Intelligent Medical Imaging Systems I

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Medical Imaging

- Fluoroscopy
- Magnetic resonance imaging (MRI)
- Nuclear medicine
- Positron emission tomography (PET)
- X-ray imaging
- Computer tomography (CT scan)
- Ultrasound imaging
- Direct Camera imaging
  - Endoscopy
  - Colonoscopy

  etc.

Ultrasound imaging

- Ultrasound was originally used for industrial purposes,
  - value as a diagnostic tool initially recognized in the late 1940s.
- Ultrasound imaging became an accepted imaging diagnostic technique in the early 1970s
- Ultrasound is currently a standard technique for
  - screening patients at risk for atherosclerosis in the absence of clinical symptoms or
  - for a detailed diagnosis of symptomatic subjects

Ultrasound imaging

- Ultrasound is a sound wave,
  - frequency that exceeds 20 KHz
- It transports energy and propagates through several means as a pulsating pressure wave
- It is described by a number of wave parameters
  - pressure density, propagation direction, and particle displacement
- particle displacement is parallel to the propagation direction then the wave is called longitudinal or a compression wave
- If the particle displacement is perpendicular to the propagation direction the wave is called shear or transverse wave

Ultrasound imaging

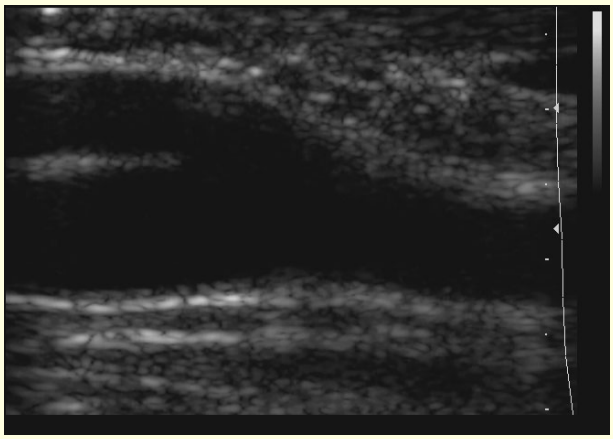
- Interaction of ultrasound waves with tissue subject to the laws of geometrical optics
  - reflection, refraction, scattering, diffraction, interference and absorption
- Main characteristic of an ultrasound wave
  - the wavelength λ which is a measure of the distance between two adjacent maximum or minimum values of a sine curve
  - frequency f which is the number of waves per unit of time
  - The product of these two measures give the velocity of ultrasound wave propagation, v,
    - $v=f\lambda$.
- Ultrasound techniques, mainly based on measuring the echoes transmitted back from a medium when sending an ultrasound wave to it.
- Mainly two principles are used in ultrasound diagnostics, t
  - the echo-impulse technique
  - the Doppler technique.

Ultrasound imaging

- Echo impulse technique
  - A-mode (amplitude mode scanning)
    - Rarely used especially for cardiovascular disease
  - B-mode (brightness mode)
    - quality of produced image depends on image resolution, axial and lateral. Resolution is defined as the smallest distance between two points at which they can be represented as distinct.
    - ultrasound pulses consist of one to two sinusoidal wavelengths,
      - the axial resolution is dependent on the wavelength of the waveforms
      - Lateral resolution refers to the ability to resolve two points that lie at right angle to the direction of ultrasound propagation. This is dependent on the frequency of ultrasound and the width of the ultrasound wave (beam)

Ultrasound imaging

- B-mode image of the carotid bifurcation

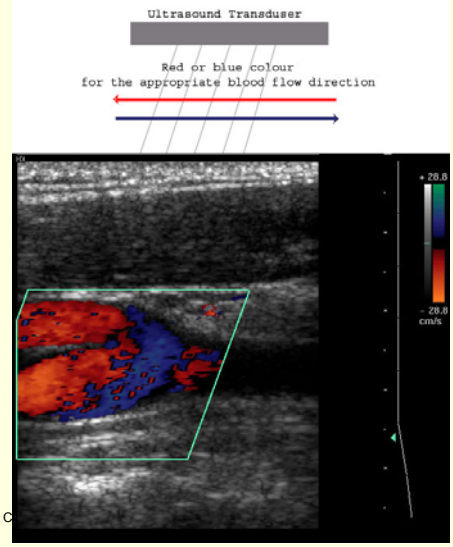


Ultrasound imaging

- Speckle is another important factor affecting the quality of ultrasound B-mode imaging.
- Described as an ultrasonic textural pattern that varies depending on the type of biological tissue.
- Tissue pathology that causes changes in the anatomical structure of tissue might also result in a change in its speckle ultrasonic appearance.

Ultrasound imaging

- Doppler technique
  - This technique is based on the principle that the perceived frequency of sound echoes reflected by a moving target is related to the velocity of the target



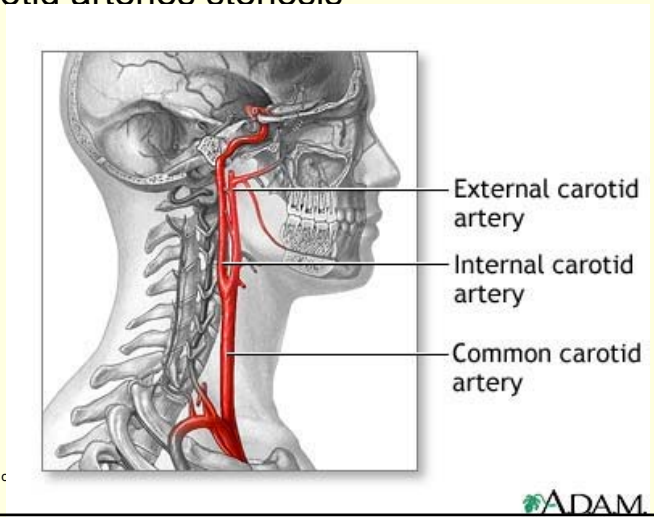
Cardiovascular diseases

- Arteriosclerosis
- Atherosclerosis
- Vascular Occlusive Disease
- Coronary Artery Disease
- Hardening of Arteries

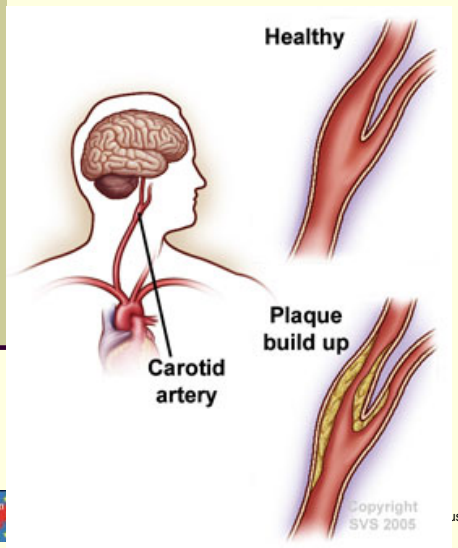
- Describe a process of cholesterol accumulation in the wall of the arteries

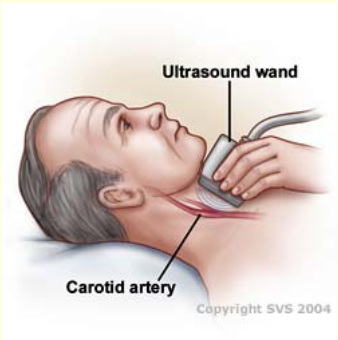
Cardiovascular diseases

- Carotid arteries stenosis

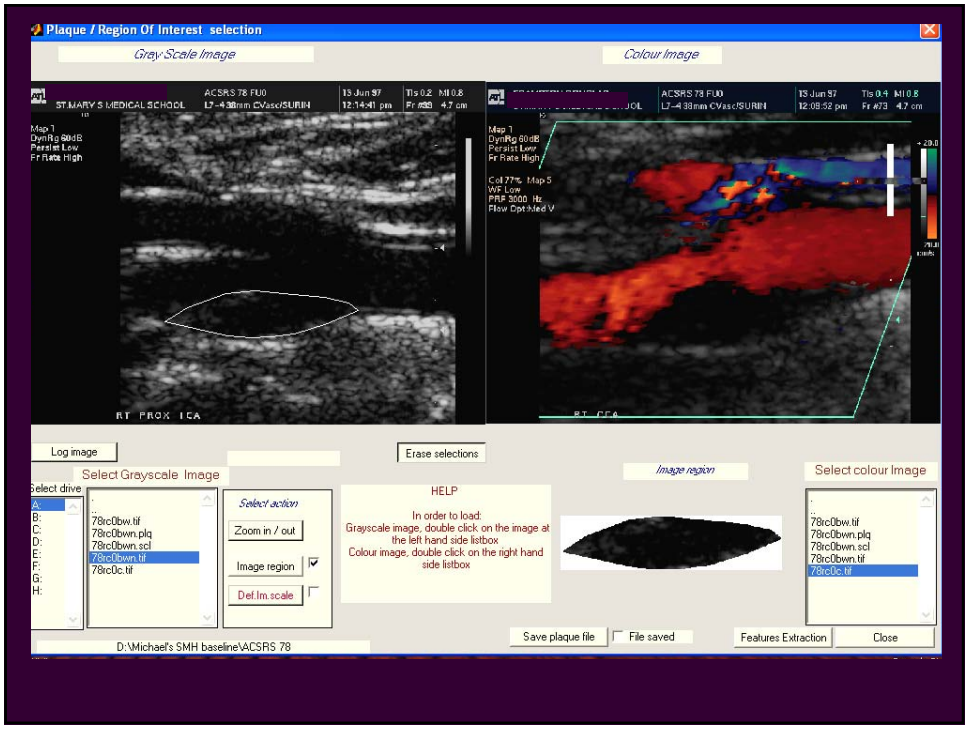


Carotid arteries stenosis

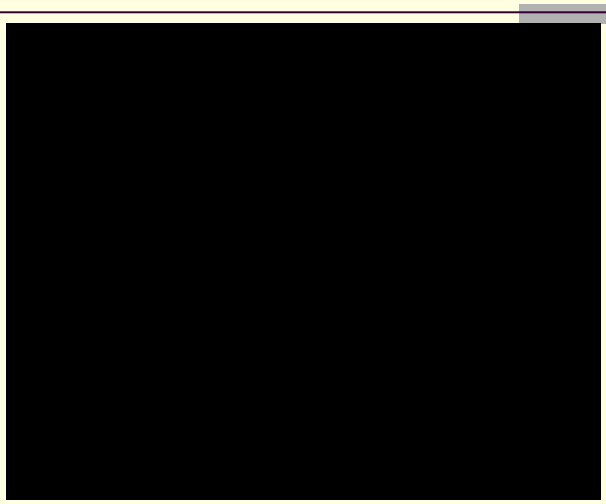


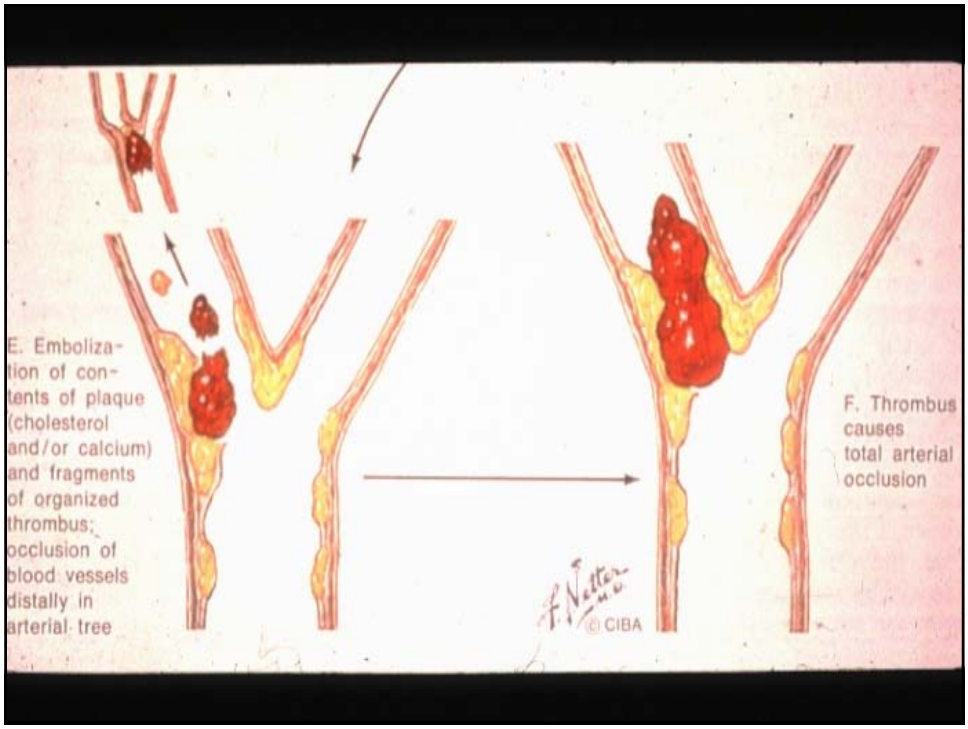


Patient examination



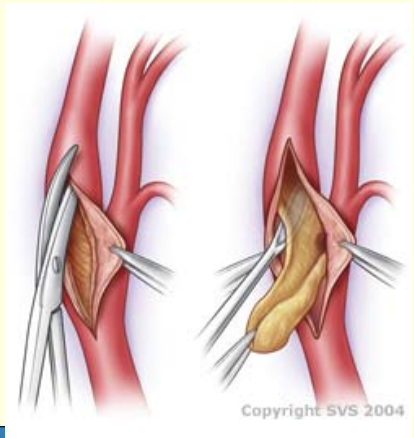
Real ultrasound video example

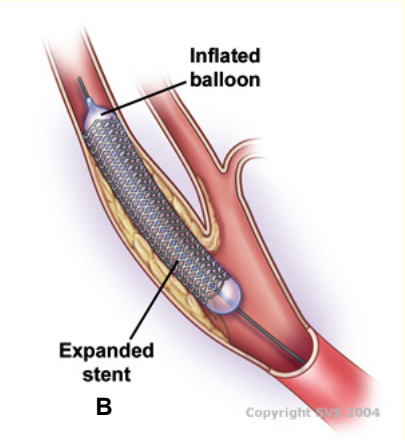




Carotid arteries stenosis

- Treatment





Prevention

- Prevention is better than cure
- Individuals at risk can be identified
- At least 50% of premature heart attacks and strokes can be prevented

Epidemiological studies

- Epidemiological studies
  - Framingham
  - PROCAM
  - British Regional Heart
  - Follow up of groups of persons for many years (the final result was a cardiovascular event)
  - Result: Equations able to identify the risk of stroke based on several risk factors (Smoking, Hypertension, High Cholesterol, Diabetes etc.)
- Disadvantages:
  - Equations from epidemiological studies can identify high risk groups
  - But only 40-50% of cardiovascular events happen in these groups
  - The rest happens in low risk groups

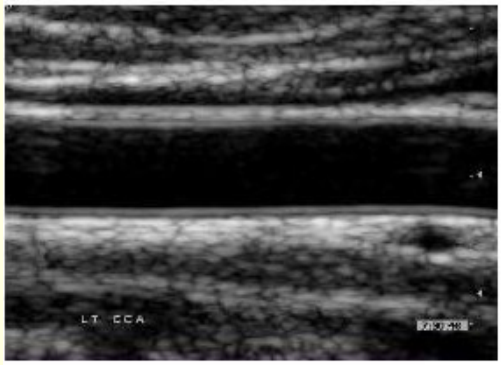
Why?

- 50% of the persons having a hard attack or stroke did not have the usual risk factors
- Many newly discovered risk factors were not measured In these epidemiological studies)
- Many genetic markers are currently associated as risk factors

Stable and Unstable Atherosclerotic plaques: Ultrasonic Detection and significance

Arterial groups
Group Ia: Low risk – absence of plaque

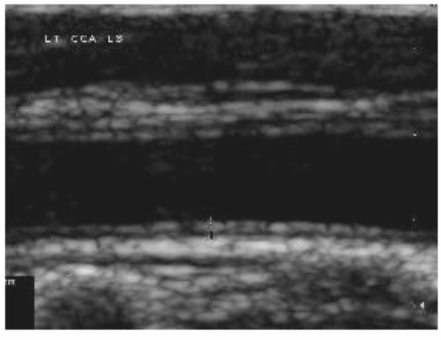
Class Ia



Smooth IM in young individual

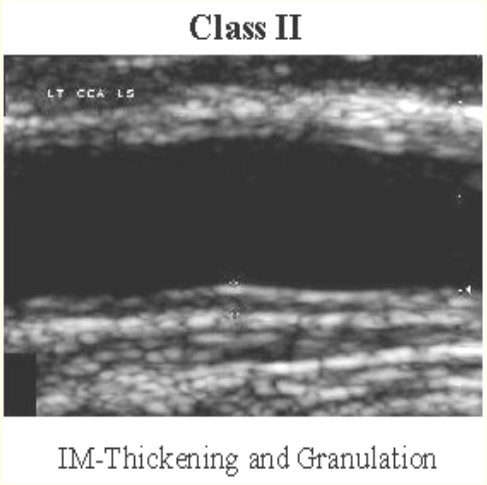
Arterial groups
Group Ib: Low risk – absence of plaque

Class Ib

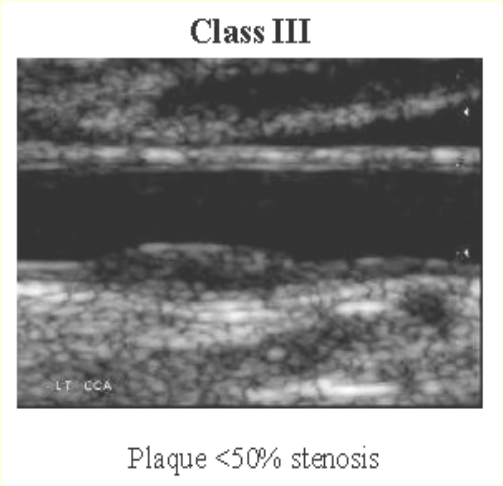


Appearance of acoustic hotes in middle age

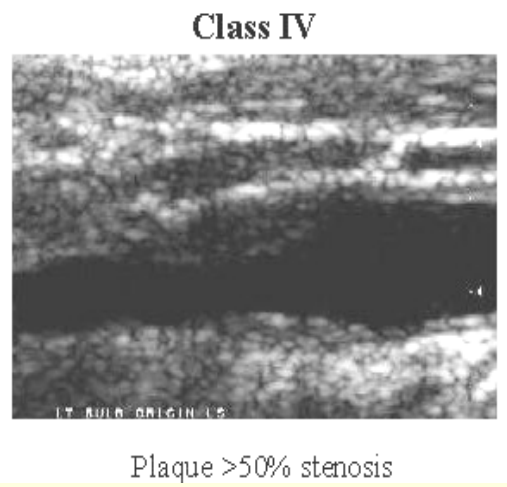
Arterial groups
Group II: Slightly increased risk



Arterial groups
Group III: High risk – Presence of Plaque

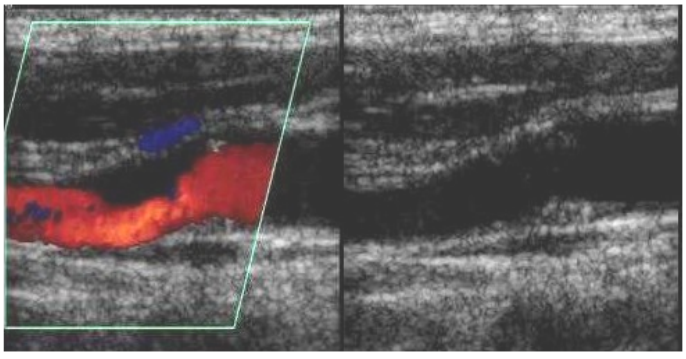


Arterial groups
Group IV: Very high risk – Presence of plaque



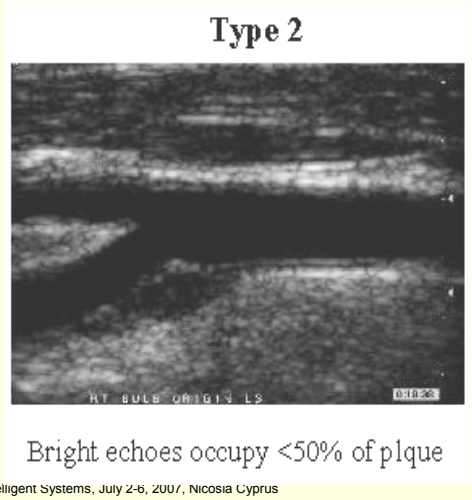
Plaque >50% stenosis

Plaque types 1-4
Type 1 - Hypoechoic plaque: High Risk

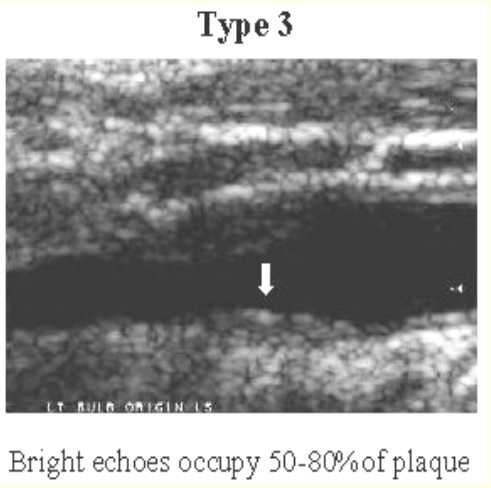


Nine out of ten Type 1 plaques can be seen as filling defects only when colour flow is used

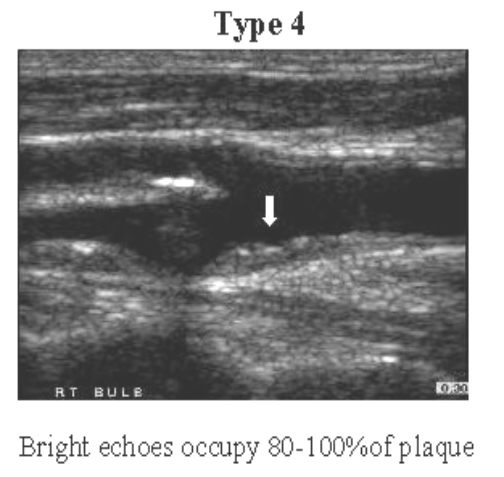
Plaque types
Type 2 - Hypoechoic plaque: High Risk



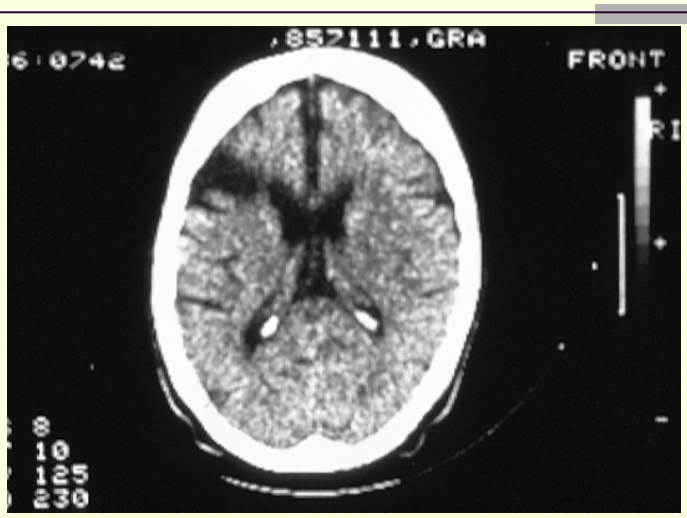
Plaque types
Type 3 - Hyperechoic plaque: Middle Risk

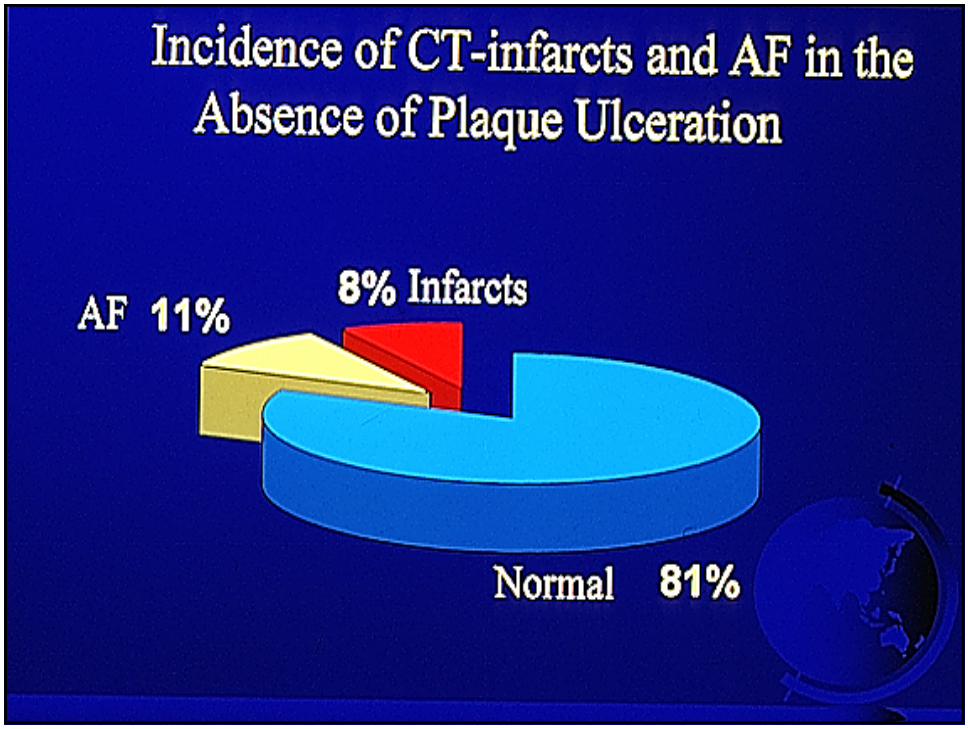


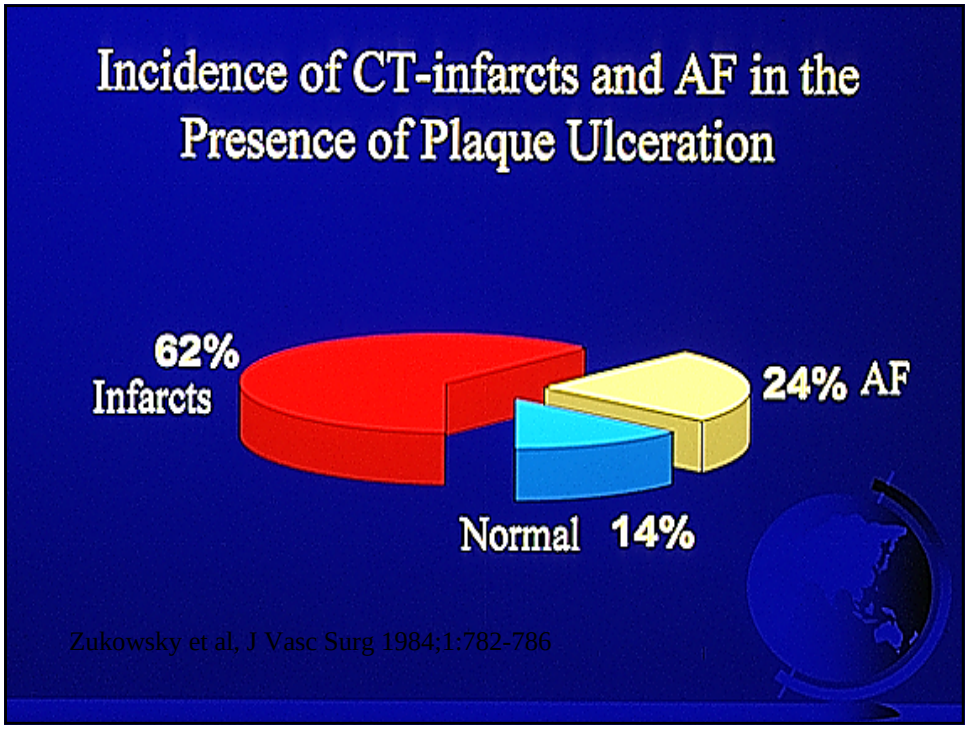
Plaque types
Type 4 - Hyperchoic plaque: Low Risk



Silent CT-Brain Infarcts

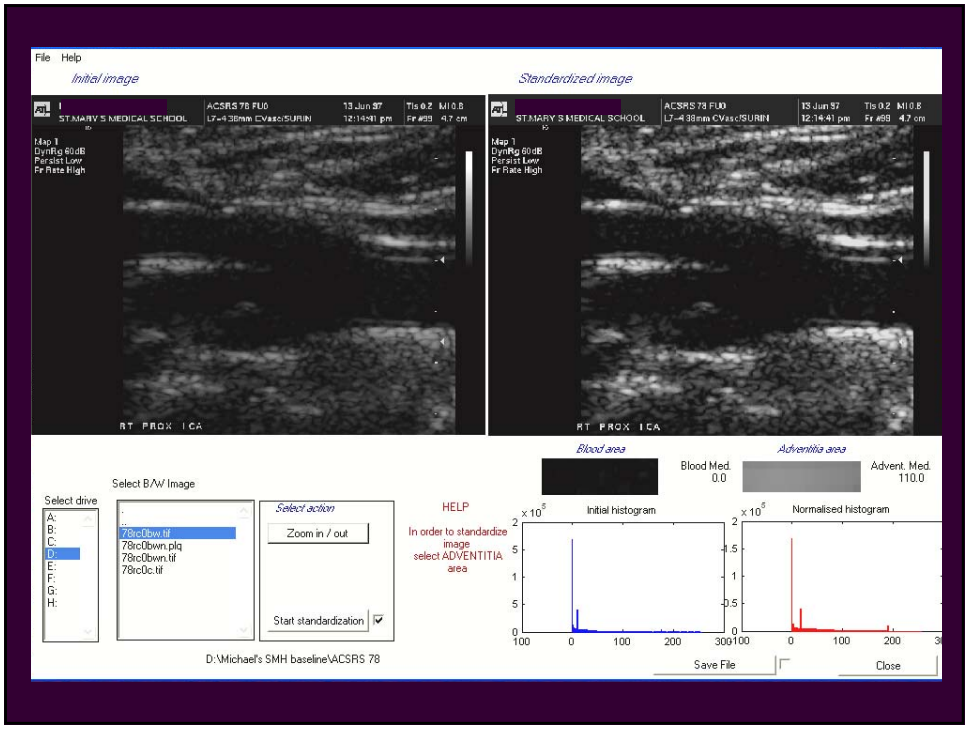



Incidence of CT-infarcts and AF in the Absence of Plaque Ulceration
AF 11%
8% Infarcts
Normal 81%


Incidence of CT-infarcts and AF in the Presence of Plaque Ulceration
62% Infarcts
24% AF
Normal 14%
Zukowsky et al, J Vasc Surg 1984;1:782-786

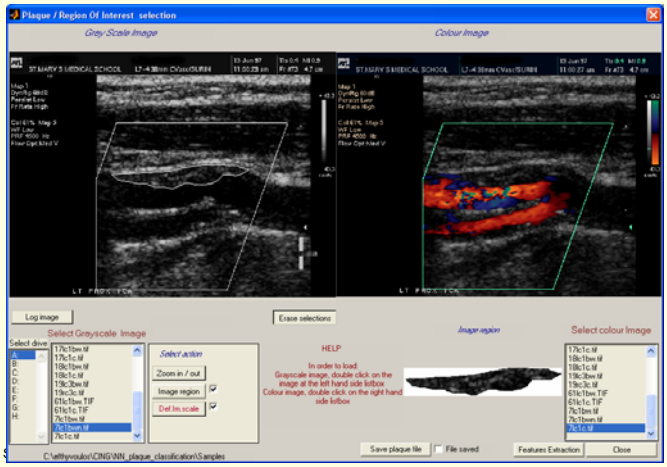
Ultrasonic Plaque Characterisation

- Image normalization has opened the gate that had been holding us back for 20 years:
- Provides images on which reproducible
- measurements of texture features can be made
- Makes identification of unstable plaque possible



Produced system

- Step 2 Plaque selection



The Value of Grey Scale Median (GSM)

- There are 3 key studies demonstrating hypoechoic plaques are associated with an increased risk of stroke
  - Polak et al, Radiology 1998 RR = 2.8
  - Tromso Study
    Mathiesen et al, Circulation 2001 RR = 4.6
  - Gronholdt et al, Circulation 2001 RR = 3.1

Material - Image Acquisition

- A total of 274 carotid plaque ultrasound images (137 asymptomatic plaques and 137 symptomatic plaques associated with retinal or hemispheric symptoms (33 stroke, 60 TIA, and 44 AF).
  - Patients with cardioembolic symptoms or distant symptoms (> 6 months) were excluded from the study.
  - Symptomatic plaques were truly asymptomatic if they had never been associated with symptoms in the past (retinal or hemispheric).
- Images collected in the Irvine Laboratory for Cardiovascular Investigation and Research, Saint Mary's Hospital, UK.
  - ATL (model HDI 3000) duplex scanner,
  - Transducer, linear broadband width 4-7 MHz (multifrequency), at approximately a resolution of 20 pixels/mm.
- Images normalized manually
  - Gray scale images 0-255 gray levels.
  - Adjusting the image linearly so that the median gray level value of blood was in the range of 0-5, and the median gray level of adventitia (artery wall) was in the range of 180-190.

Computer Aided Diagnosis System

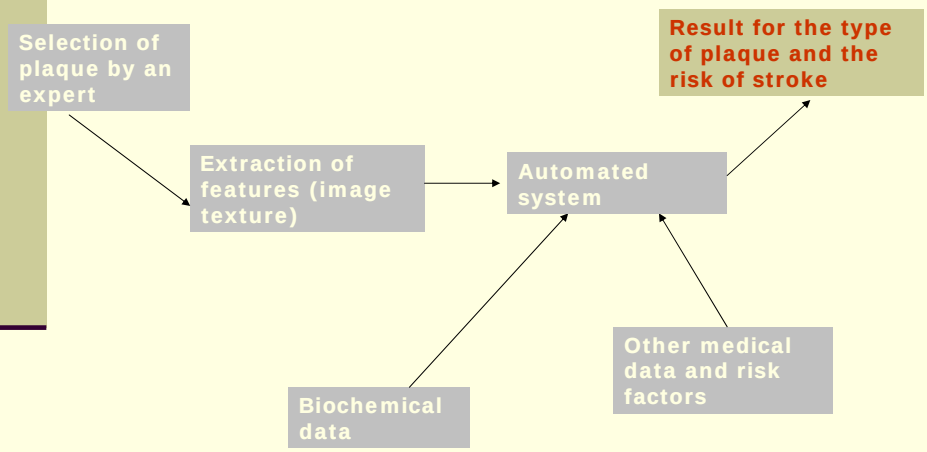


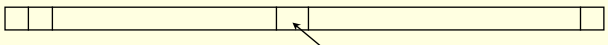
Image Texture analysis

- **Statistical features (first order) (SF)**
- **Spatial Gray Level Dependence Matrices (SGLDM)**
- **Gray Level Difference Statistics (GLDS)**
- **Neighbourhood Gray Tone Difference Matrix (NGTDM)**
- **Statistical Feature Matrix (SFM)**
- **Fractal dimension texture analysis**
- **Laws Texture Energy measures**

Gray Level Difference Statistics (GLDS)

"The GLDS is based on the assumption that useful texture information on an image can be extracted using first order statistics"

- **Image intensity function I**
  - Distance: $\delta(\Delta\chi, \Delta y)$, $(\Delta\chi, \Delta y$ integers)
  - $I_\delta = |I(x,y)-I(x+\Delta\chi, y+\Delta y)|$



- P_δ : 0 1 i m

Probability that I_δ will have value i

- **Coarse texture $\Longrightarrow$ I_δ near zero $\Longrightarrow$ Values of P_δ near zero**
- **Smooth texture $\Longrightarrow$ I_δ higher values $\Longrightarrow$ Values of P_δ spreat out**

Feature used: Entropy $\equiv -\sum p_\delta(i)\log(p_\delta(i))$

Fractal Dimension Texture Analysis (FDTA)

"This technique is based on Fractional Brownian Motion (FBM) model developed by Madelbrot"

- FBM: A nonstationary stochastic process can be described by a single parameter the fractal dimension D.

  Where D=E+1-H E+1 Euclidean dimension of the embedding space of the fractal

  H Hurst coefficient

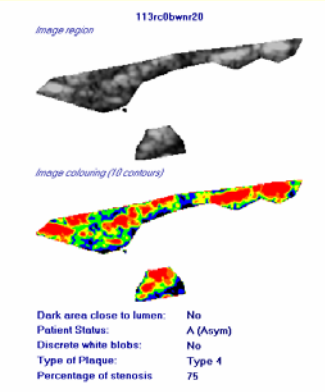
- **Rough surface (Coarse texture) D large, (H small)**
- **Smooth Surface (Smooth texture) D small, (H large)**

Texture characteristics of symptomatic vs asymptomatic plaques

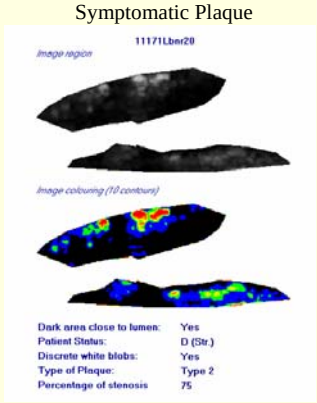
Symptomatic Plaques	***Asymptomatic Plaques***
more dark	brighter
higher contrast	less contrast
more rough	more smooth
more heterogeneous	more homogeneous
less periodical	more periodical
less coarse, i.e. less local uniformity in intensity	more coarse, i.e. large areas with small gray tone variations

Plaque Characteristics

Asymptomatic plaque



Symptomatic Plaque



SGLDM(mean)-Inv. Dif. Mom.:	**0.163**	**0.41**
SF – median:	**84.31**	**20.4**

Gray Scale Morphological Analysis

- **Morphological features & events**
  - e.g. black (echolucent) plaques
    white blobs ➡ Very dangerous

- **Morphological Image processing**
  - Characterisation of blob-components (white)
  - Hole components (black)
  - Cross Structural element ('+')
    - No directionality sensitivity
    - Range 1 to 70
  - Pattern spectrum defined in terms of Discrete Size Transform (DST):

$$f \rightarrow (d_0(f;B), d_1(f;B), \ldots d_k(f;B))$$

where: $d_k(f;B) = fokB - fo(k+1)B$

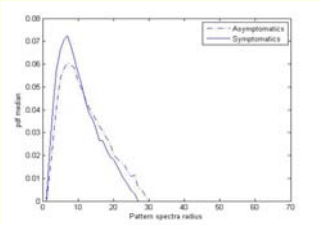
o denotes an open operation

Cumulative distribution function *(cdf)* and Probability density function (*pdf)* of plaques

- Pattern spectra, computed for gray scale images
  - structural element of range 1 to 70.
  - Probability density function *(pdf)* and cumulative distribution function *(cdf)* computed for each plaque

Asymptomatic plaque

Symptomatic plaque

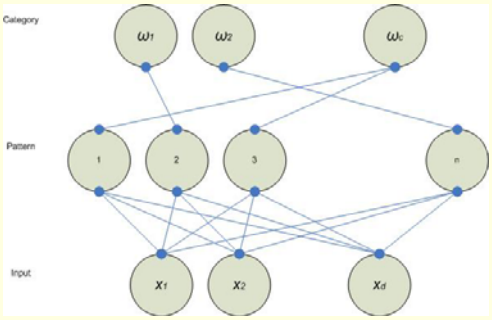


Classification techniques

- Probabilistic Neural Network (PNN)
  - Tested for several spread radius
- Support Vector Machine (SVM)
  - Tested using the Gaussian Radial Basis Function (RBF) Kernels
- Both classifiers were investigated using 10-fold cross validation in order to identify best parameters
- Data dimensionality was reduced using Principal Components Analysis (98% of the total variance)

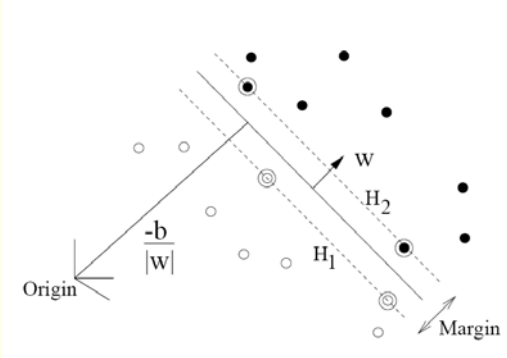
Probabilistic Neural Networks (PNN)

- PNN consists of d inputs, n pattern units and c category units.
  - Each pattern unit forms inner product of its weighted vector and the normalized pattern vector x to form $z=w^t x$
  - Each category unit sums contributions from the pattern unit connected to it



Support Vector Machines (SVM)

- Rely on preprocessing the data in order to represent patterns in a high dimension, typically much higher than the original feature space.
- Patterns along the hyperplanes, called support vectors



Classification Texture Feat.

Texture Analysis Algorithms – Classification results				
Texture Features	**PNN CC %**		**SVM (RBF kernel function) CC %**	
	Original	**Using PCA (98%)**	**Original**	**Using PCA (98%)**
SF	65.3	65.3	69.3	70.1
SGLDM(mean)	**71.2**	70.8	69.7	68.6
SGLDM(range)	61.0	62.4	64.6	64.2
GLDS	60.6	60.6	65.0	65.0
NGTDM	55.8	55.8	68.3	67.9
SFM	54.4	54.4	58.4	58.4
TEM	61.0	58.4	69.3	67.5
FDTA	59.5	59.5	61.3	62.4
All 54 features	55.5	59.9	69.7	64.2
SF & NGTDM	62.8	62.4	**71.2**	69.3
SF & SGLDM(mean)	66.8	68.6	68.6	65.7
SF & SGLDM(mean) & TEM & NGTDM	65.3	64.2	70.8	70.1

Classification –Morphology Feat.

- The *cdf*s and *pdf*s of different pattern spectra were used in order to classify the two classes of images using the PNN and SVM classifiers.
- Both classifiers were tested on both the *pdf* and c*df* feature sets.
  - The first set included features produced for the whole range of the radii investigated (1-70)
  - The second set included the pattern spectra of selected radii (2, 3, 5, 10, 21, and 23)
    - Decision was taken through the discriminatory power of the different pattern spectra radii using the C4.5 decision trees algorithm. The C4.5 was run and the pattern spectra radius with the highest discriminative score was computed. This pattern spectra was then removed and the C4.5 was run again to compute the next one discriminative feature. This procedure was carried out for 5 iterations.
- Classifiers were tested using Leave one out method.

Classification results – SVM Classifier

SVM classifier	%CC	%FP	%FN	%SE	%SP
SVM rbf spread = 2.2627 *pdf* radii 2,3,5,10,21,23 **+PCA**	**66.79**	20.44	45.99	54.01	79.56
SVM rbf spread = 0.5657 *pdf* radii 2,3,5,10,21,23	65.33	28.47	40.88	59.12	71.53
SVM rbf spread = 2.2627 *cdf* radii 1-70 **+PCA**	63.14	42.34	31.39	68.61	57.66
SVM rbf spread = 2.2627 *cdf* radii 1-70	62.41	32.12	43.07	56.93	67.88
SVM rbf spread = 1.1314 *pdf* radii 1-70 **+PCA**	60.22	43.80	35.77	64.23	56.20
SVM rbf spread = 0.5657 *pdf* radii 1-70	**63.14**	**36.50**	**37.23**	**62.77**	**63.50**

Classification results – PNN Classifier

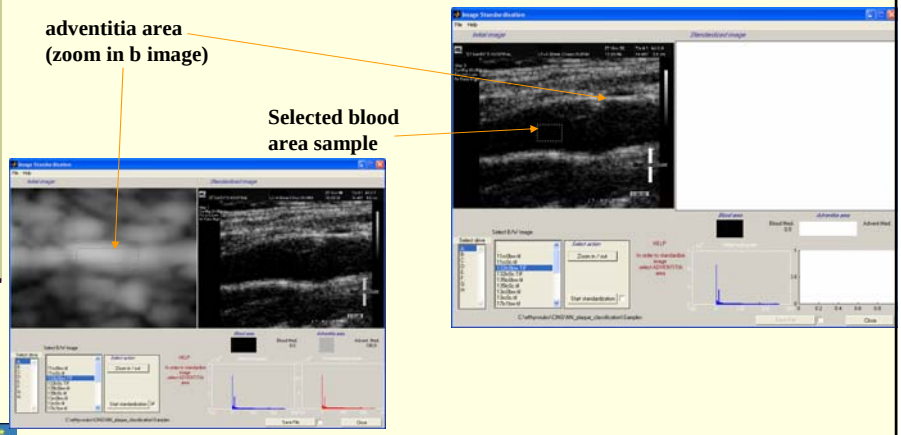
PNN classifier	%CC	%FP	%FN	%SE	%SP
PNN spread =5 *pdf* radii 2,3,5,10,21,23 **+PCA**	56.57	22.63	64.23	35.77	77.37
PNN spread =5 *pdf* radii 2,3,5,10,21,23	56.57	22.63	64.23	35.77	77.37
PNN spread =5 *cdf* radii 1-70 **+PCA**	60.58	36.50	42.34	57.66	63.50
PNN spread =5 *cdf* radii 1-70	**62.04**	**35.77**	**40.15**	**59.85**	**64.23**
PNN spread =5 *pdf* radii 1-70 **+PCA**	58.76	42.34	40.15	59.85	57.66
PNN spread =5 *pdf* radii 1-70	60.22	48.91	30.66	69.34	51.09

Concluding Remarks

- The work presented is part of work performed in order to help in the identification of the risk of stroke
- Texture features can help us understand the ultrasonic appearance of plaques (black, with great white spots etc.)
- Morphological features can help us understand the interrelations among different plaque intensity regions in ultrasound imaging of the carotid
- **Next steps**
  - Better evaluation of the system and investigation of the correct classification rate on larger and different data sets and the use of clinical factors.
  - Continuous training of physicians
- **Beneficial for the patient:**
  - Only 25 operations instead of 100 will be needed in order to avoid a stroke event in 1 year
  - 2/3 of patients having known symptoms that where about to have carotid endarterectomy will avoid an unnecessary operation

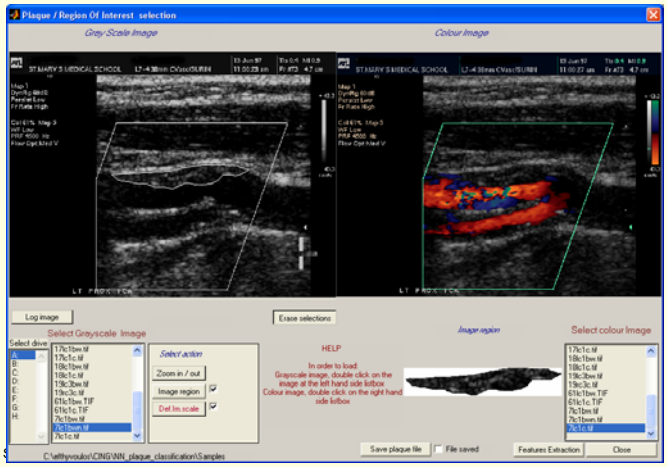
Produced system

- Step 1 – Image normalisation



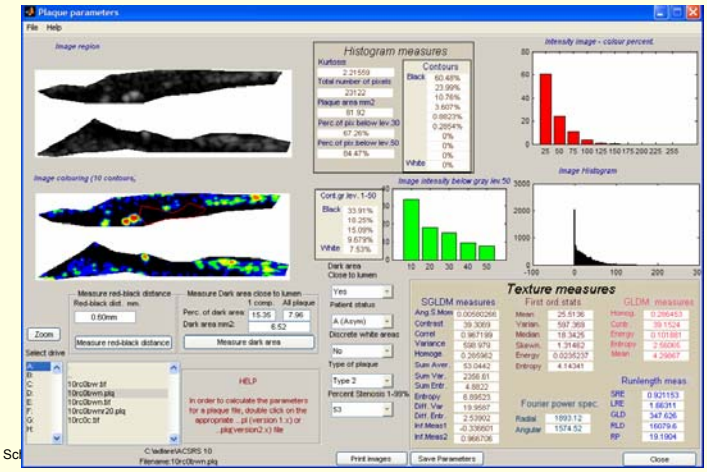
Produced system

- Step 2 - Plaque selection



Produced system

- Step 3 – features extraction



Produced system

- Additional features