INVESTIGATION OF HUMAN CAROTID ARTERY WALL AND ATHEROSCLEROTIC PLAQUE MECHANICS USING B-MODE ULTRASOUND

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ABSTRACT

Sequences of B-mode ultrasound images of human carotid arteries were analyzed to assess regional variations in the motion of the wall and atherosclerotic plaques on them. Measurement of the frame-by frame position of discrete speckle patterns enabled the estimation of both radial (circumferential) and axial (longitudinal) motion of the wall. Large differences could be observed between the cyclical patterns and degree of motion even at relatively close sites indicating large strains of the intervening tissue.

METHODS

Patients passing through a vascular surgery clinic were scanned using a ATL Ultramark 4 duplex scanner with a linear array transducer operating at 7.5 MHz. This system gave images with a spatial resolution of about 16 pixels/mm and gave estimations of tissue motion of less than 0.1mm. Images were collected at 25 frames per second onto a magneto-optical disc for subsequent analysis.

The images were imported into a software package which had been modified from a version previously developed in our laboratory [1]. Briefly the system displays the first image of the sequence and allows selection of a "region of interest" (ROI), a small segment for which the operator wishes to estimate the motion. This is commonly at the blood/wall or plaque interface and is of 50x40 pixels, corresponding to a tissue area of 3.2 x 2.5 mm^2.

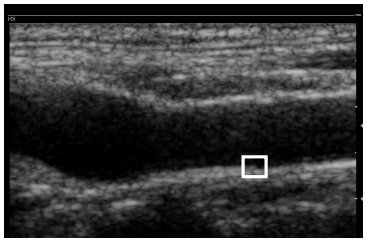

Fig 1. Ultrasound image of a normal carotid artery showing a pre-selected ROI

The program then searches the subsequent images for corresponding ROI's which display a distribution of pixel intensities which have the highest correlation with the original one. In this matching process, account is also taken of the distance between the ROI's in adjacent frames. This modification was based on the assumption that tissue would be most unlikely to move more than 0.8 mm between adjacent frames.

Any difference between the center of a best matched ROI in one image and that in the previous image is then assumed to indicate the movement that has occurred between frames. Early studies showed a limited reliabilty in motion tracking for randomly selected ROI's in some image sequences. To ensure the robustness of predictions, five ROI's were generally selected at the center and apices of 10 x 10 pixel squares and data was only accepted if there was agreement between the predicted motion of each.

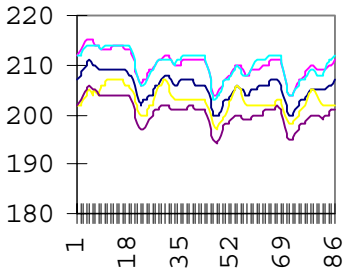

Fig. 2 Predicted axial motion of five regions of interest located on the blood/atherosclerotic plaque interface. (Ordinate = pixels, abcissa has bars = 1/25 sec.

In figure 2, all the ROI's appear to be moving in parallel, though the tracking of one of those starting a vertical pixel 203 appears to shift about half a second into the recording period. These points on the plaque surface are showing a cyclical pattern consistent with heart

beats with an axial displacement of about 10 pixels (0.6mm) in each cycle. Analyses have been performed on 6 subjects (ages 50-71) who all had atherosclerotic plaques proximal to the carotid bifurcation. Motion was estimated over at least three cardiac cycles at multiple sites including parts of the wall unaffected by plaque as well as on the plaque itself. The difference between the predicted centers of ROI's at two sites indicated their relative motion and could be used to estimate the cyclical strain between them.

RESULTS

The absolute amplitudes of motion between the subjects and relative motion between different sites in the same subject were very variable. On parts of the wall unaffected by plaque, the radial motion varied between 0.12mm to 0.75mm per cycle and the axial motion by less than 0.1mm to 0.4mm. On the surface of the plaques, the radial motion again varied 0.12mm to 0.65 but the plaque motion did not always reflect that of adjacent areas of unaffected wall. In Fig.3, the centres of ROI's indicated by the arrows indicate relative motion in the radial direction.

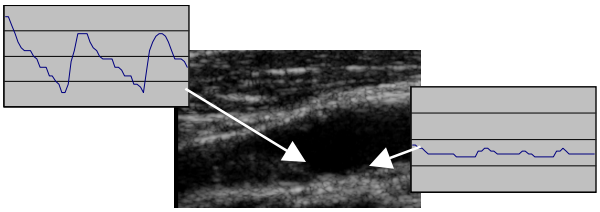

Fig.3 Predicted radial motion at the surface of a plaque and at an adjacent region of the normal wall (horizontal grid lines spaced at 3 pixels (~0.2 mm))

Much greater variation was observed in the case of axial motion; at sites of the unaffected wall the motion per cycle varied from <0.1mm to 0.3 mm. On the plaques the axial motion was less than 0.1 mm in one subject but in three subjects the axial motion exceed 0.8 mm. In these cases the plaque motion greatly exceeded that of the normal wall either side of the plaque and in one case, a cyclical stain of 40% was observed in a region close to the plaque/wall boundary.

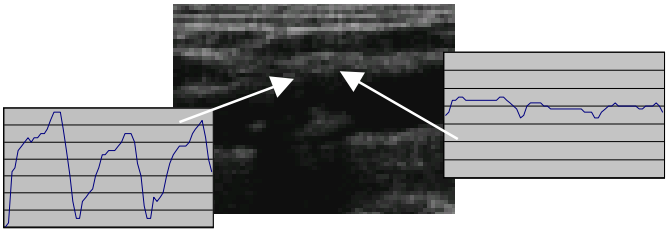

Fig.4 predicted axial motion at the surface of a plaque and of an adjoining region of the normal wall (horizontal grid lines spaced at 2 pixels (0.12mm)

CONCLUSION

Our earlier studies [1], had shown that in normal subjects this method could be used to measure both radial strain (10.2 ± 4.5%) which showed an age dependence and an axial strain (2.5 ± 0.89%). The latter value was smaller than had been reported the ascending aorta and aortic arch [2], probably reflecting the greater tethering of the carotid artery to surrounding tissue.

In the atherosclerotic subjects in the present study we observed that motion in both the radial and axial directions was much more variable than in the normal subjects. In the small numbers studied, plaque motion did not appear to correlate with the degree of stenosis (in all subjects, the degree of stenosis was in excess of 30%) or the echogenicity of the plaques.

Radial motion can be associated with pressure changes during the cardiac cycle, which can also cause axial strain. The very large axial displacements of the plaques in some subjects, may be associated with either a pressure gradient across the plaque or shear forces due to blood flow through the stenotic region. Large strains, particularly those seen at the plaque/wall interface could be associated with a predilection for rupture at this site. Observation of such large strains may be an indicator for corrective surgery.

REFERENCES

1. Golemati, S., Sassano, A., Lever, M. J., Bharath, A. A., Dhanjil, S., Nicolaides, A.N., 2000, "Carotid artery wall motion in humans, estimated from B-mode ultrasound images". J. Physiol. (Lond.) 525, pp. 11P.
2. Gentile, B. J., Gross, D. R., Chuong, C. J. C., Hwang, N. H. C., 1988, Cardiovascular Research, 22, 385-389.