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THREE DIMENSIONAL RECONSTRUCTION OF THE COMPONENTS OF THE CAROTID PLAQUE FROM STANDARD CT MEDICAL IMAGES

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ABSTRACT
The present study compares plaque and calcium volumes between sixteen diseased human carotid arteries. Half were from symptomatic patients, and half were from asymptomatic patients. In-house software was developed for the 3-D reconstruction of the plaque components from computerized tomography (CT) images. Results revealed higher mean total volume (TV) in the symptomatic group compared to the asymptomatic group. In contrast, the mean ratio of calcium volume (CV) to TV was lower for the symptomatic group compared to the asymptomatic group. This shows that symptomatic patients have a significantly greater plaque burden with minimal plaque calcification. The process of acquiring the data helped understand what tools/features are needed to conduct this work. One important feature of this software is the ability to create automated regions of interest (ROI) in addition to simple manual selection/modification of the ROIs in a GUI environment.

Keywords: Plaque volume; calcium; carotid artery; CT image.

INTRODUCTION
Angiograms have been used for many years to assess the severity of carotid artery stenosis. Methods guided by North American symptomatic carotid endarterectomy trial (NASCET), European carotid surgery trial (ECST) are popular among physicians, but all those techniques measure the degree of stenosis differently [1]. This motivated researchers to acquire CT images rather than angiograms such to obtain the 3-D geometry as well as information about plaque components. Wintermark et al. found a 72.6% agreement between CT and histological examination in carotid plaque characterization [2]. In addition, research has shown a correlation between hypercholesterolemia (cardiovascular risk factor) and plaque components using CT images to determine plaque component volumes [3]. The paper suggests ranges of Hounsfield units (HU) to be used to identify plaque components. Here we present the methodology for the development of software to analyze CT images to select ROI to determine plaque component volumes and construct a 3-D model of the plaque.

METHODS
Software (*cttech*) (Figure 1) was written in *MATLAB* (The MathWorks^{TM}, Natick, MA) to analyze medical images (CT, MRI). The software is user-friendly and allows for manual modification of automated functions. This software gives greater control than some commercially available software packages for image segmentation. The software draws polygons on the images to identify the ROIs (Figure 1). An auto-polygon feature can be used to identify regions that fall within a certain intensity range selected by the user. The polygons can then be edited manually, a feature not present in other software of the same genre. Otherwise the polygons can be drawn completely manually. The software allows the user to copy one or many polygons to another image. The intensity of each individual pixel can be displayed. The software also lets the user smooth the polygons using a moving average technique. Parameters such as number of points, number of new points created, and number of iterations can be varied to get the desired level of smoothing. The software provides a tool to create new slices with polygons in between the existing image slices through linear interpolation of the images and polygons. An increase in the number of images can improve the quality of the 3-D geometry. A distance measuring tool is also available. Information about the image (no. of pixels, pixel size, slice thickness, spacing between slices) is displayed on screen.

Sixteen diseased carotids were analyzed, half of which are symptomatic and half asymptomatic. Polygons were drawn on each image to identify the lumen, outer wall, and regions with high levels of calcium. The area of each ROI was multiplied by the spacing between slices to obtain the ROI volume of that slice. Volumes for the various components were obtained by summing the volume contribution for each slice. To create the 3D geometry of the plaque components (Figure 3), the polygons were used to create binary images with the ROI white and the rest black (Figure 2). This technique reduced ROI selection time when using *SEGMENT* (Medviso AB, Lund, Sweden) to create the 3D structures of each plaque component. The geometries were further processed using *GEOMAGIC* (Geomagic, Research Triangle Park, NC) for smoothing and to be exported in initial graphics exchange specification (IGES) format. Mean volumes of plaque components such as TV and CV were computed by *cttech* for both symptomatic and asymptomatic groups.

RESULTS
TV and CV of all the sixteen carotids were computed and compared. Both symptomatic and asymptomatic patient groups were selected based on the criterion that their NASCET scores were similar (73.8% and 60.9%, respectively). However, the present study revealed greater TV and CV difference between the two patient groups. Mean TV was observed to be higher (64.6%) in symptomatic patients than in asymptomatic patients (1706.9 ± 723.7 vs. 1037.1 ± 310.3 mm^3, $p < 0.05$) (Figure 4a). In contrast, mean CV was slightly lower (21.9%) in symptomatic patients than in asymptomatic patients (183.8 vs. 235.3 mm^3). However, the mean ratio of CV to TV was lower in symptomatic patients than in asymptomatic patients (8.9 ± 7.3 vs. 22.6 ± 13.9%, $p < 0.05$) (Figure 4b).

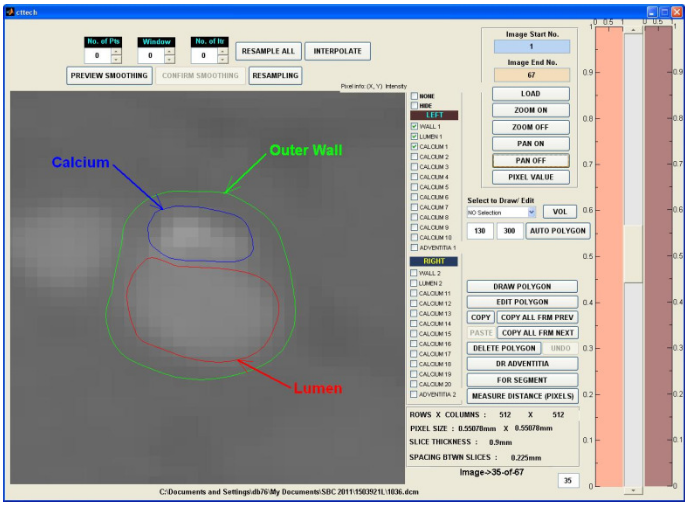

Figure 1: Screenshot of *cttech* with polygons encompassing ROIs in one typical medical CT image of a diseased carotid artery

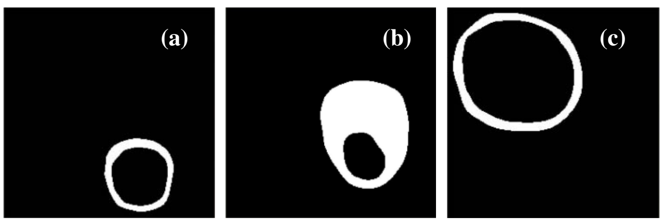

Figure 2: Binary images output from software *cttech* for healthy internal carotid (a), maximum stenosed internal carotid (b) and healthy common carotid artery (c)

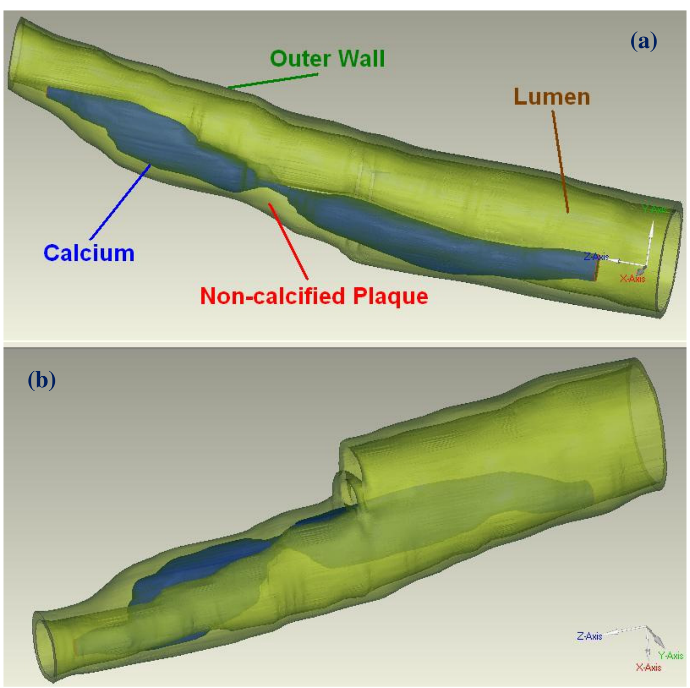

Figure 3: 3D reconstructed diseased carotid artery bifurcation, front and back view with plaque components (external carotid artery is not shown)

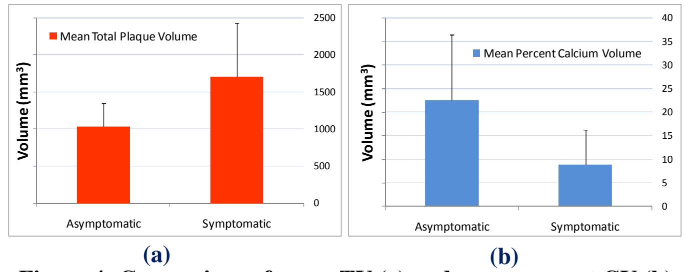

Figure 4: Comparison of mean TV (a) and mean percent CV (b) between symptomatic and asymptomatic groups

DISCUSSION

The present analysis provides a measure of TV and CV for symptomatic and asymptomatic carotid arteries. Physicians make decision on patients with carotid disease based on the ratio of the peak velocities in their internal carotid to that in their common carotid arteries and their NACET scores. However, the composition of plaque is thought to be important in the likelihood of plaque rupture or ischemic events. Knowledge of the morphologic composition of the plaque allows determination of mechanical stresses exerted on the protective fibrous cap, which may be of importance in the assessment of plaque vulnerability [4]. 3-D volumetric reconstruction of CT axial images allows for better characterization of plaque geometry and spatial distribution of plaque structural components. Here we show that symptomatic patients have a significantly greater plaque burden with minimal plaque calcification. Further development of the software includes automatic generation of the healthy adventitia and media provided the outer wall is defined. The software also has the potential to be used for phase contrast MRIs but this feature is still under development.

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