G Model
BSPC-894; No. of Pages 7
ARTICLE IN PRESS
Biomedical Signal Processing and Control xxx (2016) xxx–xxx
Contents lists available at ScienceDirect
Biomedical Signal Processing and Control
journal homepage: www.elsevier.com/locate/bspc

Association between three-dimensional vessel geometry and the presence of atherosclerotic plaques in the left anterior descending coronary artery of high-risk patients

C.A. Bulant [a,b,*], P.J. Blanco [a,b], A. Clausse [c], A.N. Assunção Jr. [d], T.P. Lima [d], L.F.R. Ávila [d], R.A. Feijóo [a,b], P.A. Lemos [d]

[a] National Laboratory for Scientific Computing, LNCC/MCTI, Av. Getúlio Vargas 333, Quitandinha, 25651-075 Petrópolis, Brazil
[b] National Institute of Science and Technology in Medicine Assisted by Scientific Computing, INCT-MACC, Petrópolis, Brazil
[c] CNEA-CONICET and National University of Central Buenos Aires, 7000 Tandil, Argentina
[d] Heart Institute, University of São Paulo Medical School, INCOR-FM-USP, Av. Dr. Eneas de Carvalho Aguiar, 44, 3rd Floor, São Paulo-SP 05403-000, Brazil

ARTICLE INFO

Article history:
Received 24 June 2016
Received in revised form 24 August 2016
Accepted 29 September 2016
Available online xxx

Keywords:
Geometric risk factors
Left anterior descending artery
Average distal curvature
Coronary computed tomography angiography
Coronary artery disease

ABSTRACT

Geometrical risk factors for coronary atherosclerosis were proposed in the eighties as a complement to fluid dynamic and biomechanical mechanisms for atherosclerotic genesis and progression. Up to date there are no conclusive results in the subject, although several studies suggest that there is an underlying relation between geometry and disease. Coronary computed tomography angiographies of 48 patients were processed, and the left anterior descending artery (LAD) of each patient was geometrically characterized by computing point-wise curvature. Distal averaging of this feature was used as discriminating variable to identify healthy and diseased arteries. Standard statistical analysis was performed and a binary classifier was used to assess the discriminating capability of the so called average distal curvature ($\bar{\kappa}_d$). A significant difference between the distribution of $\bar{\kappa}_d$ in healthy and diseased LADs was found ($p < 0.01$). Performance of the classifier for a cut-off value of $\bar{\kappa}_d = 0.0537\,\mathrm{mm}^{-1}$ in terms of accuracy, sensitivity and specificity is 75%, 70% and 80% respectively. The area under the receiver-operator curve is 0.75. The results presented here support the hypothesis of a significant correlation between low values of average distal curvature and stenotic lesions in LAD arteries.

1. Introduction

Coronary artery disease (CAD) is largely known to be one of the leading causes of death worldwide [1]. Over the last decades, several risk factors for CAD have been identified, comprising mainly modifiable and non-modifiable systemic factors, such as cigarette smoking, diabetes mellitus, hypertension, hypercholesterolemia, familial history [2–4], and genetic contribution to susceptibility for CAD [5–9]. It remains controversial, however, whether systemic risk factors can be fully accounted for the burden and presence of CAD in a given individual [10–12], mainly because they do not explain the localization and non-uniformity of atherosclerosis distribution [13,14].

In this context, a number of biomechanical and geometrical features have been described as factors that would potentially modulate the local atherosclerotic process. And such features are not limited to the coronaries arteries. Specifically, the effect of biomechanical predictors are expressed in terms of several indexes, e.g. wall shear stress and oscillatory shear index [15], and have been supported by extensive evidence [16–20]. In turn, geometrical risk factors [21] suggest that the geometric variability of the human vasculature contributes to the development of atherosclerosis. Several clinical observations back up the geometric hypothesis [22–25]. To date, however, the effects of the later factors remain scarcely reported in the literature, and are not used in clinical practice as conventional risk factors.

Previous efforts to associate lesion presence to shape of coronary arteries focused on the right coronary artery (RCA) [26–28]. This can be attributed to a well defined shape classification (namely: C or Σ) made by visual inspection. In turn, the left anterior descending (LAD) artery lacks of an analogous shape

* Corresponding author at: National Laboratory for Scientific Computing, LNCC/MCTI, Av. Getúlio Vargas 333, Quitandinha, 25651-075 Petrópolis, Brazil.
E-mail addresses: bulant@lncc.br (C.A. Bulant), pjblanco@lncc.br (P.J. Blanco), clausse@exa.unicen.edu.ar (A. Clausse), antonildes@usp.br (A.N. Assunção Jr.), thaples@usp.br (T.P. Lima), avila@incor.usp.br (L.F.R. Ávila), feij@lncc.br (R.A. Feijóo), pedro.lemos@incor.usp.br (P.A. Lemos).

http://dx.doi.org/10.1016/j.bspc.2016.09.023
1746-8094/

Please cite this article in press as: C.A. Bulant, et al., Association between three-dimensional vessel geometry and the presence of atherosclerotic plaques in the left anterior descending coronary artery of high-risk patients, Biomed. Signal Process. Control (2016), http://dx.doi.org/10.1016/j.bspc.2016.09.023

descriptor. Although several geometric features can be used in the characterization of arteries [29], vessel curvature has been used to characterized arteries of several arterial structures, including the internal carotid [30], femoral [31] and cerebral arteries [32], among others. Particularly, curvature values for normal coronary arteries have been reported previously [33].

The present study, focuses on the geometric analysis on the left anterior descending (LAD) artery, searching for any statistically significant correlation between the presence of stenosis and the curvature of the artery. In the present context, arterial geometry is not intended to be used as a standalone tool for lesion detection or diagnostic. In turn, we aimed to present a new potential geometric risk factor for CAD in the LAD: the average distal curvature of the vessel.

The remaining of this document is arranged as follows. Section 2 describes the data and presents the concept of the average distal curvature. Section 3 presents the results of the statistical analysis, which are further discussed in Section 4. Final remarks are outlined in Section 5.

2. Materials and methods

The patient sample used in this work is described in Section 2.1. Computed coronary tomography angiography (CCTA) images were analyzed and processed following a methodology described in [29], and summarized in Section 2.2. Specific aspects of the geometrical analysis for arterial structures are presented in Section 2.3.

2.1. Patient sample demographics

The patient sample used in the present work was originally selected to detect heritability of geometric features on coronary arteries [29], and hence the sample consists of sibling pairs. This is a retrospective study including patients who were referred to CCTA between February 2008 and March 2013 at the Heart Institute (InCor), University of São Paulo Medical School, Brazil. The study protocol was approved by the local ethics committee of the center. The sample selection criterion is described in [29]. A total of 48 patients were selected for this study, consisting of 24 pairs of siblings, 14 females and 34 males patients with an average age of 53 ± 13 years old.

The existence of arterial lesions in the arteries was specified by physicians, and the lesions are characterized according to [34] using a tuple of three variables, namely: stenosis grade, tissue type and lesion position. An artery was considered as diseased when a stenotic lesion of any grade, tissue and position was present in the artery. Altogether, 27 patients presented at least one lesion in the LAD artery, and 21 presented a healthy LAD. The spatial frequency of lesions along the LAD artery for the patient sample is as follows: proximal (21), middle (13) and distal (5). For the purpose of the present study, the target discriminating class is the presence of at least one stenosis (disease, D) as opposed to the complete absence of stenosis (healthy, H).

The demographics of these classes are summarized in Table 1, where continuous variables are expressed as means ± SD. Normality was assessed using Shapiro–Wilk test. Categorical data are described as numbers (percentage). Comparisons of continuous variables were made using Student's *t*-test or Mann–Whitney *U*-test for parametric and non-parametric data, respectively, and χ^2 test or Fisher's exact test for categorical ones. All these tests were performed using STATA 11.0 software (StataCorp., Texas, USA). No statistical significant difference between groups was found, except by the fact that, in our sample, patients with a diseased LAD has an increased probability to suffer stenotic lesions in the other major arteries, the right coronary (RCA) or the left circumflex artery (LCx), $p = 0.01$. Furthermore, all patients have at least one of the major CAD systemic risks factors (smoker, hypertension, diabetes or dyslipidemia). Despite the familial relationship present in the data set, it was shown in [29] that the patient sample is representative from the point of view of the anatomical description of the coronary vasculature, i.e. circulation dominance, lumen radius and arterial occurrence.

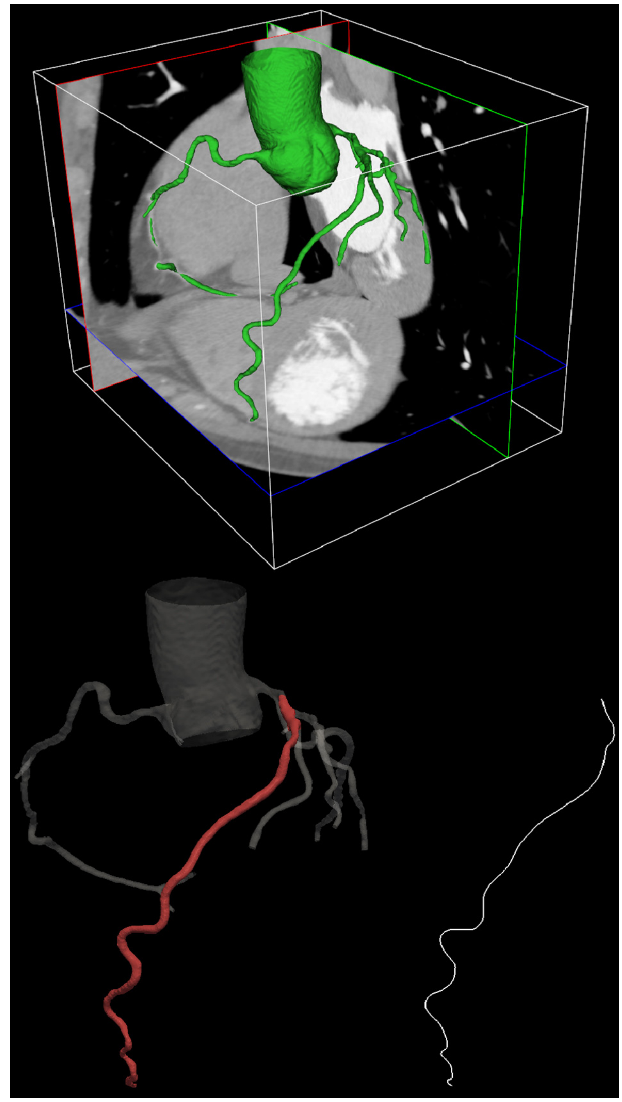

Fig. 1. Illustration of the image processing and centerline construction procedures. Arterial structures segmentation from CCTA (top), mesh post-processing and centerline generation (bottom).

2.2. Data acquisition and processing

The arterial data used in the present study was obtained by means of CCTA. There are also other efficient methods to determine the geometry of arteries, in particular, invasive coronary angiography [37–39], biplane angiography [36], and C-arm scans [40]. However, these other methods may produce distortions of the true curvature of the artery, which is the target of our current interest. Counter to this, noninvasive CCTA images have the advantage of preserving the true spatial disposition of the centerline.

All the medical images were acquired in two devices: a 64-row scanner with a slice thickness of 0.5 mm (Aquilion 64, Toshiba Medical Systems, Japan) and a 320-row scanner system (Aquilion ONE, Toshiba Medical Systems, Japan). All acquisitions were