

A CAD system for Atherosclerotic Plaque Assessment

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Abstract—Recently, several atherosclerotic plaque characterization methods were proposed based on plaque morphology assessed through 2D ultrasound. It is of extreme importance to establish an objective quantification measure which allows the physicians to determine the risk of plaque rupture, and thus, of brain stroke. Having these, sometimes complex, measures easily and quickly assessed might prove invaluable for the physician an patient alike. This paper is a first attempt to incorporate such scores in a user-friendly software platform for *Computer-aided Diagnosis*. This tool provides a way to objectively and interactively characterize the atherosclerotic plaque, to store relevant patient data and to use several processing tools to outline the plaque and compute different echogenicity measures. Combinations of these features are used to provide two objective measure with clinical significance, known as activity index and enhanced activity index.

I. INTRODUCTION

Carotid atherosclerosis represents the most important cause of brain stroke. The degree of stenosis (arterial lumen narrowing) is up to now considered one of the most important features for determining the risk of brain stroke. This feature, together with other patient information such as age, health, clinical history and risk factors, are the main criteria for determining the risk of stroke and thus to decide about surgical intervention to remove the plaque [1]. Ultrasound is a suitable imaging technique to assess this pathological condition mostly because it provides real-time visualization and interpretation of the carotid plaques, it is non-invasive, does not involve ionizing radiation and it is cheap.

Past studies established a strong correlation between plaque morphology (appearance), including echogenicity (degree to which sound waves are reflected by a tissue) and texture, in ultrasound images and its risk of rupture [2], [3], [4]. Furthermore, studies have been developed aiming to statistically describe the plaque morphology, making use of power-spectrum [5], Wavelet extracted features [6], stratified

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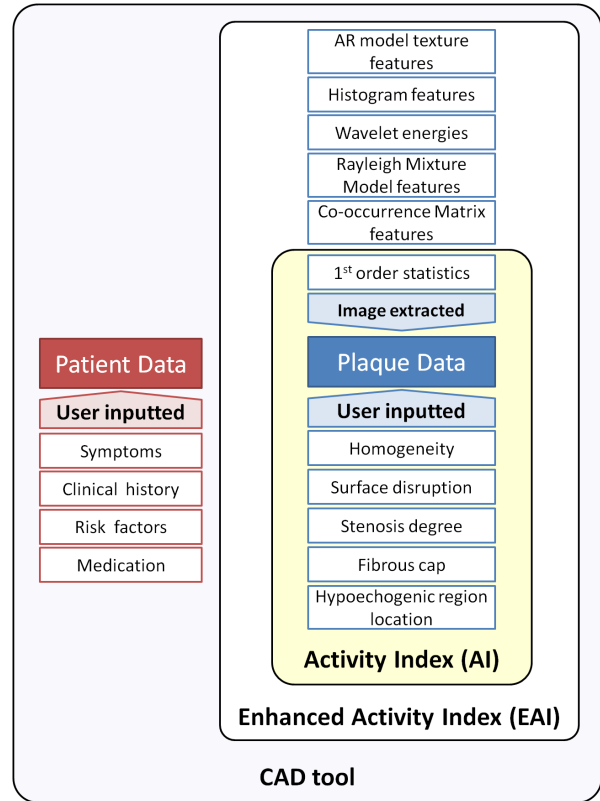


Fig. 1. Data used in [©]AtheroRisk and features required/extracted for calculus of plaque activity indexes

Gray-Scale Median (GSM) analysis and color mapping of the plaque [7], textural features [8] and a combination of the last two [9], [2]. Moreover, a study conducted in [9] revealed that the GSM and the P_{40} are two features significantly correlated to plaque symptoms. The GSM is used to classify plaques as hypoechogetic ($GSM < 32$) or hyperechogetic ($GSM > 32$) [9], [2]. The total percentage of hypoechogetic pixels (P_{40} defined as the percentage of pixels with gray levels below 40, potentially reveals the amount of ulcerated tissue, an indicator of plaque instability.

A seminal work [9] proposed a clinical index, known as *Activity Index* (AI), to quantify the degree of plaque activity, based on a combination of plaque features. This measure may have relevant clinical significance in therapeutic decision in patients with asymptomatic carotid lesions or with

symptomatic stenosis with moderate obstruction.

Building upon the AI score, the work in [10] increased the feature space (see Fig. 1) and improved the classifier, providing an *Enhanced Activity Index* (EAI) method with higher accuracy, when compared with AI. Considering other state-of-the-methods, a direct effectiveness comparison is not possible because the ultrasound data used is not the same. Still, the accuracy margin between the EAI method (88%) and comparable methods ($\approx 74\%$ in [8], [5] and 83.7% in [6]) is large enough to argue that the proposed method indeed outperforms other related plaque classification approaches.

The intent of this paper is to extend the paradigm of AI and EAI to the medical community by proposing an intuitive and objective tool for ultrasonic plaque analysis. This tool aims to quantifying the plaque *activity index* and *enhanced activity index* based on features inherent to the patient and also on a considerable set of plaque features, as described in Fig. 1.

II. METHODS

The atherosclerotic risk assessment software ($\text{\textcircled{A}}AtheroRisk$) functions in the framework depicted in Fig. 2, and has the final purpose of distinguishing between symptomatic and asymptomatic lesions, consequently, providing an accurate description of the vulnerable plaque. It is implemented in C++ and uses the open-source *CImg library* [11] for image management. This low-level implementation allows the software to be very efficient in doing the heavy processing it requires and to be stand-alone.

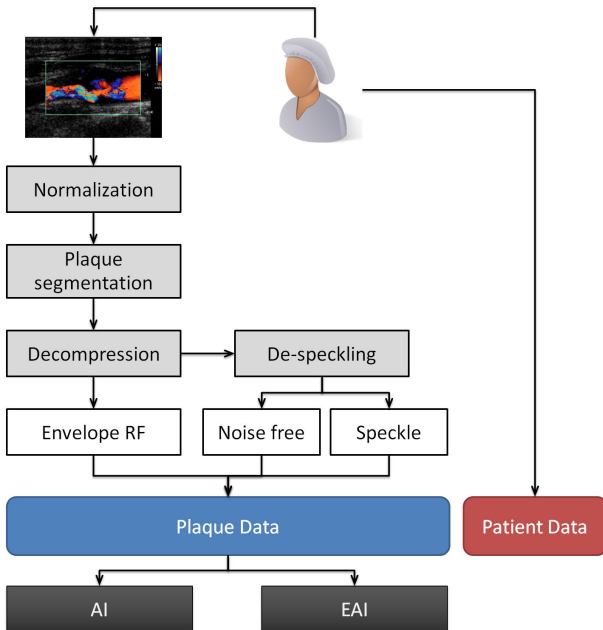


Fig. 2. $\text{\textcircled{A}}AtheroRisk$ framework diagram.

The user has access to a set of buttons/commands to upload, process and save images, input information, calculate the risk scores and store results. These commands are divided in several sections (see Fig. 3), now described from left to right. To help locate commands in the GUI, the reference

marks (1) to (11) present on Fig. 3 are used. Notice that, for the moment, the application envisage both clinical and research purposes, hence together with the display of plaque activity scores, other intermediate images/results can be generated.

a) *Patient Data*: where all relevant data related to the patient is stored. This includes general purpose fields (for identification, name, age and gender) and the following subsections.

- 1) *history*, providing clinical symptoms and interventions as well as elapsed time from their occurrence in units of weeks, months or days.
- 2) *risk factors*, providing clinical conditions related to carotid atherosclerosis.
- 3) *medication* currently being taken by the patient.

b) *Plaque*: This section allows the physician to input data related to the plaque as well as compute some of its features. Degree of stenosis, plaque homogeneity/heterogeneity, existence of plaque surface disruption and of plaque fibrous cap are examples of vital features for the final classification scores. Notice that some options turn on/off other dependent options.

c) *Images*: Allows to load the B-mode US image (2), containing the plaque slice to be processed, and the Doppler image to assist in the image segmentation procedure (see paragraph d) and Fig. 5). Simultaneously, it's possible, at any stage, to visualize all loaded and processed images onto the software buffer (see Fig. 4).

d) *Process*: Additionally, a set of commands are provided to normalize the image (3), segment the plaque *Region Of Interest* (ROI) (4), decompress the BUS image back to it's original ERF image (5) [12], extract the image speckle and despeckle fields (6) [12] and extract all the required features (7) from the outputs of the previous processing steps. Also, all images in the software buffer can be stored to disk in (11) for future reference or re-processing.

Final EAI [10] and AI [3], [13], [9] scores are computed in (9) and (10) respectively. They both provide a final 0–100 score, where a higher score is typical of an active plaque, whereas a low score indicates a stable plaque.

e) *Without sections*: There are some functions with no section boxes. At the top of $\text{\textcircled{A}}AtheroRisk$ it's possible to load or save the current project (1) and also exit the software. At the bottom-left corner a message box displays intermediate results, populated during the processing steps. This box can also be populated at any time with the current features using the respective button on the bottom-right corner of $\text{\textcircled{A}}AtheroRisk$. In that area an histogram of the plaque ROI can be generated, such as in Fig. 6.

III. RESULTS

Having described the main features of the proposed $\text{\textcircled{A}}AtheroRisk$ tool, it is now important to present some details through an example.

Fig. 3 shows the tool's main window with a theoretical example of an hypertensive 73 year old male patient with a right-sided atherosclerotic plaque that lead to an amaurosis

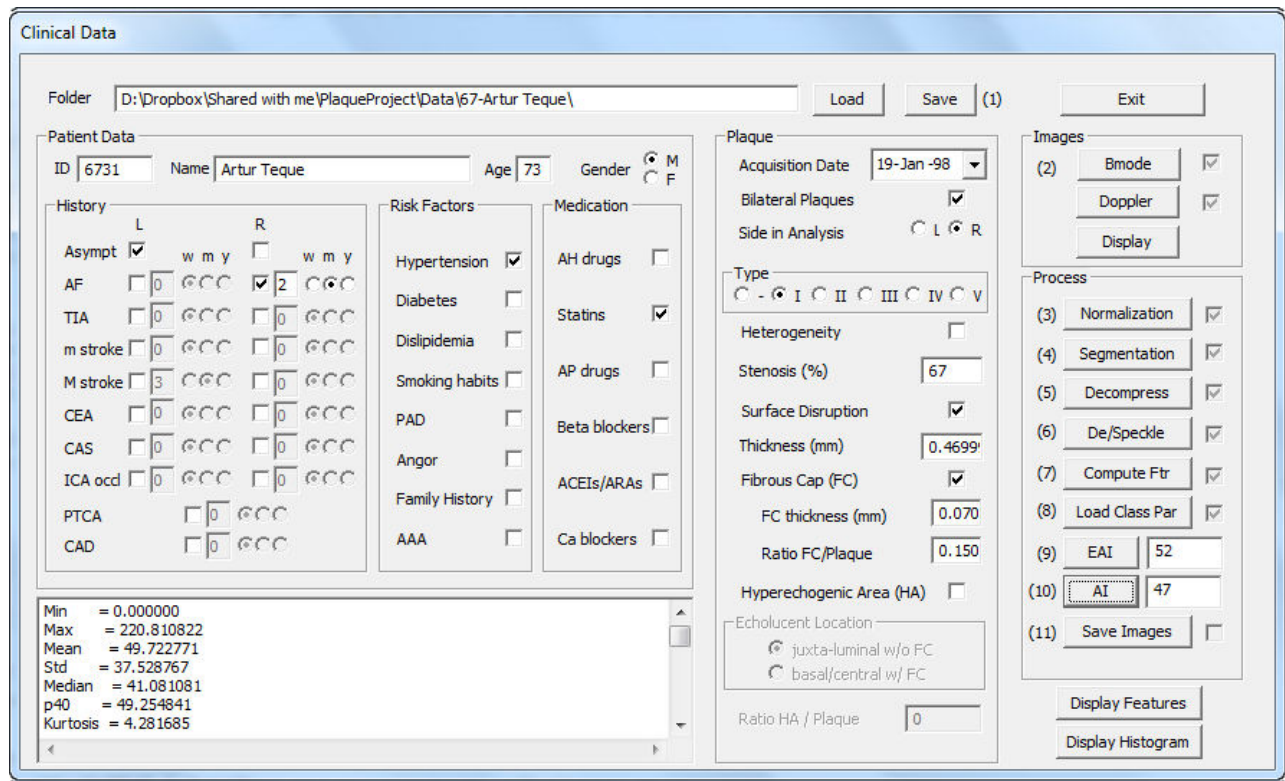


Fig. 3. ©AtheroRisk main GUI. A virtual example is presented where all "steps" are completed except for saving the buffer images.

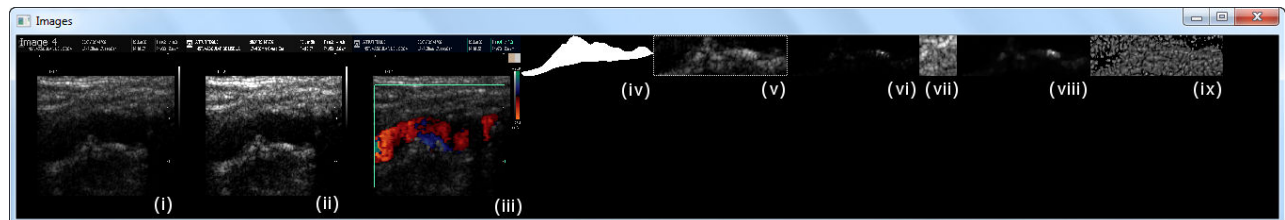


Fig. 4. Software image buffer with all loaded and intermediate images. (i) Loaded B-mode image; (ii) Normalized i image; (iii) Loaded Doppler image; (iv) Plaque ROI mask (segmented from ii); (v) Plaque ROI bounding box; (vi) retrieved RF image from v through logarithmic decompression (normalized for display); (vii) inputted homogeneous region used for decompression parameters; (viii) Speckle image; (ix) DeSpeckle image.

fugax 2 months ago. The plaque has a fibrous cap and produces an estimated stenosis of 67%. He also has another plaque on the left carotid, but it's asymptomatic. After inputting patient and plaque features it is recommended to follow the numeration in the GUI from (1) to (11) to save, load, process data and display results.

For sake of compatibility and with other medical software, ©AtheroRisk projects are saved in a XML file and all images in RAW format.

The first processing step, normalization (3), requires user input (via mouse) of one lumen and one adventitia pixels, which are then used to adjust the intensities of all other pixels as proposed in [9](see Fig. 3.(ii)). As seen in Fig. 2, Histogram features are extracted from this normalized image.

Decompression step (4) requires an user segmentation of a non-null homogeneous region of the normalized image by inputting its bounding pixels (in the same way as in the normalization step (3)). This region is then used to

estimate the parameters of the log-compression model [12] and retrieve an image closer to the original RF image. As seen in Fig. 2, from this, *Rayleigh Mixture Model* (RMM) features are extracted.

The following processing steps do not require more user inputs. At this stage all images are available in the software buffer (see Fig. 4) and all 114 required features are computed. Computation of the AI and EAI results in 47 and 52 for our patient respectively.

The decision to submit to surgery is now dependent on the physician criteria. A simple (and typical) criteria to define a cut-off is to look at the point on the *Receiver Operating Characteristic* (ROC) plot (Fig. 7) where the sensitivity equals specificity. In the present situation, the plaque is non vulnerable has its score is lower than both cut-offs for AI and EAI, hence the patient should not be appointed to surgery. Performance of the method, discussed in more detail in [10] and [12], evaluated as the area under the curve are 64.96%,

73.29% and 90.57% for DS, AI and EAI, respectively.

Finally, if more detailed information is desired, a quick guide manual for the software can be found at [14].

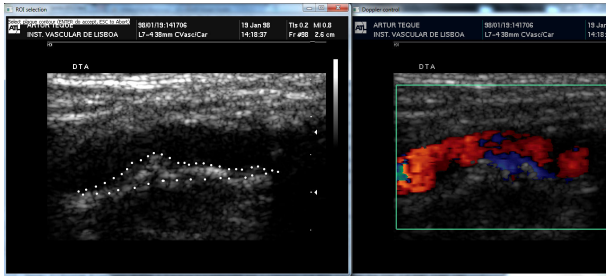


Fig. 5. Manual B-mode segmentation procedure providing. If available, the Doppler image is also presented to aid delineating the "Plaque contour".

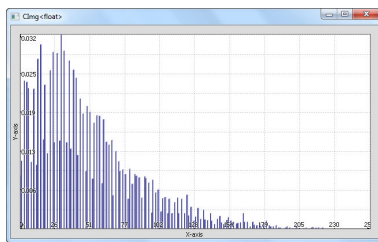


Fig. 6. Histogram of the normalized B-mode plaque ROI.

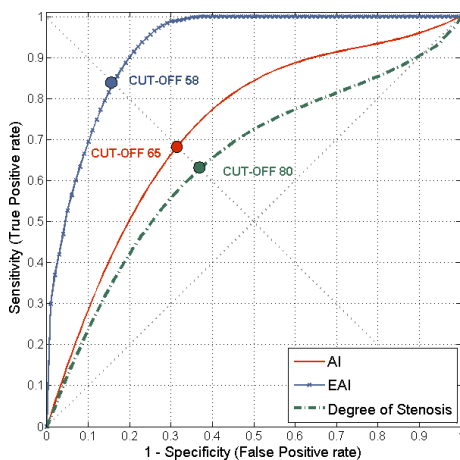


Fig. 7. Classifier Receiver Operator Curve for the test dataset with cut-Off criteria example of equal sensitivity and specificity. See Details on [10]

IV. CONCLUSIONS

This paper proposes a stand-alone software platform for CAD of atherosclerotic plaque risk via ultrasonic imaging, whose main features were here demonstrated and exemplified. This tool allows the physicians to upload their own medical data, to perform their own studies by using suitable processing tools provided, to compute two *activity index* scores, to store and share their information/results.

Hence, this tool is useful because it provides an objective characterization of the plaque morphology and quantification of risk of rupture.

Although currently beyond the scope of both AI and EAI, the specification of patient clinical history including early symptoms, medication and habits, through the proposed CAD application could improve the accuracy of plaque diagnosis.

Also, future versions will permit re-training the classifier in the users own dataset, which might be important if the physician is worried about population variability or just wants to augment the training set to increase classification performance.

Moreover, it is our goal to simultaneously provide this platform as an online service. Here the physician and patient data (without identification) are kept in a web server's database. This will allow the analysis of data coming from different clinical facilities, acquired under different conditions and processed by different physicians, which can, in a near future, be used in a large-scale study.

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