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Well-balanced system for coronary calcium detection and volume measurement in a low resolution intravascular ultrasound videos

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ABSTRACT

Background: Accurate and fast quantitative assessment of calcium volume is required during the planning of percutaneous coronary interventions procedures. Low resolution in intravascular ultrasound (IVUS) coronary videos poses a threat to calcium detection causing over-estimation in volume measurement. We introduce a correction block that counter-balances the bias introduced during the calcium detection process.
Method: Nineteen patients image dataset (around 40,090 frames), IRB approved, were collected using 40 MHz IVUS catheter (Atlantis® SR Pro, Boston Scientific®, pullback speed of 0.5 mm/sec). A new set of 20 generalized and well-balanced systems each consisting of three stages: (i) calcium detection, (ii) calibration and (iii) measurement, while ensuring accuracy of four soft classifiers (Threshold, FCM, K-means and HMRF) and workflow speed using five multiresolution techniques (bilinear, bicubic, wavelet, Lanczos, Gaussian Pyramid) were designed. Results of the three calcium detection methods were benchmarked against the Threshold-based method.
Results: All 20 well-balanced systems with calibration block show superior performance. Using calibration block, FCM versus Threshold-based method shows the highest cross-correlation 0.99 ($P < 0.0001$), Jaccard index 0.984 ± 0.013 ($P < 0.0001$), and Dice similarity 0.992 ± 0.007 ($P < 0.0001$). The corresponding area under the curve for four calcium detection techniques is: 1.0, 1.0, 0.97 and 0.93, respectively. The mean overall performance improvement is **38.54%** and when adapting calibration block. The mean workflow speed improvement is **62.14%** when adapting multiresolution paradigm. Three clinical tests shows consistency, reliability, and stability of our well-balanced system.
Conclusions: A well-balanced system with a combination of Threshold embedded with Lanczos multiresolution was optimal and can be useable in clinical settings.

1. Introduction

Coronary artery disease (CAD) and heart attack are the main cause of death in the United States and globally [1]. Progression of atherosclerosis [2] due to calcium, blocks the arteries [3] which can lead to myocardial infarction. Clinical symptoms of atherosclerosis appear late in the CAD [4], and therefore, early prediction of calcium volume is crucial in the diagnosis of coronary artery stenosis which is vital during the planning phase of percutaneous coronary interventional (PCI) procedures [5,6]. An illustration of the stenotic coronary artery is displayed in Fig. 1.

Intravascular ultrasound (IVUS) is mostly chosen over other imaging modalities such as CT, OCT, and MRI due to the reasons such as its safety, low acquisition, economics, and easy to use with real-time diagnosis [7,8]. Estimating the calcium regions in IVUS frames and its ensemble over entire IVUS video helps to compute calcium volume [5,6].

Previously, a team led by Suri [9–12] had estimated coronary calcium volume by considering equally distant sample frames in the coronary artery video. It was recent that full coronary video has been

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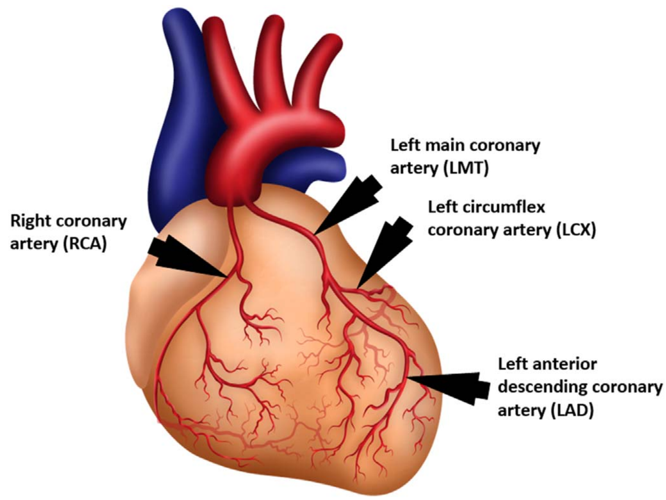

Fig. 1. Illustration of coronary arteries showing plaque formation and stenosis (Courtesy of AtheroPoint™, Roseville, CA, USA.

taken into consideration by Araki et al. [5] based on four soft classification methods such as Threshold-based [13], Fuzzy c-Means (FCM) [14], K-means [15] and Hidden Markov Random Field (HMRF) [16]. In this study, there was no attempt to improve the speed of the calcium detection architecture. To overcome the challenge of processing time for entire video, Banchhor et al. [6] considered five multi-resolution techniques [17] such as: bilinear [18], bicubic [19], wavelet [20], Lanczos [21] and Gaussian pyramid [22]. The concept of down sampling was combined with soft classification paradigm.

While taking the consideration of the entire video for accurate volume computation, challenges like motion artifact [23,24] and non-linear noise due to imaging setup [25] degrade the image quality of the IVUS video frames causing it to be low in resolution. The conversion from DICOM format (16 bits a pixel) to lossless JPEG format (8 bits a pixel) further degrades the video frames [26]. Due to the above factors, there is a bias due to over-estimation leading to unreliable volume estimation. Therefore, there is a clear need for removing this bias while keeping the speed paradigm intact. Bias removal is popular in medical imaging [27,28] and is necessary for the system to be well-balanced while keeping accuracy and workflow speed. Thus, our main contribution is a design of a system-based paradigm while maintaining clinical accuracy and workflow speed, categorizing this as a novel system.

2. Material and methods

2.1. Patients demographics

In a single-center study [29] between July 2009 and December 2010, 19 patients IVUS data were chosen who underwent PCI using iMAP (Boston Scientific®) IVUS examinations. Among the 19 patients selected, 16 were men and 3 women in the age group of 36–79 years. Eleven patients had a calcified location on the left anterior descending, seven on right, two on left circumflex and two on left main coronary artery. Out of 19 patients, nine had proximal, six at the middle and four at a distal location. The mean hemoglobin was 6.04 g/dl and mean total, LDL, and HDL Cholesterol was 169 mg/dL, 97 mg/dL, and 46 mg/dL, respectively. Eleven patients from the pool of 19 were smokers. Before performing PCI procedures, a mixed dose of clopidogrel (75 mg/d) and aspirin (100 mg/d) were given to the patients.

2.2. Data acquisition

During data set acquisition, a full ethics review by the respective institutional review board and written informed consent from all the patients was obtained. A 40 MHz IVUS catheter (Atlantis® SR Pro, Boston Scientific®) was used for data acquisition. MATLAB® 2013a (Math Works, Inc.) was used for the image analysis. This clinical study did not consider gating method while performing the data acquisition. For simplicity of the model, we have assumed that there is no repetition of frames and gap between the frames is negligible. A standard protocol was used during all the computations using the resolution factor of one pixel =1/60 mm=0.0167 mm.

2.3. Region of Interest (ROI) estimation

The vessel wall region is the region between the external elastic lamina (EEL) interface and internal elastic lamina (IEL) interface. For

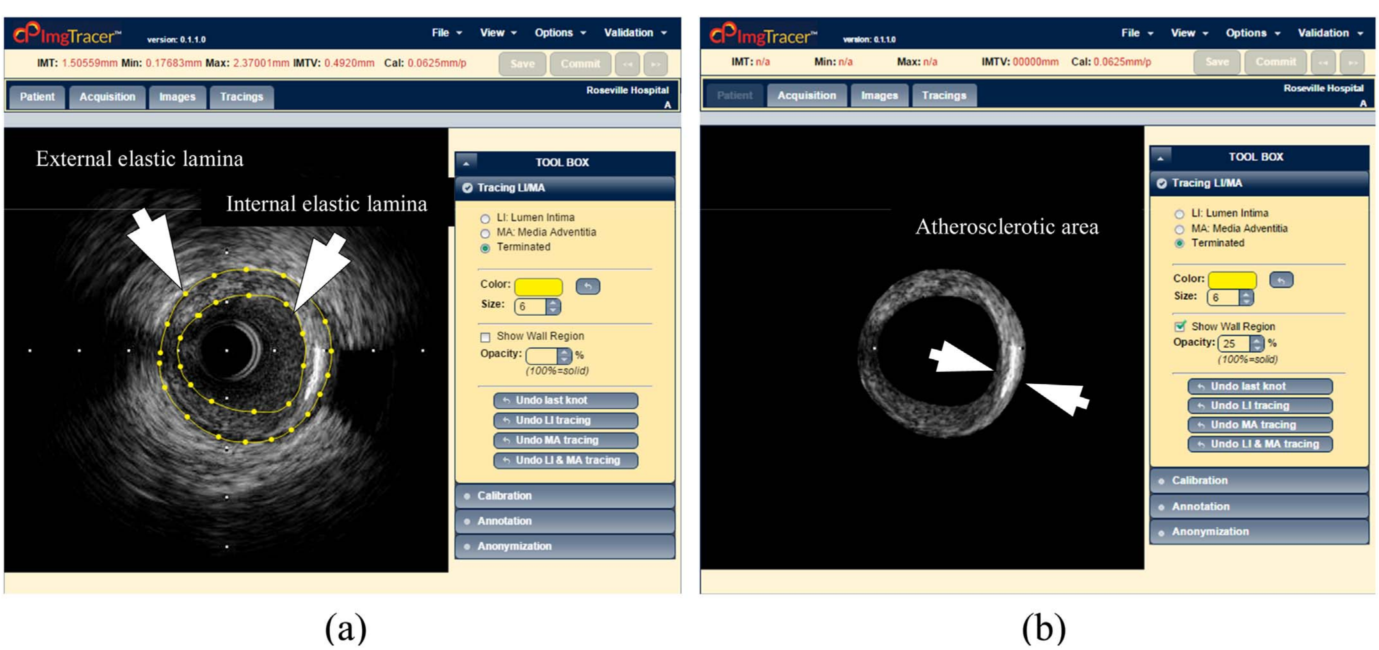

Fig. 2. (a) Inner and outer yellow rings in the vessel wall region indicate the internal elastic lamina (IEL) and external elastic lamina (EEL), respectively obtained by manually tracings using ImgTracer™.
(b) Atherosclerotic greyscale ring image computed from the raw input image (Courtesy of AtheroPoint™, Roseville, CA, USA) (Courtesy of source [6]).