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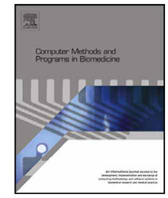

Characterization of coronary plaque regions in intravascular ultrasound images using a hybrid ensemble classifier

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ABSTRACT

Background and objectives: The purpose of this study was to propose a hybrid ensemble classifier to characterize coronary plaque regions in intravascular ultrasound (IVUS) images.

Methods: Pixels were allocated to one of four tissues (fibrous tissue (FT), fibro-fatty tissue (FFT), necrotic core (NC), and dense calcium (DC)) through processes of border segmentation, feature extraction, feature selection, and classification. Grayscale IVUS images and their corresponding virtual histology images were acquired from 11 patients with known or suspected coronary artery disease using 20 MHz catheter. A total of 102 hybrid textural features including first order statistics (FOS), gray level co-occurrence matrix (GLCM), extended gray level run-length matrix (GLRLM), Laws, local binary pattern (LBP), intensity, and discrete wavelet features (DWF) were extracted from IVUS images. To select optimal feature sets, genetic algorithm was implemented. A hybrid ensemble classifier based on histogram and texture information was then used for plaque characterization in this study. The optimal feature set was used as input of this ensemble classifier. After tissue characterization, parameters including sensitivity, specificity, and accuracy were calculated to validate the proposed approach. A ten-fold cross validation approach was used to determine the statistical significance of the proposed method.

Results: Our experimental results showed that the proposed method had reliable performance for tissue characterization in IVUS images. The hybrid ensemble classification method outperformed other existing methods by achieving characterization accuracy of 81% for FFT and 75% for NC. In addition, this study showed that Laws features (SSV and SAV) were key indicators for coronary tissue characterization.

Conclusions: The proposed method had high clinical applicability for image-based tissue characterization.

1. Introduction

Intravascular ultrasound (IVUS), a catheter-based ultrasound, is known as one of the most useful diagnosis modalities for identifying the existence of coronary plaque [1]. IVUS can acquire images in real time. It provides two dimensional (2-D) cross sectional images of vessels. Angiography is another method for the diagnosis of coronary disease. It depicts a 2-D contour of the lumen. However, IVUS is more widely used in clinical applications because it can accurately estimate the lumen, plaque size, vessel wall dimensions, and compositions of the plaque [2–4].

Traditional IVUS examination assesses the distribution and compositions of the atherosclerotic plaque through visual inspection. Its disadvantage is that inter- and intra- observer interpretation might be variable [1,5]. It is also relatively difficult to track the history of medication for patients. To overcome these limitations, plaque characterization approach has been introduced. This approach allows clinicians to choose appropriate clinical intervention and assess the efficacy of therapy by providing accurate diagnosis information of a plaque region [6]. The most useful technique in clinical setting is virtual histology (VH) IVUS. VH analyses IVUS data based on radio frequency of backscattered ultrasonic signal [7–10]. VH characterizes a plaque region into fibrous tissue (FT), fibro-fatty tissue (FFT), necrotic core (NC), and dense calcium

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(DC). It provides a color-coded image according to results of plaque characterization. Results of VH have been verified to be highly correlated with those of histopathology in *in vivo* studies [6,11]. However, VH is not always available because it needs a specific console and software [12]. In addition, only one frame per cardiac cycle can be captured because it uses electrocardiogram gated acquisition (peak R-wave) method. Moreover, VH provides a low longitudinal resolution [4,13–16].

To address these limitations, image-based plaque characterization has been tried. Zhang et al. [17] have classified plaque region into three kinds (hard calcified plaque, hard non-calcified plaque, and soft plaque) and obtained an accuracy of 75.82%. Vince et al. [6] have characterized plaque region by using several texture analysis approaches (First-order statistics (FOS), Haralick's method, Laws method, Neighborhood gray-tone difference matrix, and texture spectrum method). Taki et al. [18] have suggested an image-based histological method to address the limitation of low longitudinal resolution of VH. However, this approach considered FT and FFT as one class. Athanasiou et al. [15] have characterized plaque region into four tissues (FT, FFT, NC, and DC) by using random forest (RF). Its sensitivity for FFT was 63.7%. After a few years, Taki et al. [4] have characterized plaque region into three tissues by extracting textural features including local binary pattern (LBP), modified run-length, and neighboring gray-level. They obtained an accuracy of 73%. Vasilis et al. [19] have suggested a genetic fuzzy rule-based classification model and obtained an accuracy of 74.17%.

These current image-based approaches suffer from three limitations. First, they have difficulty in characterizing FFT and FT. It is important to characterize FFT similar to lipid components to detect vulnerable plaque [19]. Second, they usually have low accuracies for NC (56.6% [4] or 72.95% [19]). However, classification of NC is a key issue in plaque characterization technique [15,20]. If NC area is increased in a plaque region, the probability of acute coronary disease occurrence is high. Lastly, plaque characterization is needed for all IVUS image sequence to analyze vulnerable plaque of a patient comfortably [4,12,19,21–23].

In this study, a novel image-based classification model of coronary plaque characterization in intravascular ultrasound images was introduced. Few studies have attempted to use texture features to characterize coronary plaque in intravascular ultrasound images. Existing studies have characterized coronary plaque regions mostly by using a single classifier such as feed forward neural network, support vector machine, or random forest. However, this study used a hybrid ensemble model to improve the accuracy of image-based coronary plaque characterization. This method also preliminarily classified NC/DC from a FT/FFT group based on different pixel characteristics of plaque tissues. To the best of our knowledge, such studies have not been reported previously.

To characterize plaque regions in IVUS image, this study suggested a hybrid ensemble classifier and quantitatively evaluated its classification accuracy. The rest of this study was organized as follows. Section 2 introduced overall processes used in the characterization, including feature extraction, feature selection, classification, and validation. Sections 3 and 4 provided experimental results and discussions, respectively. Finally, Section 5 concluded the paper and identified future directions.

2. Materials and methods

To implement an image-based plaque characterization, the proposed method allocated pixels to one of four tissues (FT, FFT, NC, and DC) through processes of border segmentation, feature extraction, feature selection, and classification as shown in Fig. 1. Sensitivity, specificity, and accuracy were calculated to determine the performance of the proposed approach. A ten-fold cross validation approach was used to determine the statistical significance of the suggested method.

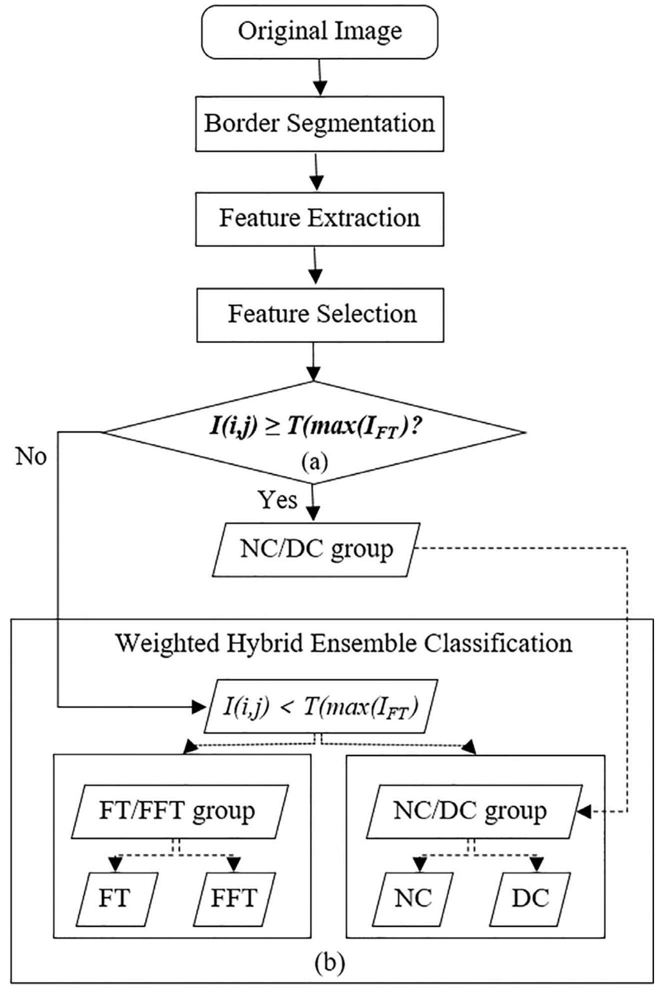

Fig. 1. Overall flowchart of the proposed method for tissue characterization from sequential IVUS images. Threshold value (a) was used to divide the NC/DC group from the FT/FFT group. The hybrid ensemble classification (b) was employed to characterize four tissues.

2.1. Image acquisition and border segmentation

Grayscale IVUS images and their corresponding VH images were acquired from eleven patients using a 20 MHz catheter (Fig. 2). A total of 252 IVUS frames were used to image these eleven patients with unstable angina who underwent coronary artery stenting. Specifically, measurements of NC and DC (for example, area and volume) by VH-IVUS were considered. Ages of these patients ranged from 45 to 83 years. Of these 11 patients, six (54.5%) were males. If patients had an IVUS-detected thrombotic lesion, left main disease, or chronic total occlusion, they were excluded from this study. Written informed consent was obtained from each patient. The study was approved by the Institutional Review Board of Ulsan University Hospital. IVUS frames were obtained with phased-array catheters (Eagle Eye 2.9-F 20 MHz, Volcano Corp., Rancho Cordova, CA, USA) using a dedicated VH-IVUS console and VH software. To reduce bias, 20–25 frames were selected for each patient, each of which included all plaque types (fibrous tissues, fibro-fatty tissues, necrotic core, and dense calcium). IVUS images had 400 × 400 pixels. IVUS image sequences were acquired with a pull-back system at a speed of 0.5 mm/s. Vessel lumen and media-