COMPUTER METHODS AND PROGRAMS IN BIOMEDICINE 128 (2016) 137–158

journal homepage: www.intl.elsevierhealth.com/journals/cmpb

PCA-based polling strategy in machine learning framework for coronary artery disease risk assessment in intravascular ultrasound: A link between carotid and coronary grayscale plaque morphology

Tadashi Araki[a], *Nobutaka Ikeda*[b], *Devarshi Shukla*[c], *Pankaj K. Jain*[c], *Narendra D. Londhe*[c], *Vimal K. Shrivastava*[c], *Sumit K. Banchhor*[c], *Luca Saba*[d], *Andrew Nicolaides*[e,f], *Shoaib Shafique*[g], *John R. Laird*[h], *Jasjit S. Suri*[i,j,k,*]

[a] *Division of Cardiovascular Medicine, Toho University Ohashi Medical Center, Tokyo, Japan*
[b] *Cardiovascular Medicine, National Center for Global Health and Medicine, Tokyo, Japan*
[c] *Department of Electrical Engineering, NIT Raipur, Chhattisgarh, India*
[d] *Department of Radiology, University of Cagliari, Italy*
[e] *Vascular Screening and Diagnostic Centre, London, England, United Kingdom*
[f] *Vascular Diagnostic Center, University of Cyprus, Nicosia, Cyprus*
[g] *CorVasc Vascular Laboratory, 8433 Harcourt Rd #100, Indianapolis, IN, USA*
[h] *UC Davis Vascular Center, University of California, Davis, CA, USA*
[i] *Monitoring and Diagnostic Division, AtheroPoint™, Roseville, CA, USA*
[j] *Point-Of-Care Devices, Global Biomedical Technologies, Inc., Roseville, CA, USA*
[k] *Department of Electrical Engineering, University of Idaho (Affl.), Pocatello, ID, USA*

ARTICLE INFO

Article history:
Received 20 October 2015
Accepted 16 February 2016

Keywords:
Coronary artery
IVUS
Carotid IMT
Machine learning
PCA
Risk assessment

ABSTRACT

Background and objective: Percutaneous coronary interventional procedures need advance planning prior to stenting or an endarterectomy. Cardiologists use intravascular ultrasound (IVUS) for screening, risk assessment and stratification of coronary artery disease (CAD). We hypothesize that plaque components are vulnerable to rupture due to plaque progression. Currently, there are no standard grayscale IVUS tools for risk assessment of plaque rupture. This paper presents a novel strategy for risk stratification based on plaque morphology embedded with principal component analysis (PCA) for plaque feature dimensionality reduction and dominant feature selection technique. The risk assessment utilizes 56 grayscale coronary features in a machine learning framework while linking information from carotid and coronary plaque burdens due to their common genetic makeup.

* *Corresponding author at*: Monitoring and Diagnostic Division, AtheroPoint™, Roseville, CA, USA. Tel.: +1 916 749 5628.
E-mail address: jasjit.suri@atheropoint.com (J.S. Suri).
http://dx.doi.org/10.1016/j.cmpb.2016.02.004

Method: This system consists of a machine learning paradigm which uses a support vector machine (SVM) combined with PCA for optimal and dominant coronary artery morphological feature extraction. Carotid artery proven intima-media thickness (cIMT) biomarker is adapted as a gold standard during the training phase of the machine learning system. For the performance evaluation, *K*-fold cross validation protocol is adapted with 20 trials per fold. For choosing the dominant features out of the 56 grayscale features, a polling strategy of PCA is adapted where the original value of the features is unaltered. Different protocols are designed for establishing the stability and reliability criteria of the coronary risk assessment system (cRAS).

Results: Using the PCA-based machine learning paradigm and cross-validation protocol, a classification accuracy of 98.43% (AUC 0.98) with $K = 10$ folds using an SVM radial basis function (RBF) kernel was achieved. A reliability index of 97.32% and machine learning stability criteria of 5% were met for the cRAS.

Conclusions: This is the first Computer aided design (CADx) system of its kind that is able to demonstrate the ability of coronary risk assessment and stratification while demonstrating a successful design of the machine learning system based on our assumptions.

1. Introduction

The major cause of morbidity in the world is due to cardiovascular disease (CVD). In 2012 alone, CVDs caused 17.5 million deaths worldwide, out of which, 7.4 million deaths were due to coronary arterial disease and 6.7 million were due to stroke or cerebrovascular disease [1]. A higher occurrence of CVD in the young and middle-aged population is observed in the south-east Asia region. About 35% of all such deaths are between the age group of 35–64 years and are estimated to happen in India [2] between the years of 2000 and 2030.

CVD includes coronary artery disease and cerebrovascular disease. These diseases occur due to atherosclerosis – a progressive and slow process of narrowing the artery, interrupting the flow of blood from the heart or to the brain. In severe cases, plaque deposits inside a vessel of the coronary artery and later ruptures causing myocardial infarction Fig. 1a (left).

The current-state-of-art methods for screening the severity of this disease is: computed tomography (CT), ultrasound (US), and magnetic resonance imaging (MRI). Due to radiation, CT may compromise the patients' safety, but it is often used because it computes a calcium score in the coronary artery. Even though MRI was earlier not suited to show benefits for soft tissue characterization [3,4], but now has started to be beneficial, but still lacks the concept of real time scanning. On the other hand, IVUS, though invasive, provides real time data, is less time consuming, and is less expensive [5,6]. Though, IVUS is preferred over CT, because of CT radiation risk, both screening tools lack the ability to stratify risk based on plaque characteristics. This paper utilizes the novel idea of coronary artery risk stratification and assessment using the concept of the genetic makeup of the plaque in the coronary and carotid arteries (Fig. 1a (left, right)).

1.1. *Our first hypothesis*

Honda et al. [7] and de Graaf et al. [8] recently pointed out the need for patients' risk of severity prior to interventional procedures. This severity risk was linked to plaque morphology. Several authors have proposed that plaque in the coronary artery consists of several components such as: fibrous, fibrolipidic, calcified and calcified-necrotic, using modalities like CT, OCT, IVUS and elastography [9–15]. We thus hypothesize that

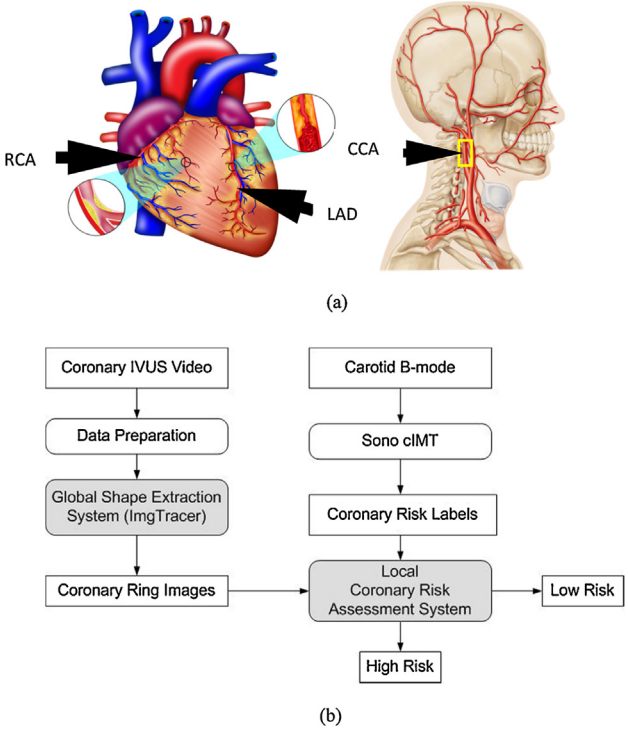

Fig. 1 – (a) (left image): Illustration of blood flow obstruction due to plaque build-up in coronary artery. Show is the two main arteries: right coronary artery (RCA) and left descending artery (LDA). (right image): Illustration of the plaque formation in common carotid artery (CCA), (Courtesy of AtheroPoint™, Roseville, CA, USA). (b) Data preparation and genetic link between coronary artery and carotid artery.