ([Endoh et al. 1988, Giddens et al. 1993, Zhu 2003]). However, these studies are based on ex-vivo or 2D angiographic measurements. These studies found that proximal bifurcations of the large arteries in the coronary ostia are prone to develop stenoses, which is related (although not conclusively) to abnormal shear stress patterns on the arterial wall, and, furthermore, is believed to be influenced by bifurcation angle.

To our knowledge there are none previous works using three-dimensional geometrical characterization of arterial anatomy obtained by CCTA to find similarity patterns between stenosed arteries. Furthermore, there are none previous work that identify likelihood of entire coronary vasculatures. Such tools could be useful to compare clinical cases, treatment outcomes and surgical planning, supporting decision making and improving diagnostic accuracy.

The remaining part of this paper describes a methodology for geometrical characterization and comparison of coronary trees, currently under development as part of a multidisciplinary project between the National Laboratory for Scientific Computing (LNCC) and the Heart Institute (InCor).

2. Work-flow

Figure 1 illustrates the proposed methodology for computing all relevant data needed to perform comparisons between arterial trees.

The type of data generated at each step presents high variability, e.g. triangulated meshes, centerlines and features (numeric values). Some of these data will be queried during the posterior data analysis, for example querying all patients with an specific feature at a given artery, or retrieving all patients which are similar (in some sense) to a given one. This presents a challenge from the point of view of the storage strategy to be used. We have decided to use a relational database, which allows that numerical data (like feature values or comparison results) to be efficiently stored and queried. The remaining data, medical images, meshes and centerlines, which can not be directly saved into the database, are kept in the file system in a hierarchical folder structure accessed by the database.

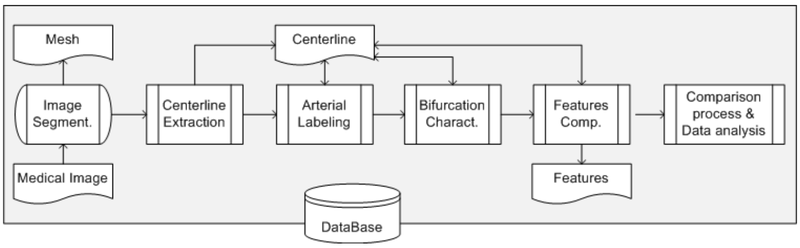

Figure 1. Proposed work-flow to achieve geometrical characterization and comparison of coronary arterial trees.

Image segmentation is the first step of the proposed work-flow. Here, a volumetric CCTA image of the heart is used as input and all visible arteries are segmented by a semi-automated segmentation procedure based on lavel-set techniques, producing initial meshes. The segmentation pipeline used in this work had been proposed in [Bulant 2013] based on [Antiga et al. 2008] and is widely accepted for the segmentation of arterial structures. The ImageLab [1] and vmtk[2] softwares were used at this stage.

Centerline extraction is the procedure by which characteristic curves of all arteries are extracted from the mesh data. These curves represent the idealized lumen radius

[1] `http://hemolab.lncc.br/imagelab`
[2] `http://www.vmtk.org`

of arteries along it course, and are called centerlines. The centerline extraction algorithm was first described in [Antiga et al. 2003], is provided as part of vmtk, and integrated into the HeMoLab[3] software environment, which is used during this step of the pipeline.

Centerline labeling consists of associating anatomical information to the centerline model, by anatomically identification of each arterial segment. This is a key step, because all relevant medical conclusions rely on correct comparison among centerlines representing the same artery on each patient. For example, comparing torsion of all anterior descendant artery (LAD) with proximal stenoses of the patient population.

Bifurcation characterization consists of automatic detection and computation of rising angles and bifurcation planes from the centerline and mesh models in a consistent way ([Piccinelli et al. 2009]). These are numerical quantities that can be directly compared.

Features computation is an automated process through which each arterial model of a vasculature is characterized by a set of geometrical features. Particularly, we include arterial length; tortuosity; minimum, maximum and mean lumen radius, arterial curvature, torsion and combined curvature. Other features like stenosis characterization and spatial location of the lesions ([Dodge et al. 1992]) are part of the ongoing work.

Comparison process between entire arterial trees or subgroups of arteries required the definition of a similarity metric that measures the likelihood of structures based on their features. Different techniques are currently under study and consideration like principal component analysis (PCA), and raw comparison between weighted normalized value of the features.

3. On-going work and future steps

Up to now, we have segmented and computing centerlines for an initial set of 73 patients. Figure 2 shows ten complete coronary trees segmented from corresponding CCTA images. The next steps involve the manual labeling of arteries for all the vasculatures, which has been performed by cardiologists at InCor. Correct definition of metrics and comparison methods in order to perform all-to-all comparisons and analyze the results are matter of ongoing research.

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Figure 2. Sample of ten coronary vasculature segmentations.

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