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A new method for IVUS-based coronary artery disease risk stratification: A link between coronary & carotid ultrasound plaque burdens

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ABSTRACT

Interventional cardiologists have a deep interest in risk stratification prior to stenting and percutaneous coronary intervention (PCI) procedures. Intravascular ultrasound (IVUS) is most commonly adapted for screening, but current tools lack the ability for risk stratification based on grayscale plaque morphology. Our hypothesis is based on the genetic makeup of the atherosclerosis disease, that there is evidence of a link between coronary atherosclerosis disease and carotid plaque built up. This novel idea is explored in this study for coronary risk assessment and its classification of patients between high risk and low risk.

This paper presents a strategy for coronary risk assessment by combining the IVUS grayscale plaque morphology and carotid B-mode ultrasound carotid intima-media thickness (cIMT) – a marker of subclinical atherosclerosis. Support vector machine (SVM) learning paradigm is adapted for risk stratification, where both the learning and testing phases use tissue characteristics derived from six feature combinational spaces, which are then used by the SVM classifier with five different kernels sets. These six feature combinational spaces are designed using 56 novel feature sets. *K*-fold cross validation protocol with 10 trials per fold is used for optimization of best SVM-kernel and best feature combination set.

IRB approved coronary IVUS and carotid B-mode ultrasound were jointly collected on 15 patients (2 days apart) *via*: (a) 40 MHz catheter utilizing iMap (Boston Scientific, Marlborough, MA, USA) with 2865 frames per patient (42,975 frames) and (b) linear probe B-mode carotid ultrasound (Toshiba scanner, Japan). Using the above protocol, the system shows the

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classification accuracy of 94.95% and AUC of 0.95 using optimized feature combination. This is the first system of its kind for risk stratification as a screening tool to prevent excessive cost burden and better patients' cardiovascular disease management, while validating our two hypotheses.

1. Introduction

According to the World Health Organization, cardiovascular disease (CVD) is responsible for 31% of the death toll among all the diseases. This amounts to 17.5 million deaths, coronary disease accounts for 7.4 million deaths while cerebrovascular accidents (CVA) or stroke accounts for 6.7 million lives [1]. South-East Asia region is having a speedy occurrence of CVDs in the young and middle-aged groups of the population. It is estimated that between 2000 and 2030, about 35% of all CVD deaths in India will occur among those aged 35 years to 64 years, compared with only 12% in United States and 2% in China [2].

Coronary artery disease and carotid artery disease are the two kinds of CVDs fundamentally caused by atherosclerosis. Atherosclerosis is a progressive process which silently and slowly narrows the arteries, putting the blood flow at risk. It damages the endothelium, primarily due to deposition of plaque in the arteries. In the most severe cases of stable plaque, it also causes considerable blockage as shown in Fig. 1(left) that suddenly ruptures and allows blood to clot in the artery. This can further cause myocardial infarction or heart attack and stroke.

Different imaging modalities have been adapted for screening coronary artery such as: computer tomography (CT) [3,4], OCT [5,6], IVUS [7–11], and elastography [12,13]. Each has its own advantages and disadvantages. Even though, CT is popularly known to quantify the coronary calcium, it possesses a threat due to CT radiation risk. Among the PCI procedures, angiography is normally used. This provides instantaneously an image of stenosis. This helps the cardiologist to proceed and take interventional procedures according to the severity of the patient. However it does not give the sufficient pathological and geometrical information on plaque burden and its composition or ability to characterize the plaque risk. On the other hand IVUS has advantages: It provide real-time grayscale images of coronary vessel wall region along with plaque morphology and its structures. Due to better signal penetration it provides accurate tomography of coronary plaque burden. This helps the cardiologist in: (1) exactly where the stent should be placed in coronary artery; (2) the assessment of condition of patients after an angioplasty or stenting procedure. The American College of Cardiology and the American Heart Association (ACC/AHA) guidelines for PCI state that: the limitation of angiography is overcome by IVUS. Further, with regards to the vulnerability of plaque, IVUS has a greater predicting ability toward vulnerable plaques. It measures all the morphological features (thin-cap fibro atheroma (TCFA), lipid core size and calcification patterns) at once, unlike the other imaging modalities such as OCT [14–16].

Prior to planning stenting and percutaneous coronary intervention procedures, interventional cardiologists using IVUS are very interested in knowing which kind of patients are at high risk and vulnerable to coronary plaque rupture [17,18]. Thus coronary plaque morphology has been the key driver for risk stratification. This morphology has been explored to understand different components of plaque such as fibrous, fibrolipidic, calcified and calcified-necrotic. Even though the diagnostic and screening tools are useful, but, they do not

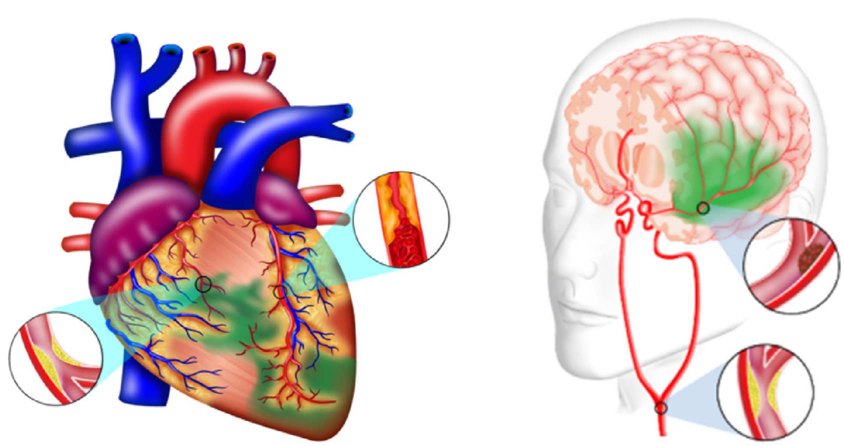

Fig. 1 – *Left image*: Illustration of the blood flow obstruction due to plaque build-up in coronary artery; *Right image*: yellow color plaque formation in the common carotid artery of the neck. Also shown in the illustration is the stenosis formation leading to embolism in the internal carotid artery (surrounding the green color brain tissue region) (Courtesy of AtheroPoint^{TM}, Roseville, CA, USA). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)