Computer-aided Diagnosis

Engineering Improved Health Care

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So…
What is
CAD?

CAD is…

- “an ill-bred man, especially one who behaves in a dishonorable or irresponsible way toward women” www.dictionary.com
- Canadian Dollar
- Computer-Aided Drafting
- Computer-Aided Design
- Computer-Aided Detection
- *Computer-Aided Diagnosis!*

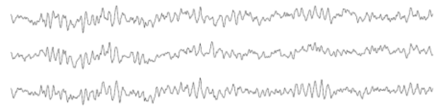
Computer-aided Analysis of Biomedical Signals and Images

Application of computational procedures including digital signal processing, digital image processing, and pattern recognition methods to enhance biomedical signals and images, segment and characterize regions of interest (ROIs), identify normal patterns and structures, and detect abnormal features and diseases for ***computer-aided diagnosis (CAD)***

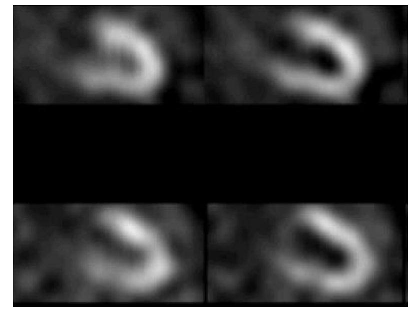
Note: "aided" or "assisted" and not "automated"

Signals and Images from the Human Body

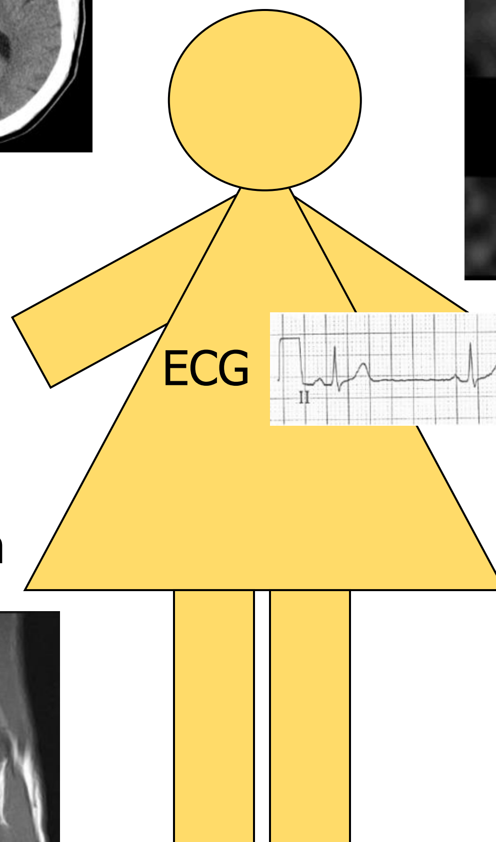
X-ray CT image of the brain



Brain waves: EEG

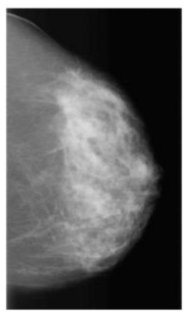


Nuclear medicine (SPECT) images of the heart



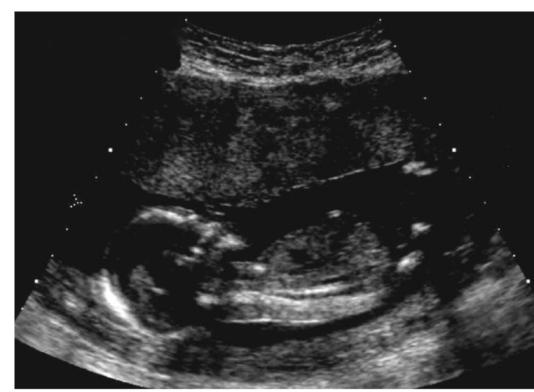
ECG

Chest X-ray image



Mammogram

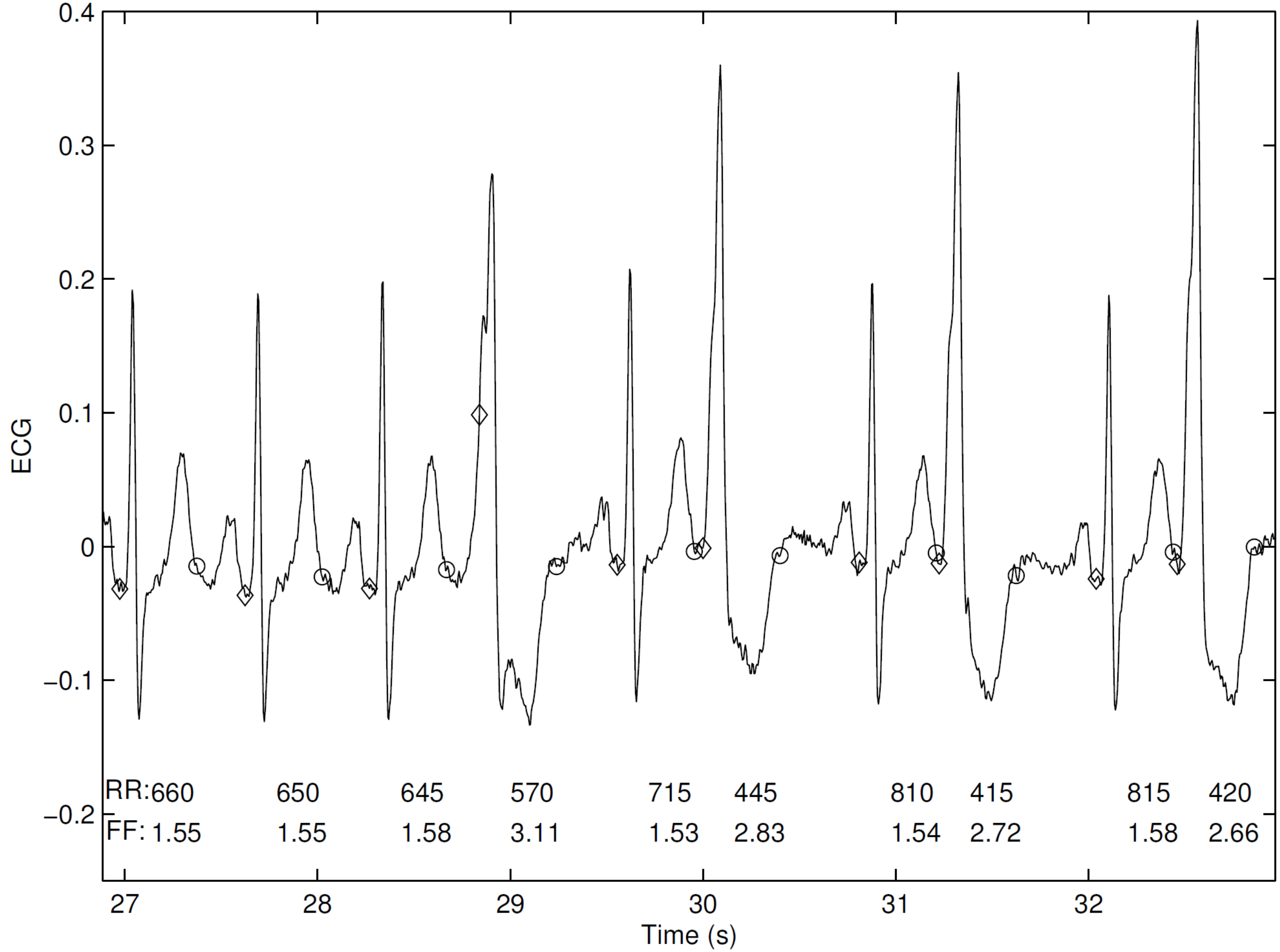
MR image of the knee



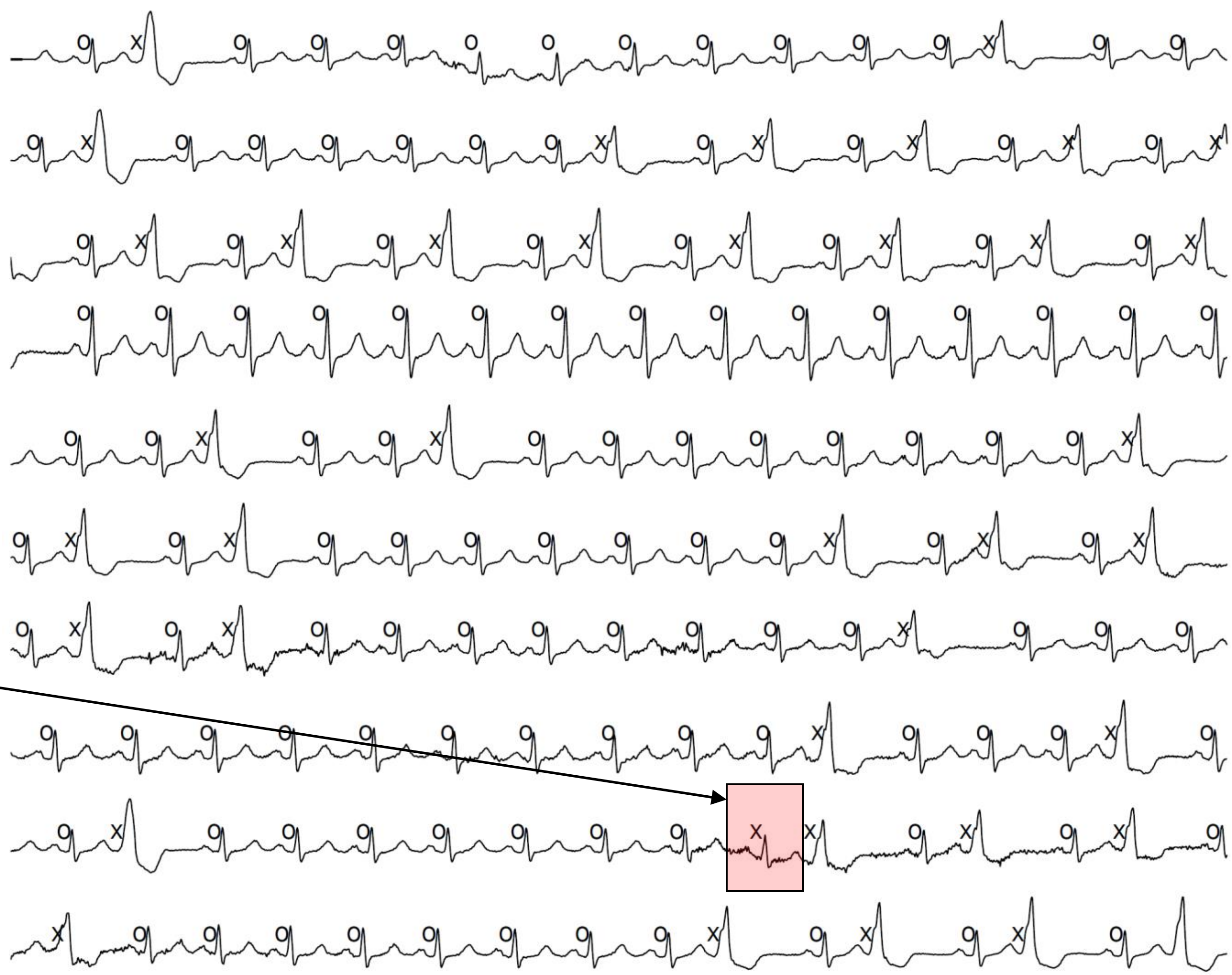
Fetal ultrasonography

Filtering of ECG to Remove Artifacts

Computer Analysis of the ECG: Feature Extraction



Computer Analysis of the ECG: Pattern Classification



False positive: normal beat misclassified as PVC

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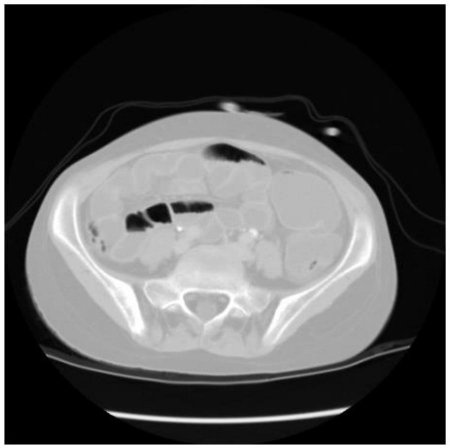
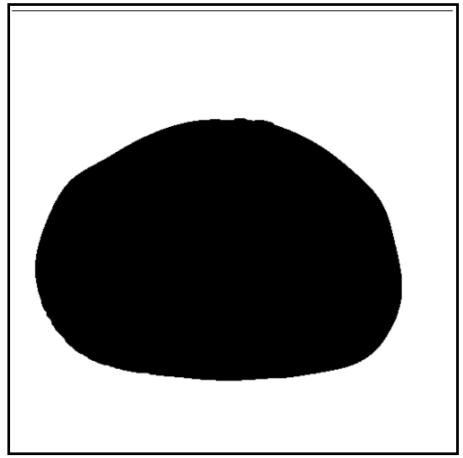
Landmarking of 3D CT Images:

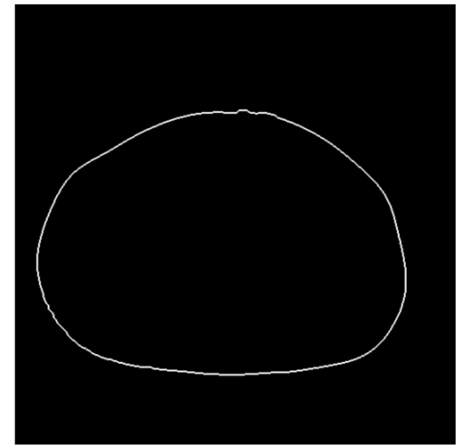
Removal of peripheral artifacts and tissues in computed tomographic images



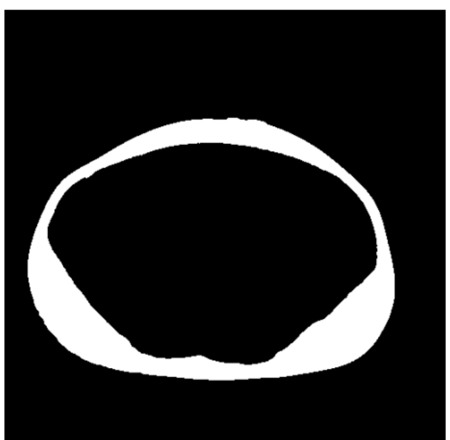
before processing



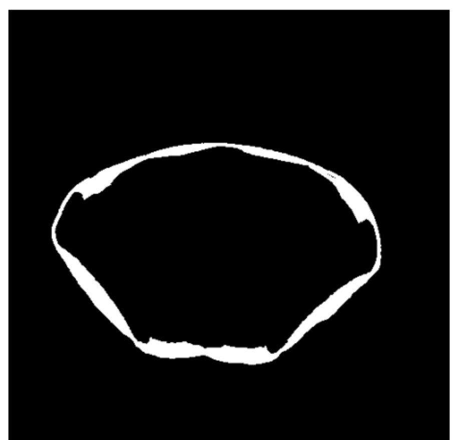
peripheral artifacts



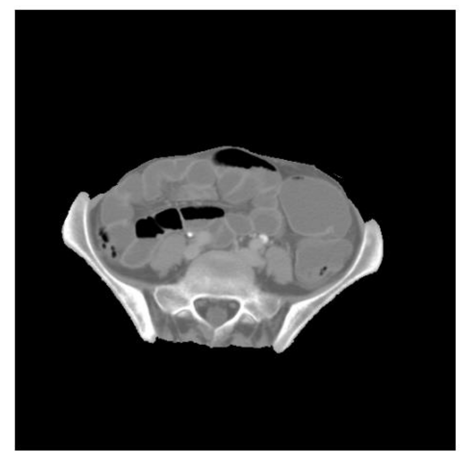
the skin layer



the peripheral fat region



the peripheral muscle

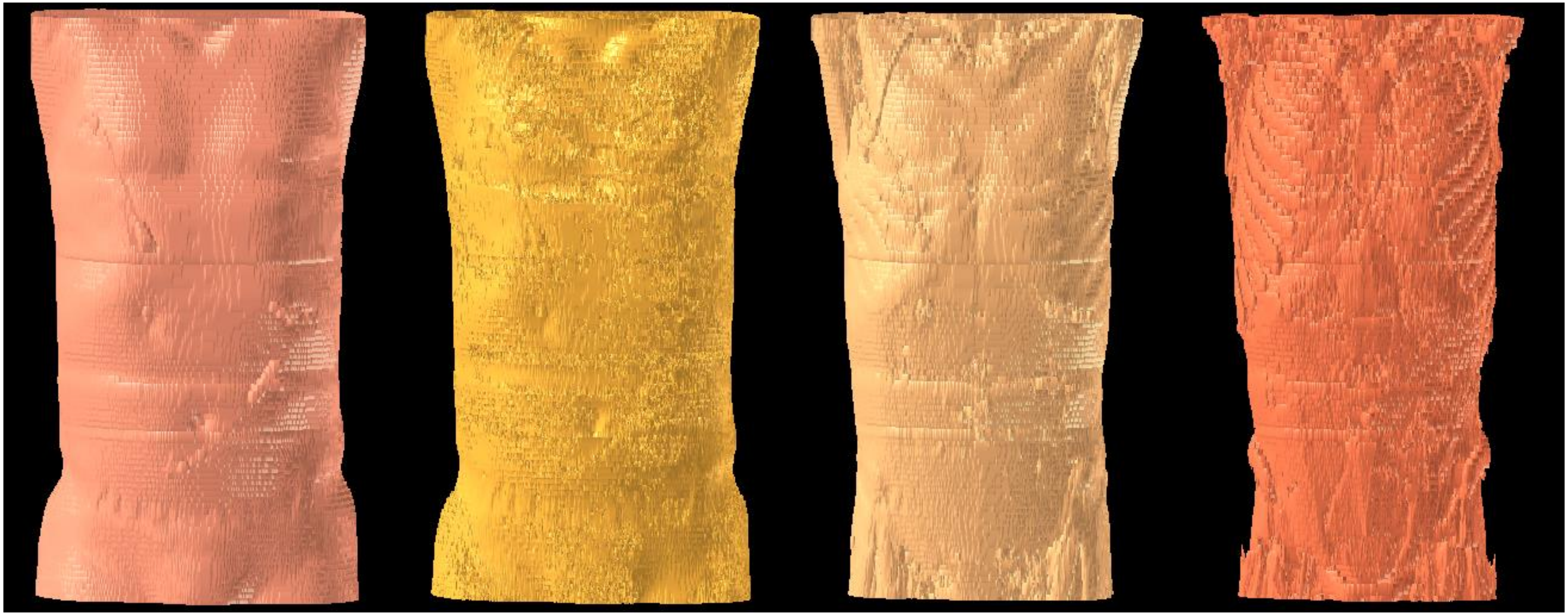


after processing

Preprocessing Steps

Surface after removal of

peripheral artifacts | the skin layer | the peripheral fat | the peripheral muscle

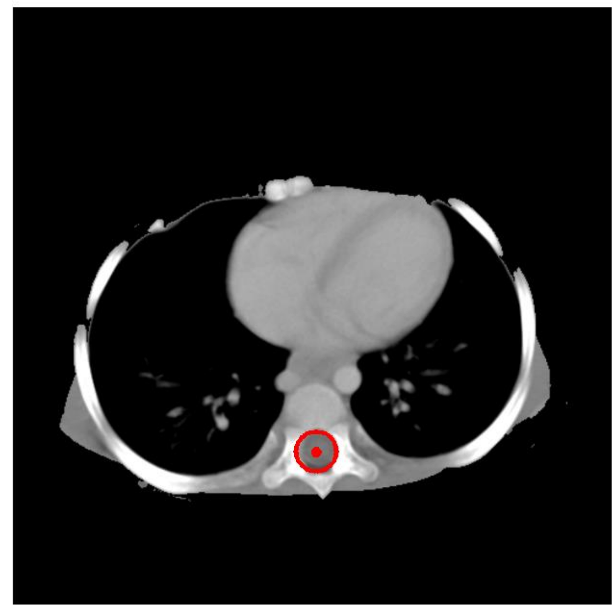


Detection of the Spinal Canal

Original image

Cropped V.C.

Edge map



Detected best-fitting circle and its center

V.C.: vertebral column

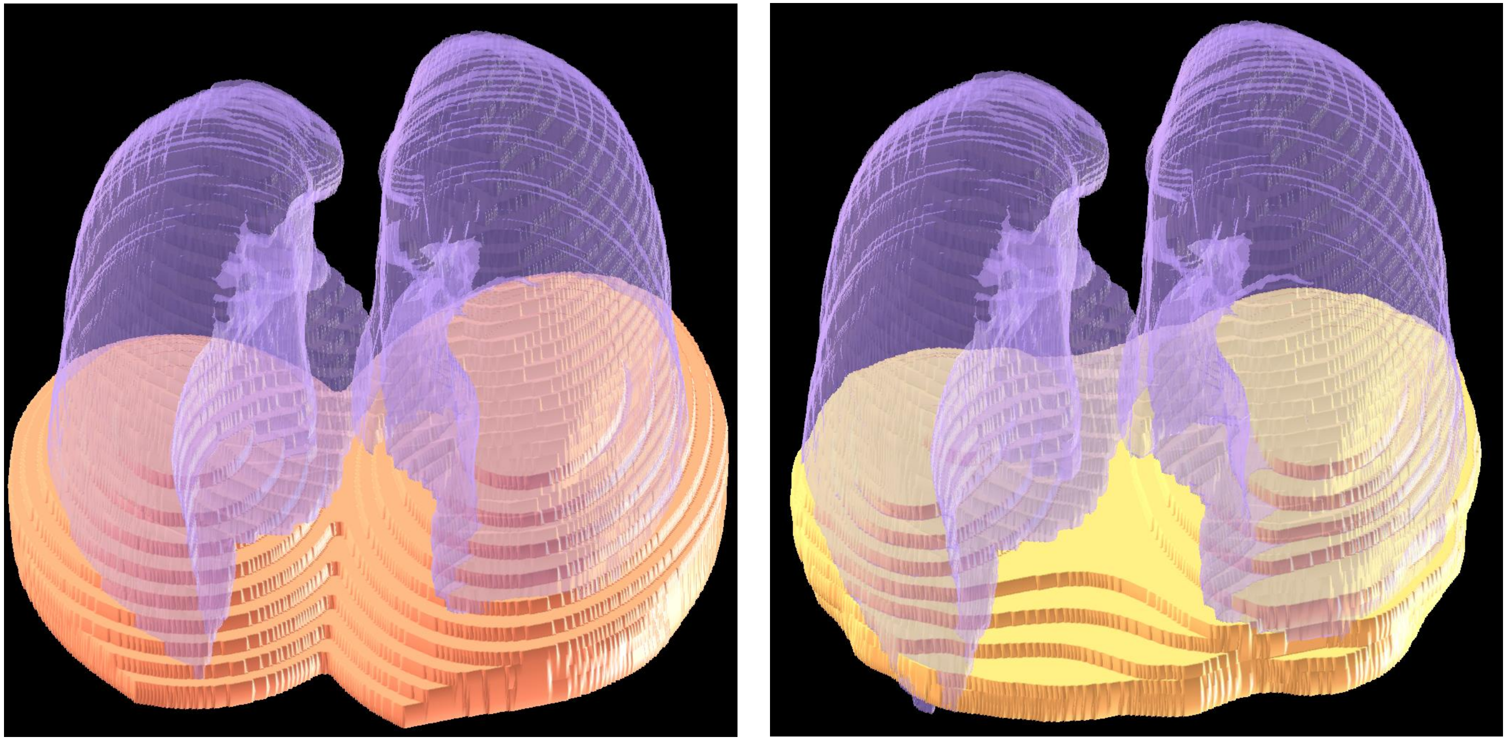
Delineation of the Diaphragm

--- *contours drawn by a radiologist*

--- *contours obtained by our methods*

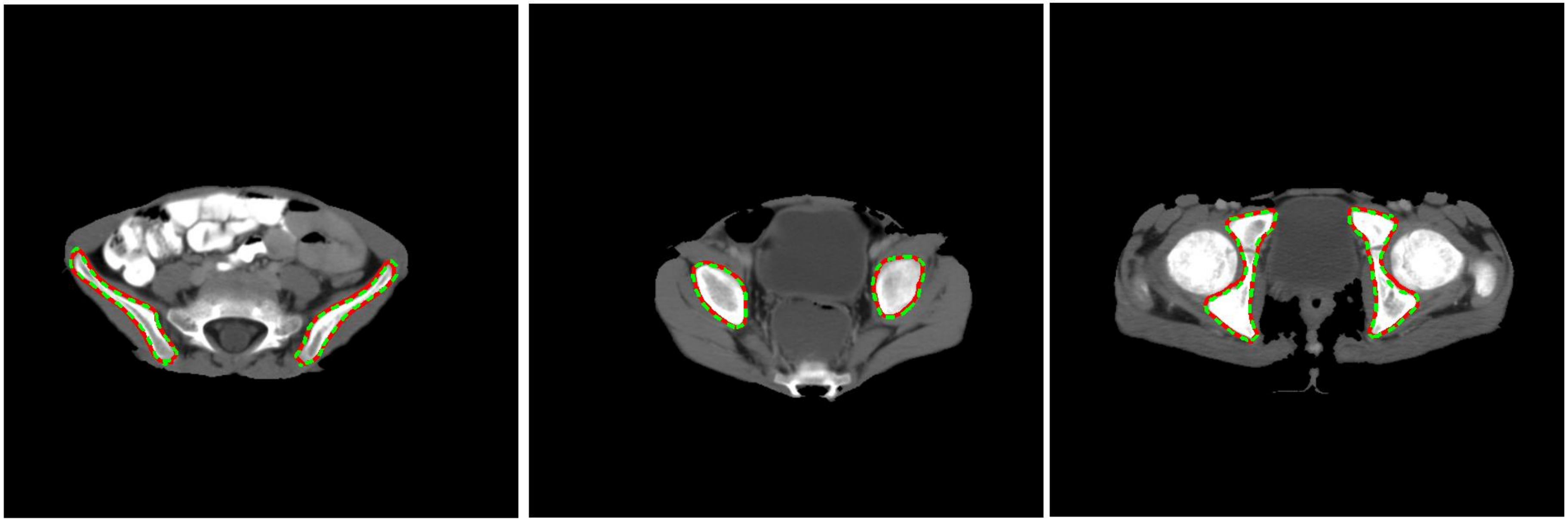
Delineation of the Diaphragm

Representation of the diaphragm using linear least squares and active contours



Segmented lungs and the diaphragm

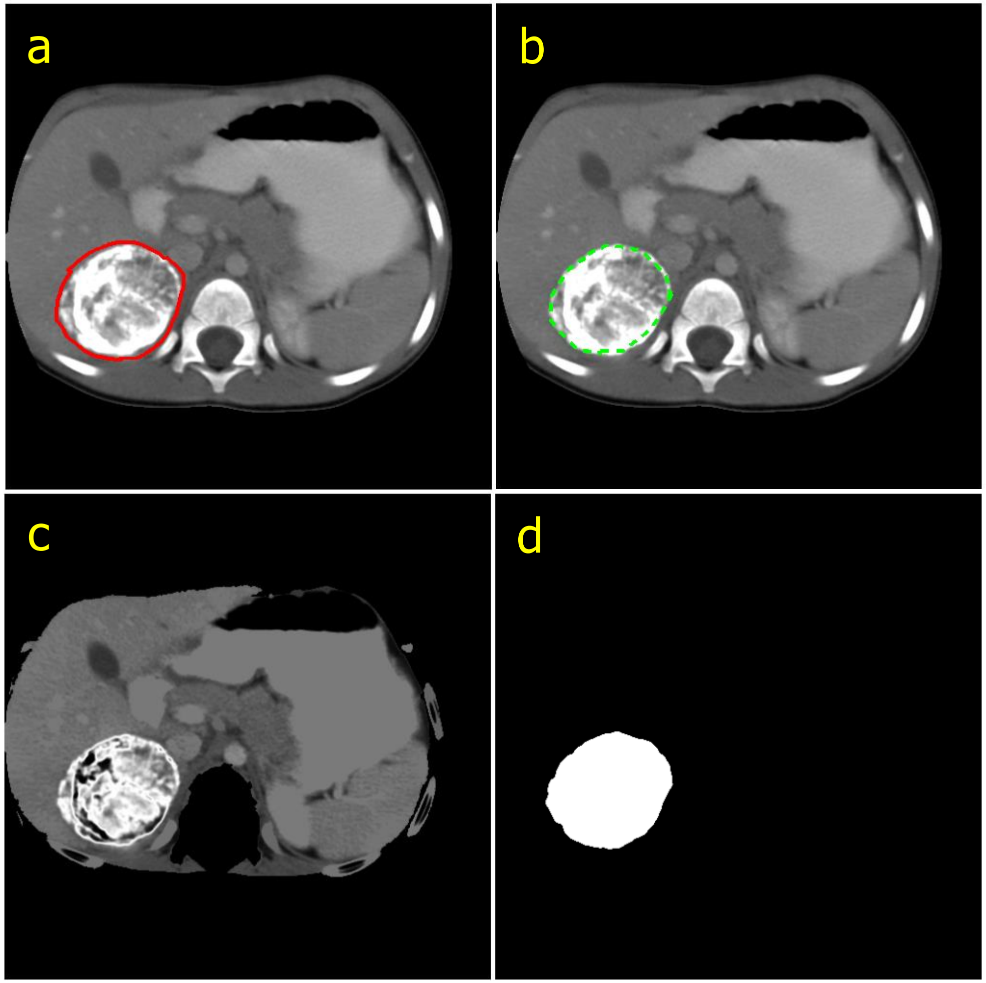
Detection of the Pelvic Girdle



-- *contours drawn by a radiologist*

-- *contours obtained by our methods*

Segmentation of Neuroblastoma



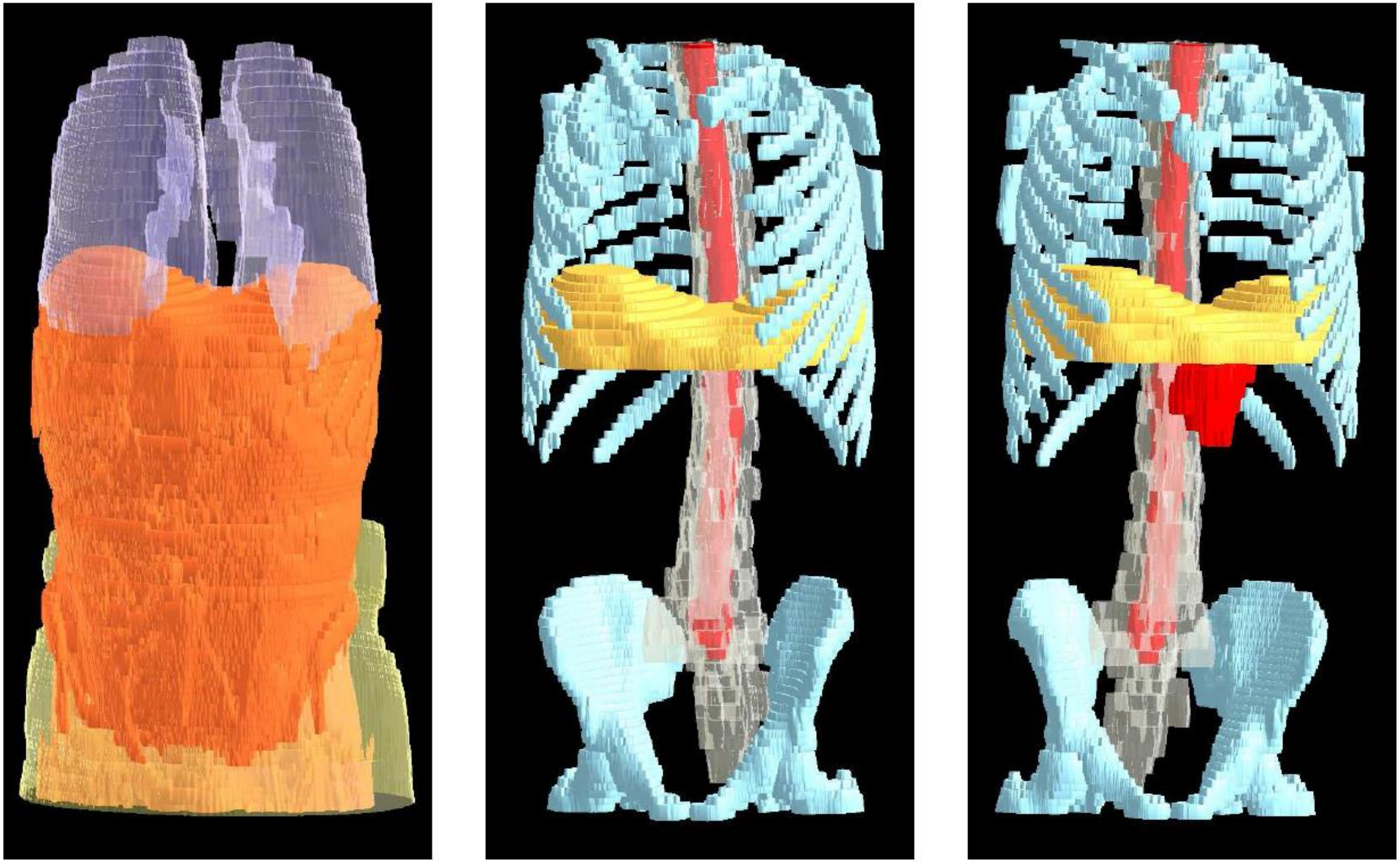
a. tumor segmented by a radiologist

b. user-selected region marker

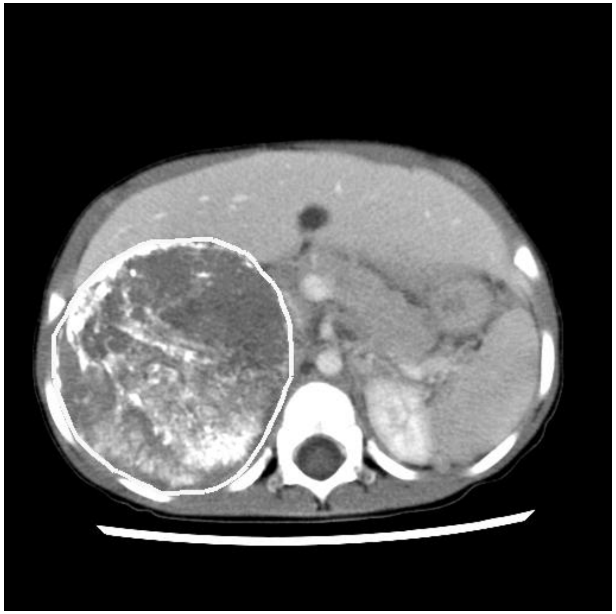
c. result of opening-by-reconstruction

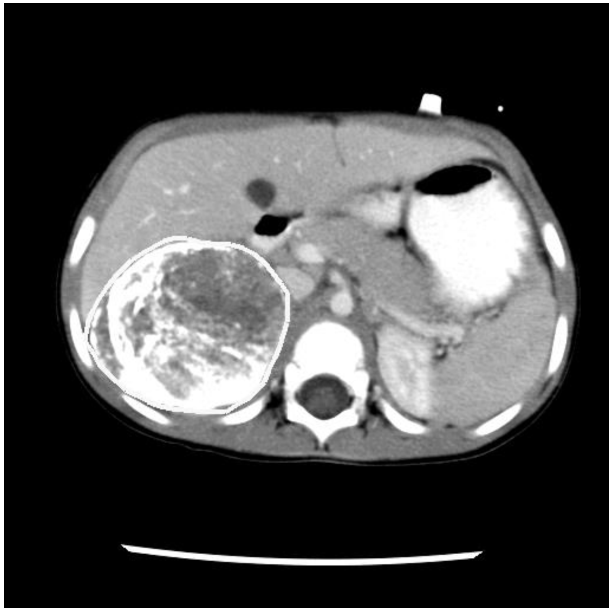
d. final result of segmentation

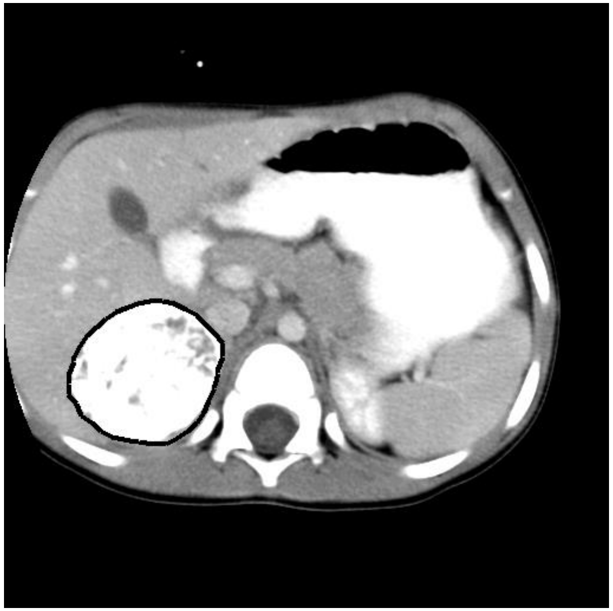
Anatomical Landmarks and the Tumor in 3D



Follow up of Treatment of Neuroblastoma





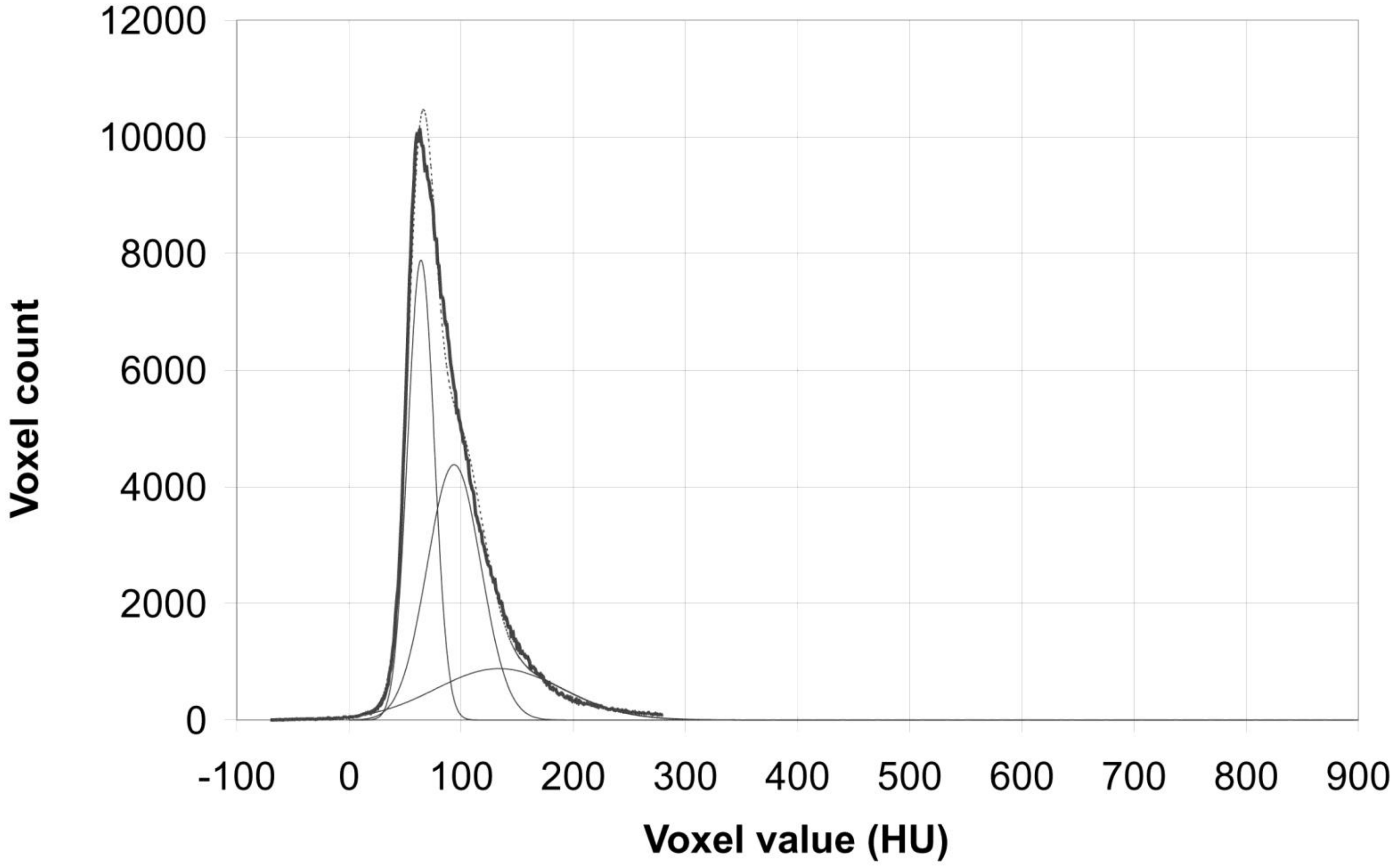


Case 1a
April 2001

Case 1b
June 2001

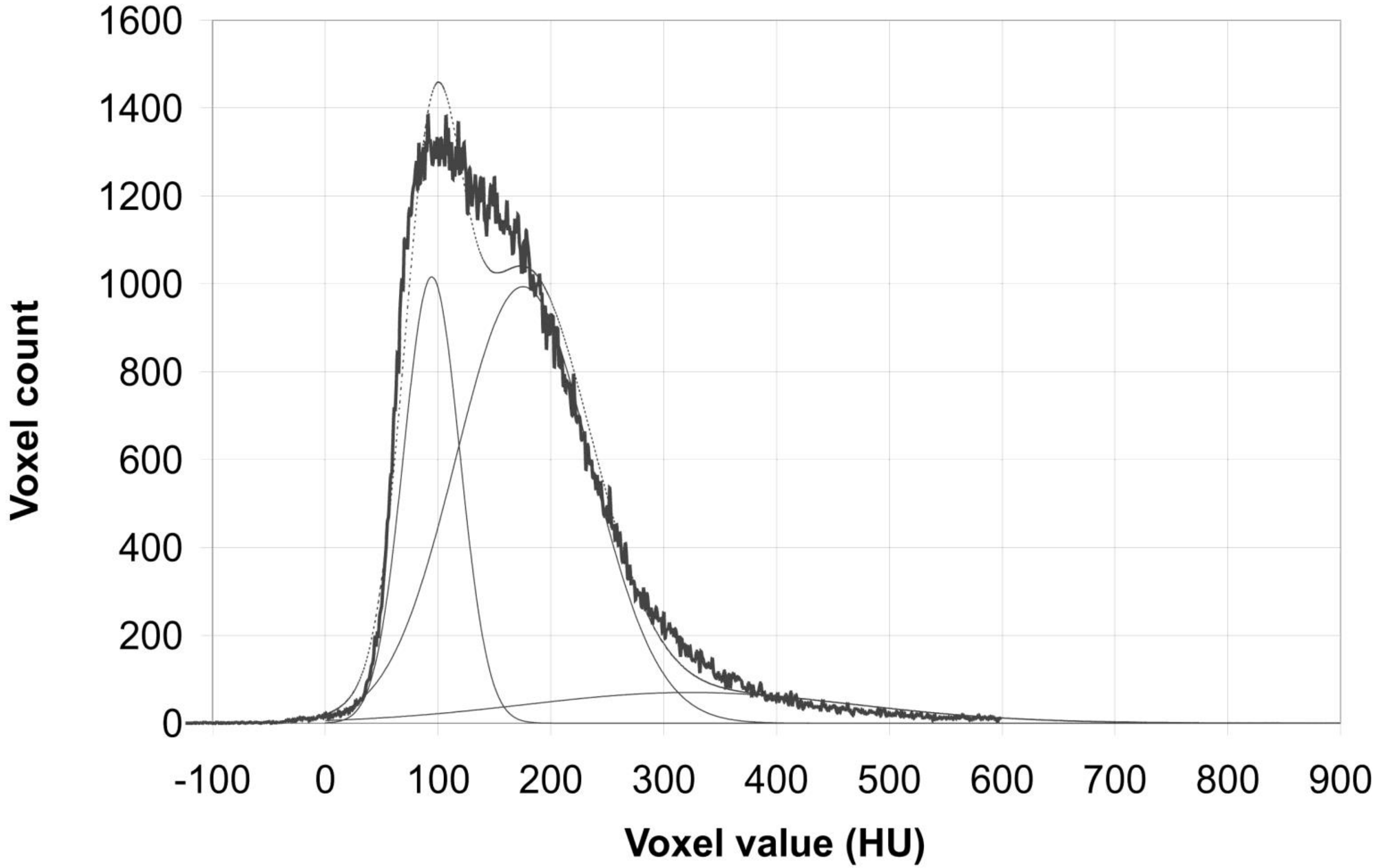
Case 1c
Sept 2001

Estimation of the Tissue Composition of the Tumor



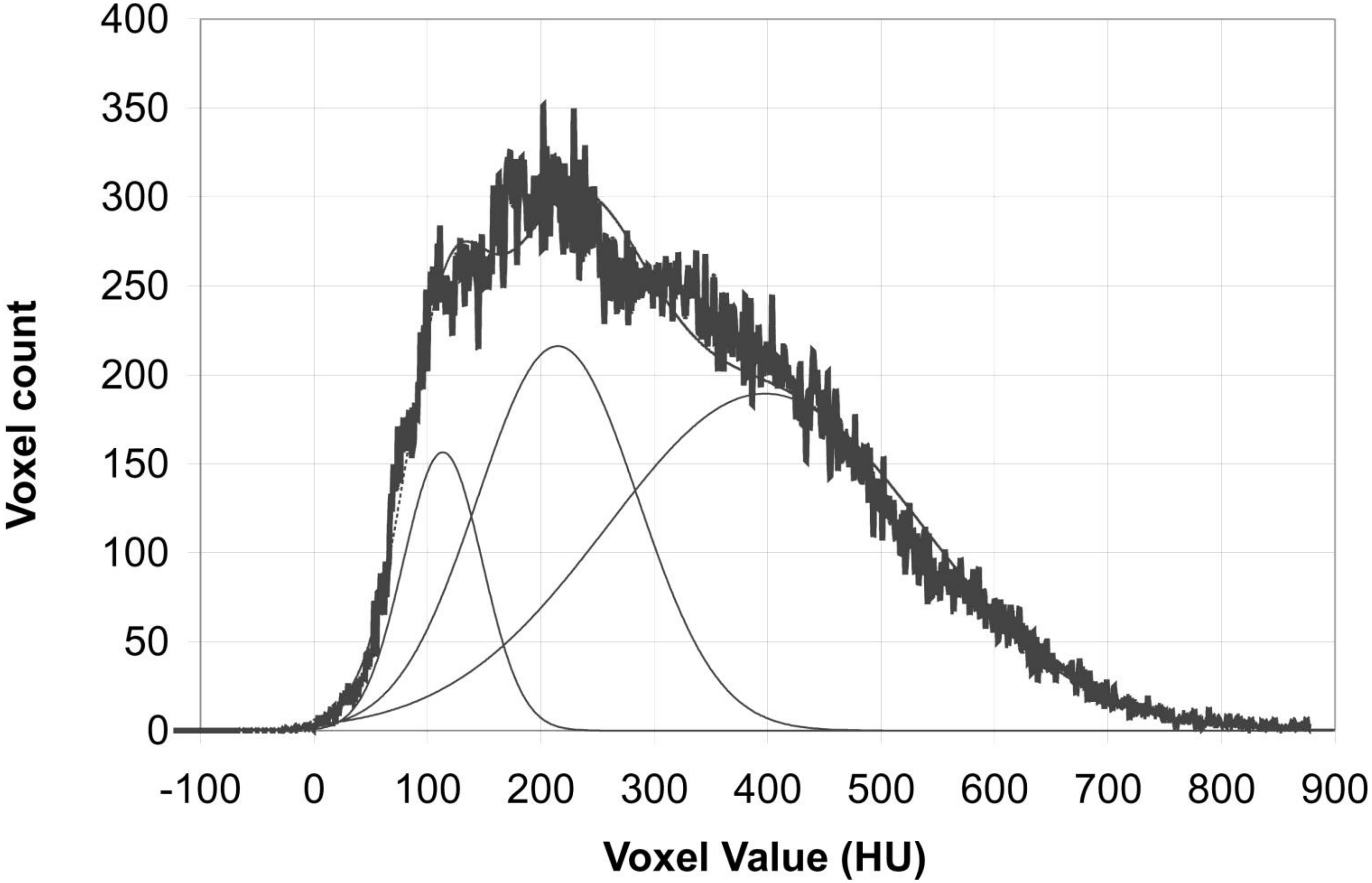
GMM for Case 1a, M = 3

Estimation of the Tissue Composition of the Tumor



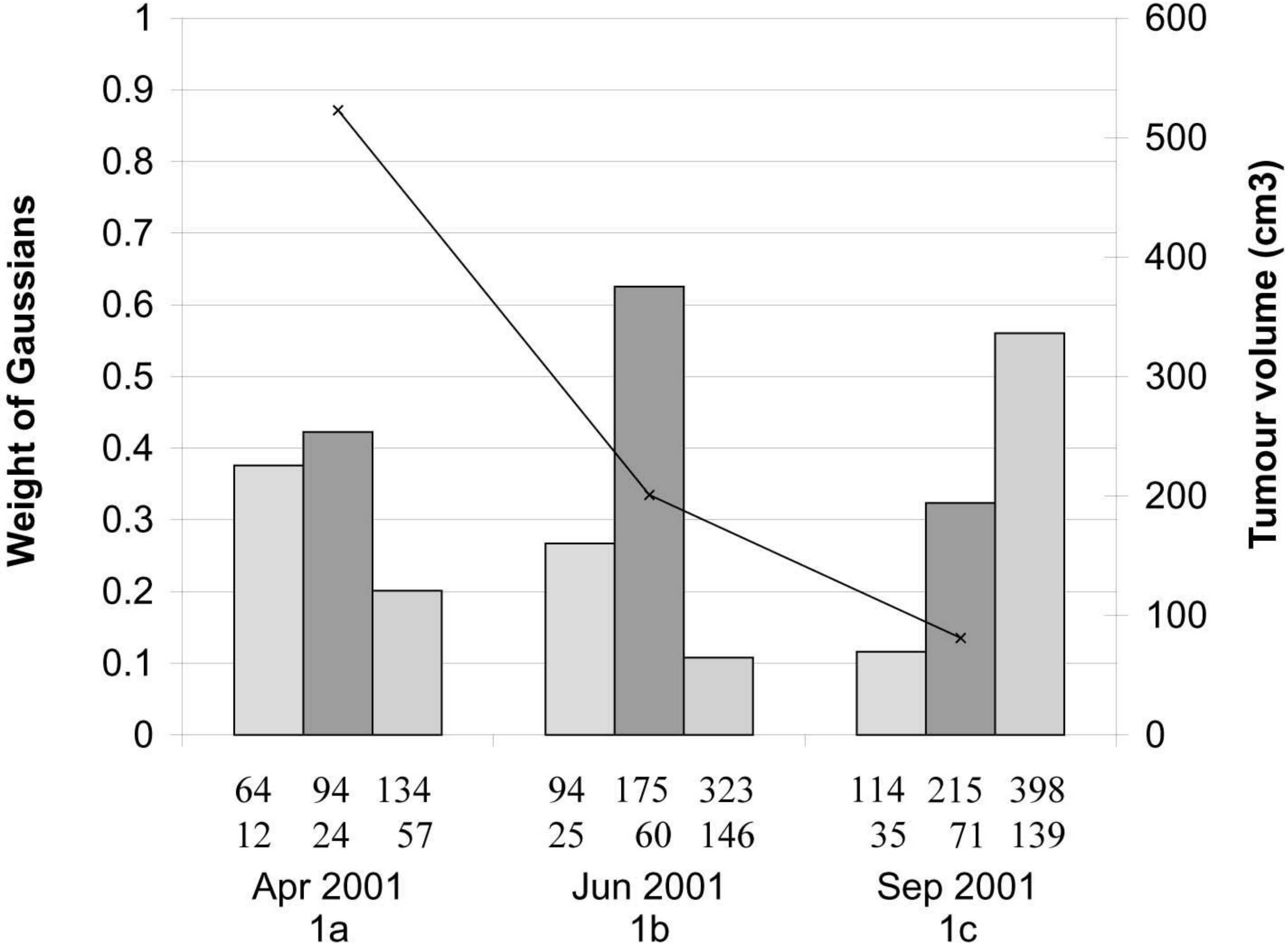
GMM for Case 1b, M = 3

Estimation of the Tissue Composition of the Tumor



GMM for Case 1c, M = 3

Analysis of the Response to Treatment of the Tumor



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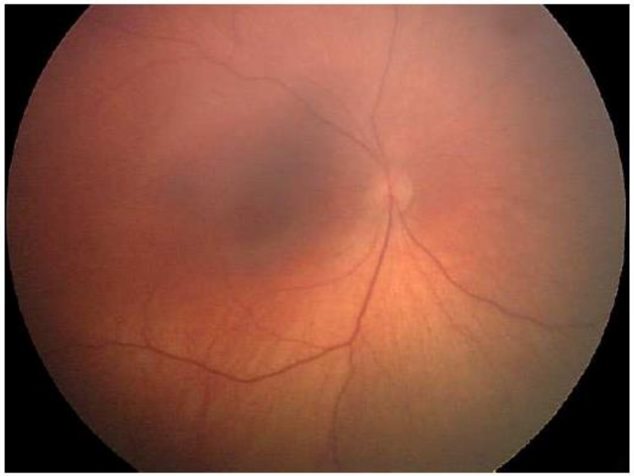
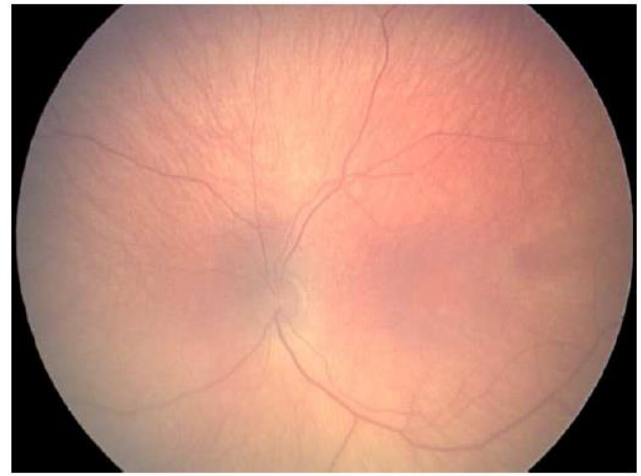
Retinopathy of Prematurity: RoP and Plus Disease

RoP 0





RoP 1

RoP 2

RoP 3

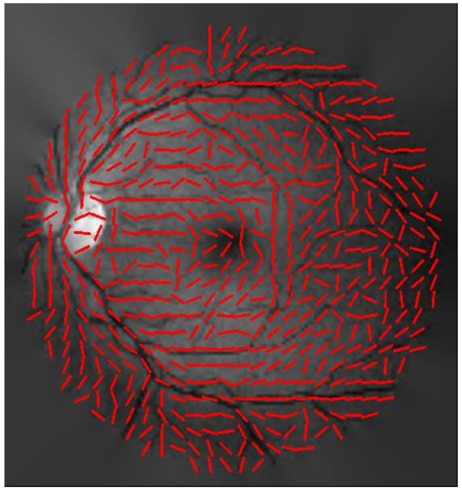
Objectives of CAD of RoP

- Detection of vessels and measurement of the thickness of the major temporal arcade (MTA)
- Quantification of the openness of the MTA via parabolic modeling and measurement of the temporal arcade angle (TAA)
- Quantification of vascular tortuosity

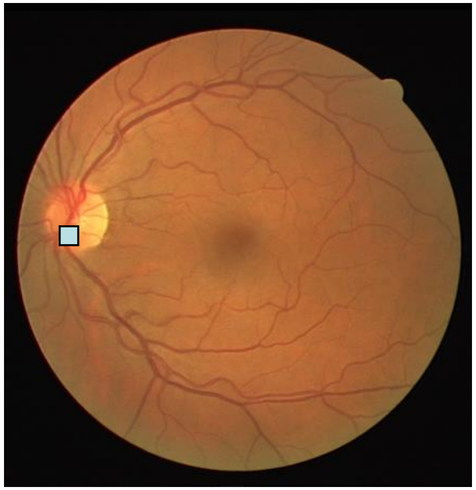
Detection of Vessels and the Center of the Optic Disk

DRIVE
Image 01

Magnitude
response of
Gabor filters

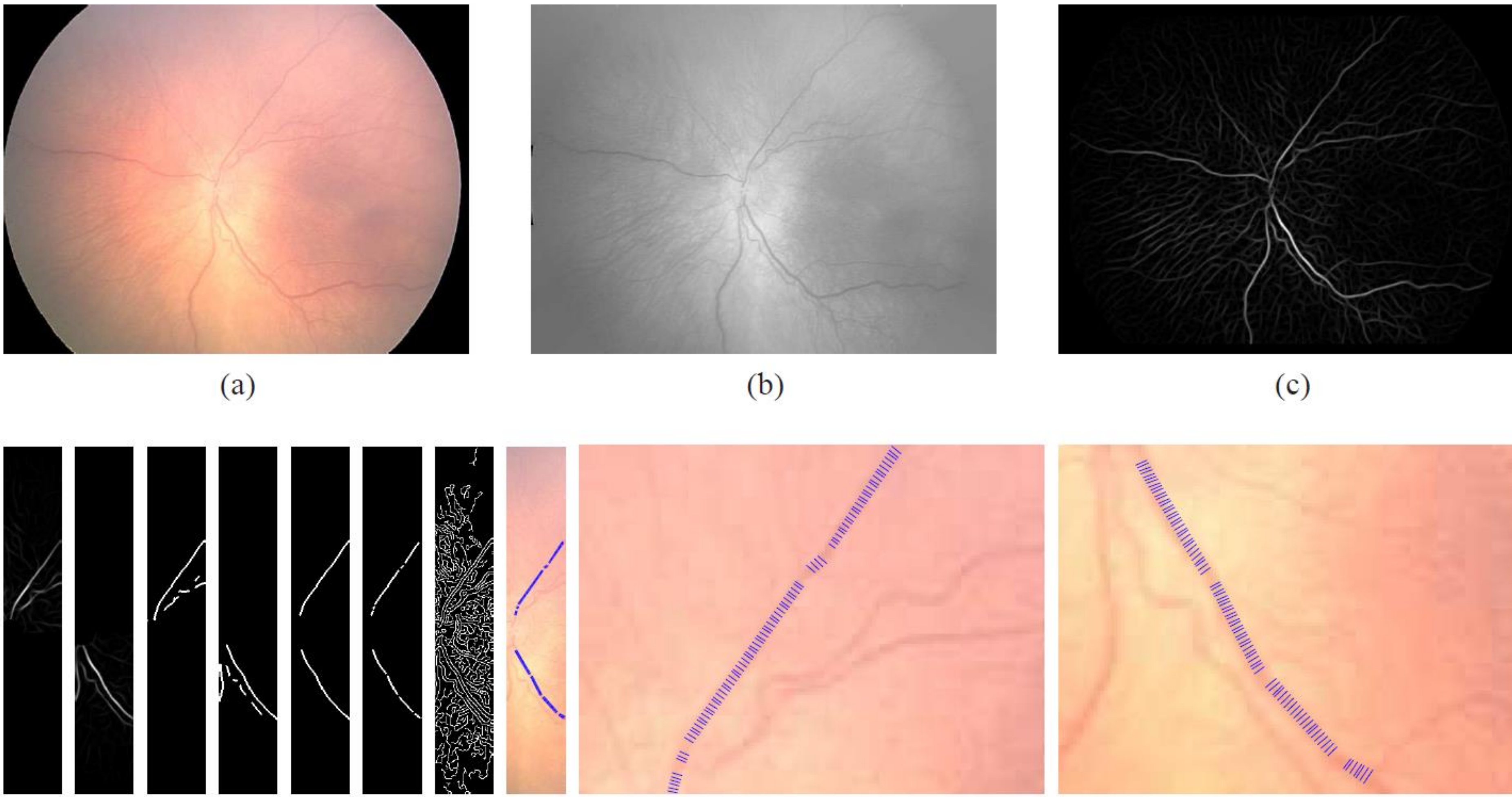


Orientation
field



Detected center
of the optic disk
using phase
portrait analysis

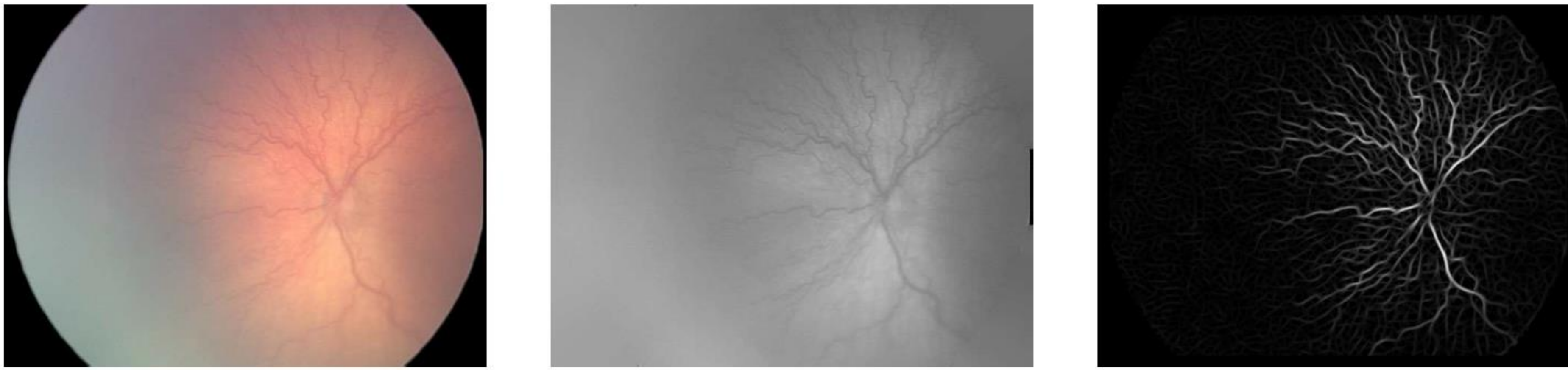
Vessel Width Measurement: No Plus Disease 111 ± 18 μm



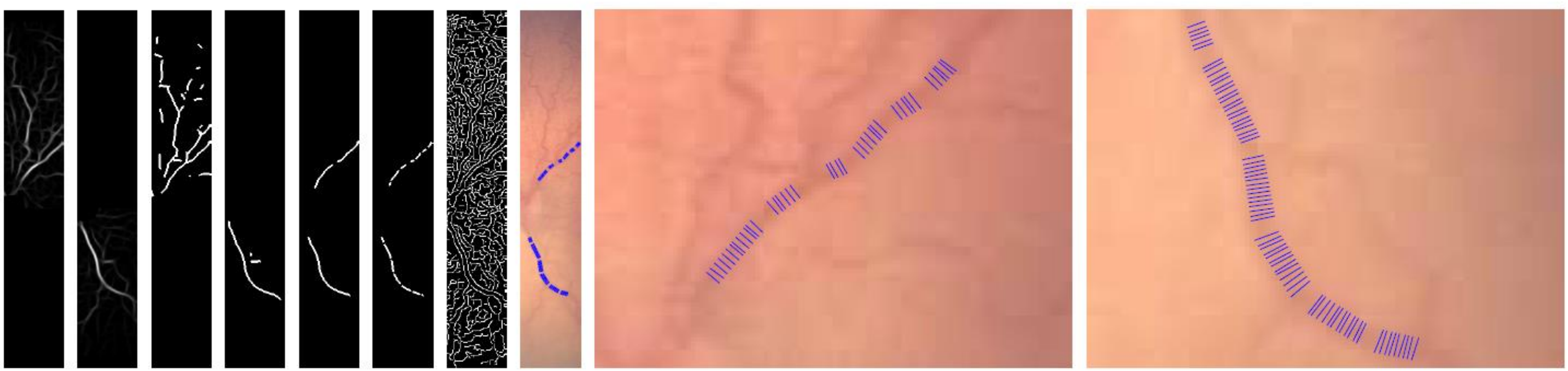
(a) (b) (c)

(d) (e) (f) (g) (h) (i) (j) (k) (l) (m)

Vessel Width Measurement: Plus Disease 125 ± 17 μm

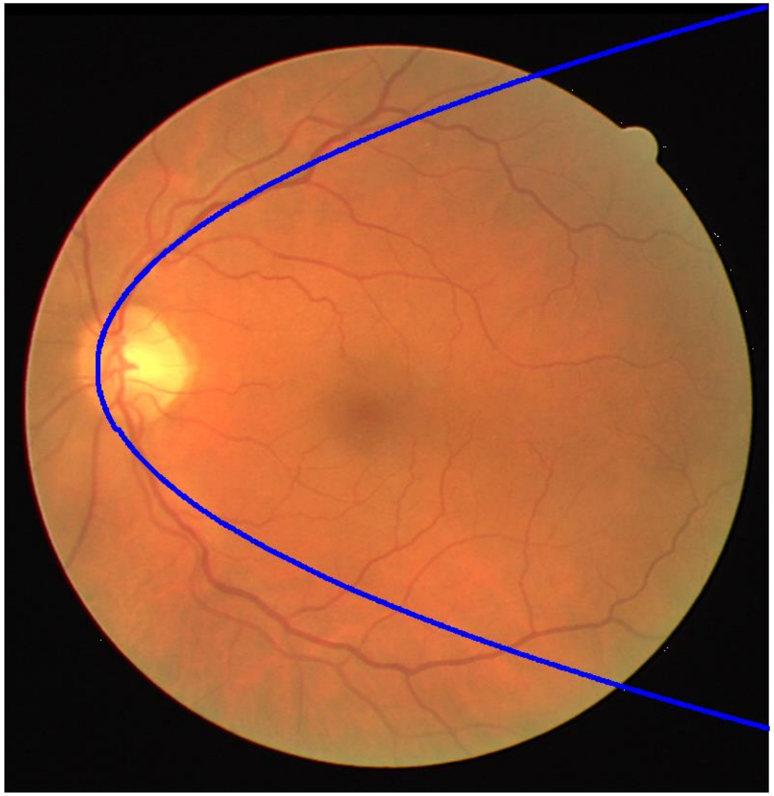


(a) (b) (c)

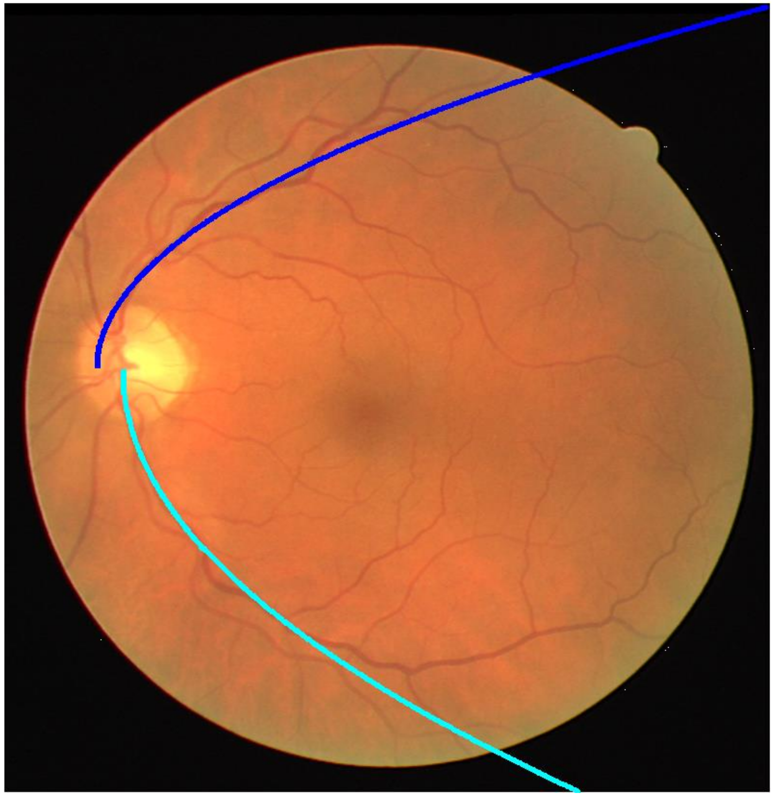


(d) (e) (f) (g) (h) (i) (j) (k) (l) (m)

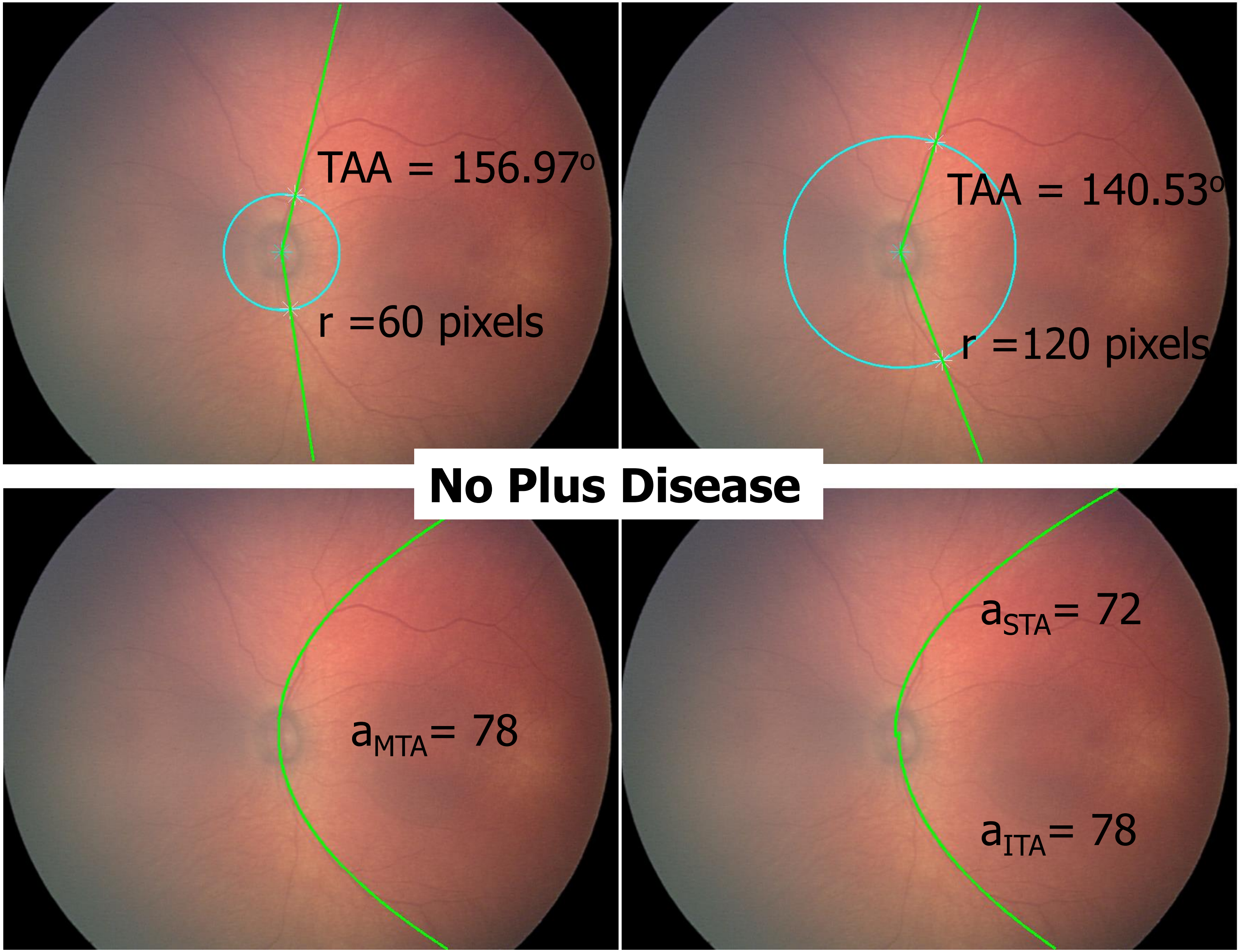
Dual-parabolic Modeling using the Hough Transform



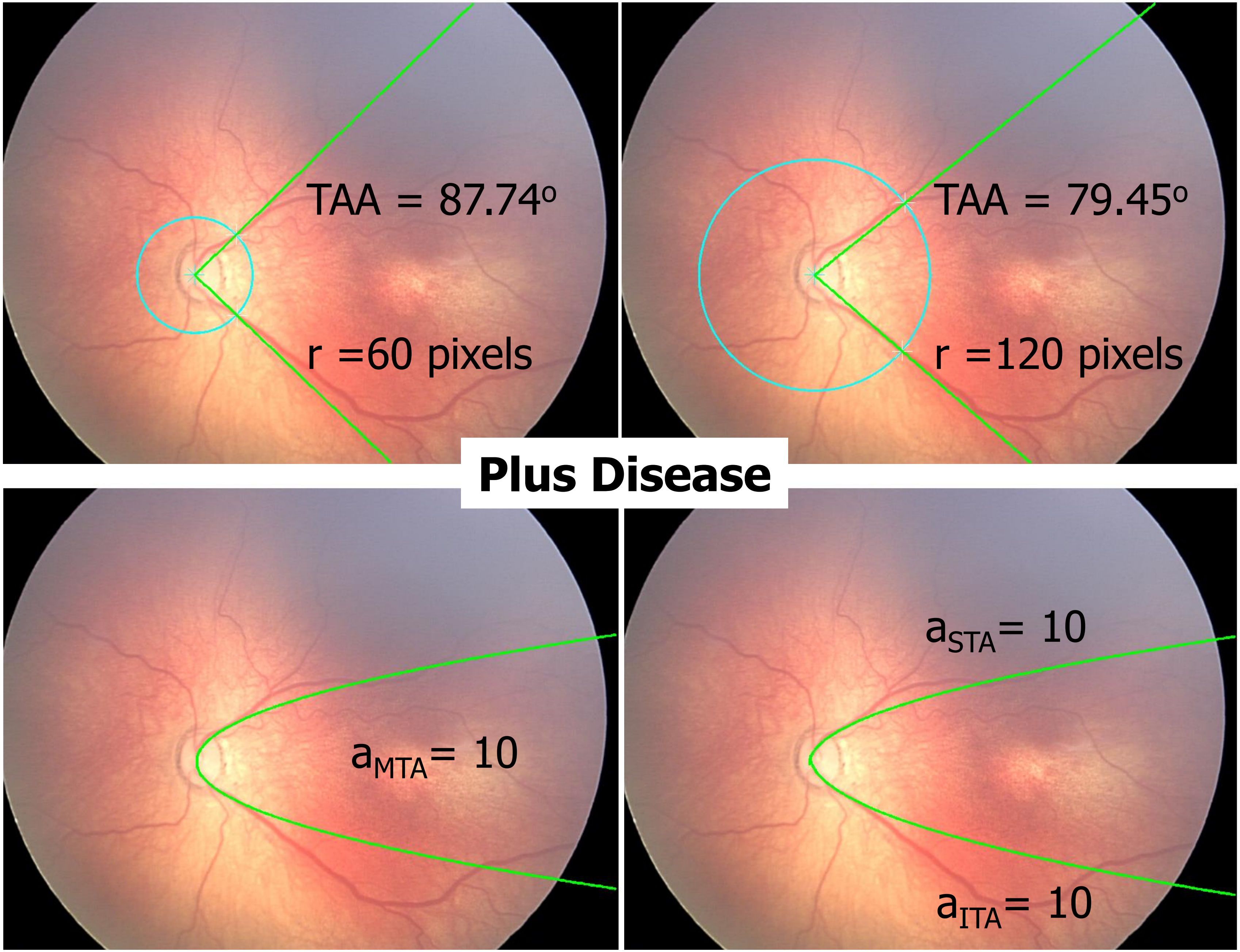
Single-parabolic fit



Dual-parabolic fit


TAA = 156.97°
r =60 pixels
TAA = 140.53°
r =120 pixels
No Plus Disease
a_{MTA}= 78
a_{STA}= 72
a_{ITA}= 78

Plus Disease



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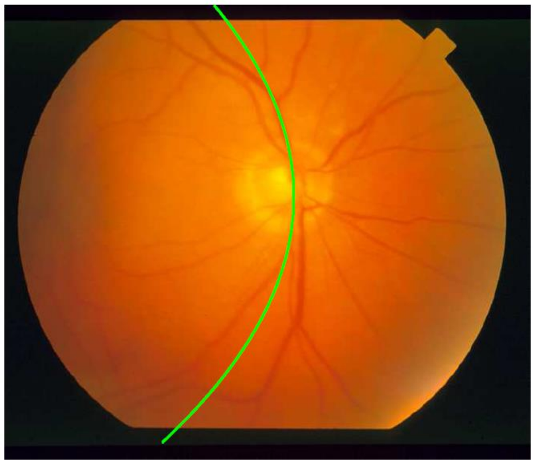
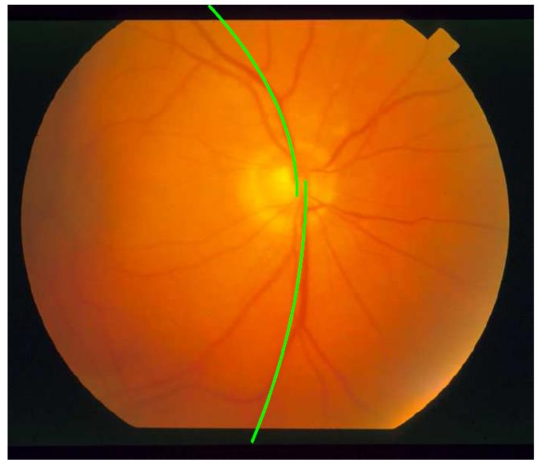
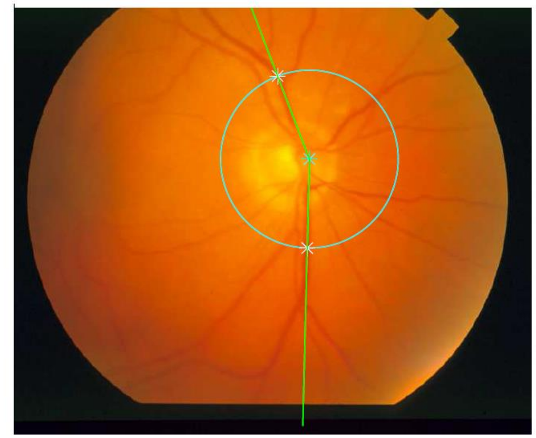
PDR: Proliferative Diabetic Retinopathy



Normal: aMTA = 153



aSTA = 138, aITA = 420



TAA = 157.8°

PDR: aMTA = 55

aSTA = 36, aITA = 48

TAA = 110.4°

Measure of Tortuosity based on Vessel Angle

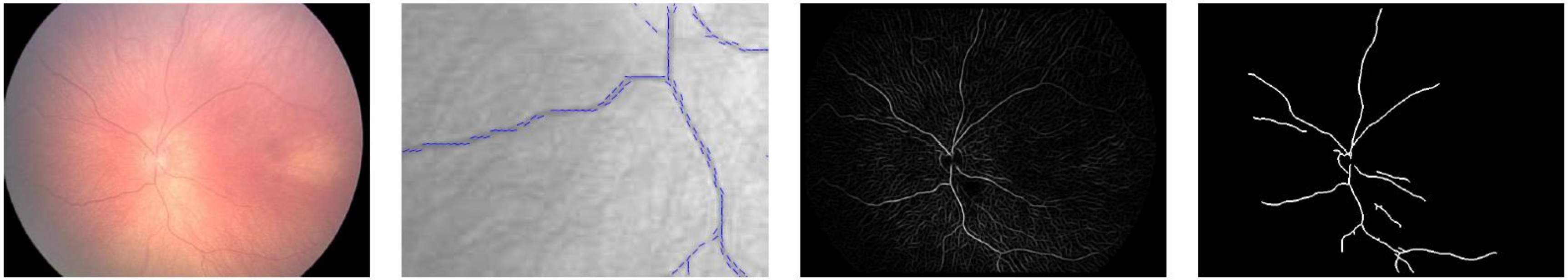
- Angle-variation index:

$$\mathrm{AVI}(p) = \frac{1}{2}\left\{\left|\sin\left[\phi(p)-\phi(p-1)\right]\right| + \left|\sin\left[\phi(p)-\phi(p+1)\right]\right|\right\}$$

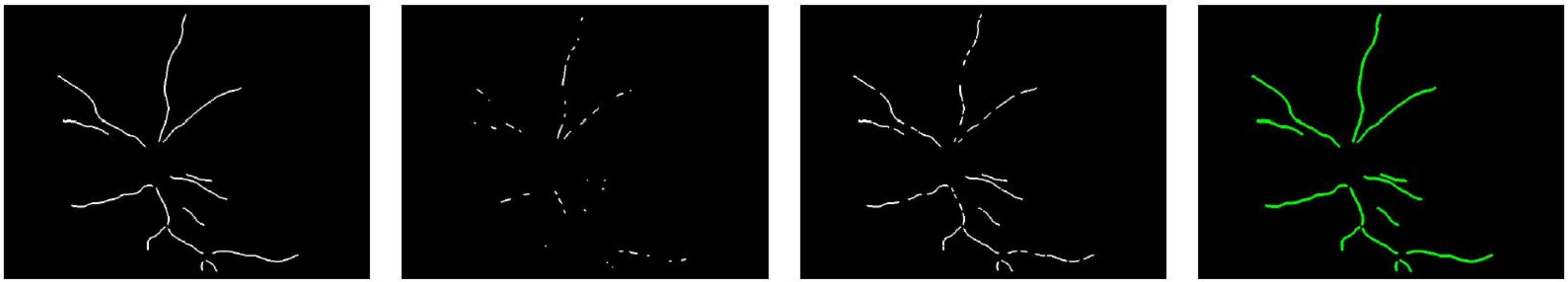
- Average AVI for a vessel segment:

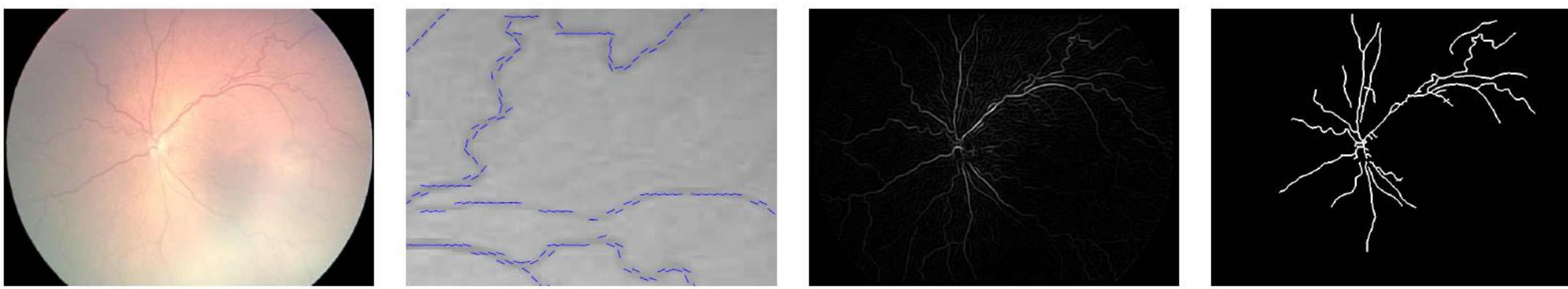
$$\mathrm{AVT} = \frac{1}{N}\sum_{n=1}^{N}\mathrm{AVI}(n)$$

- AVT normalized to [0, 1] for each segment

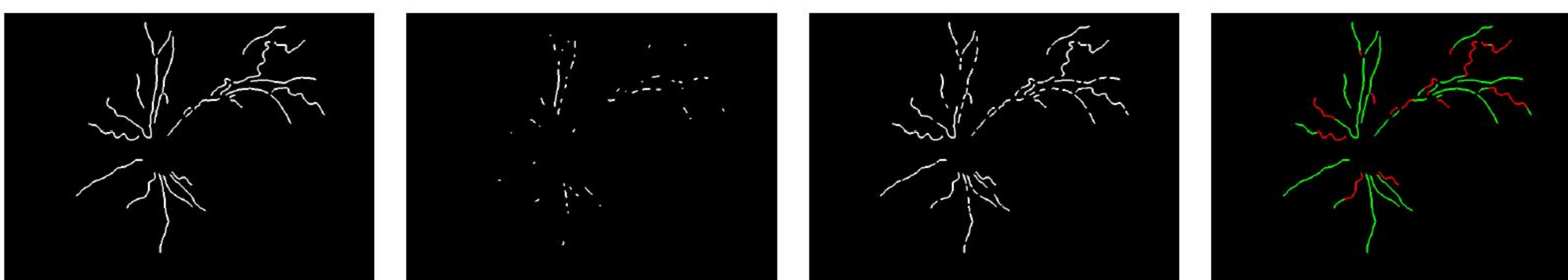


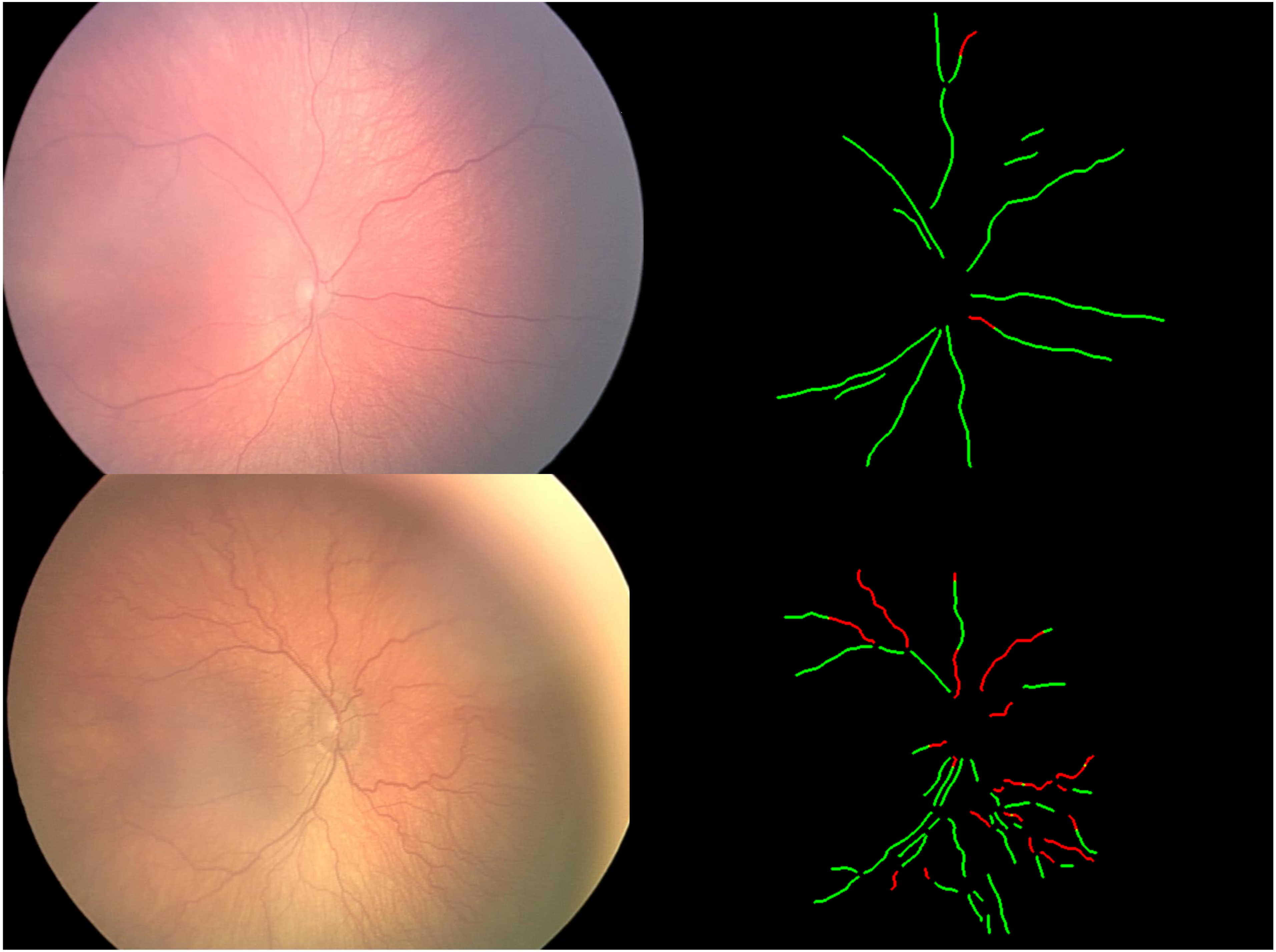
Case with no plus disease: 0 mm of tortuous vessels





Case with plus disease: 11.75, 4.20, 1.99, and 1.42 mm in the four quadrants

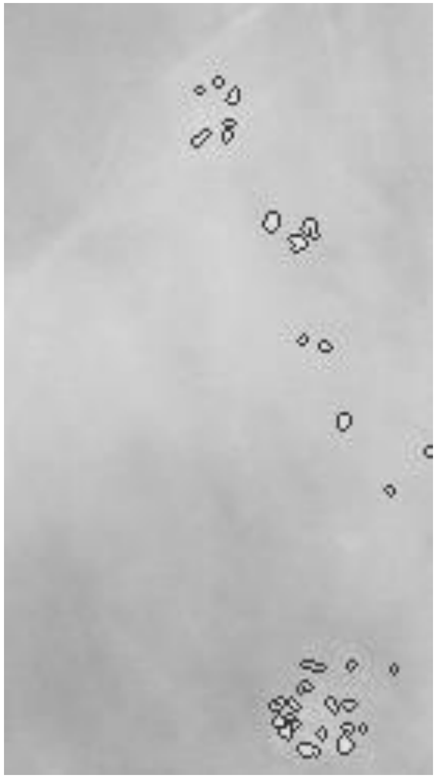




Detection of Calcifications in Mammograms

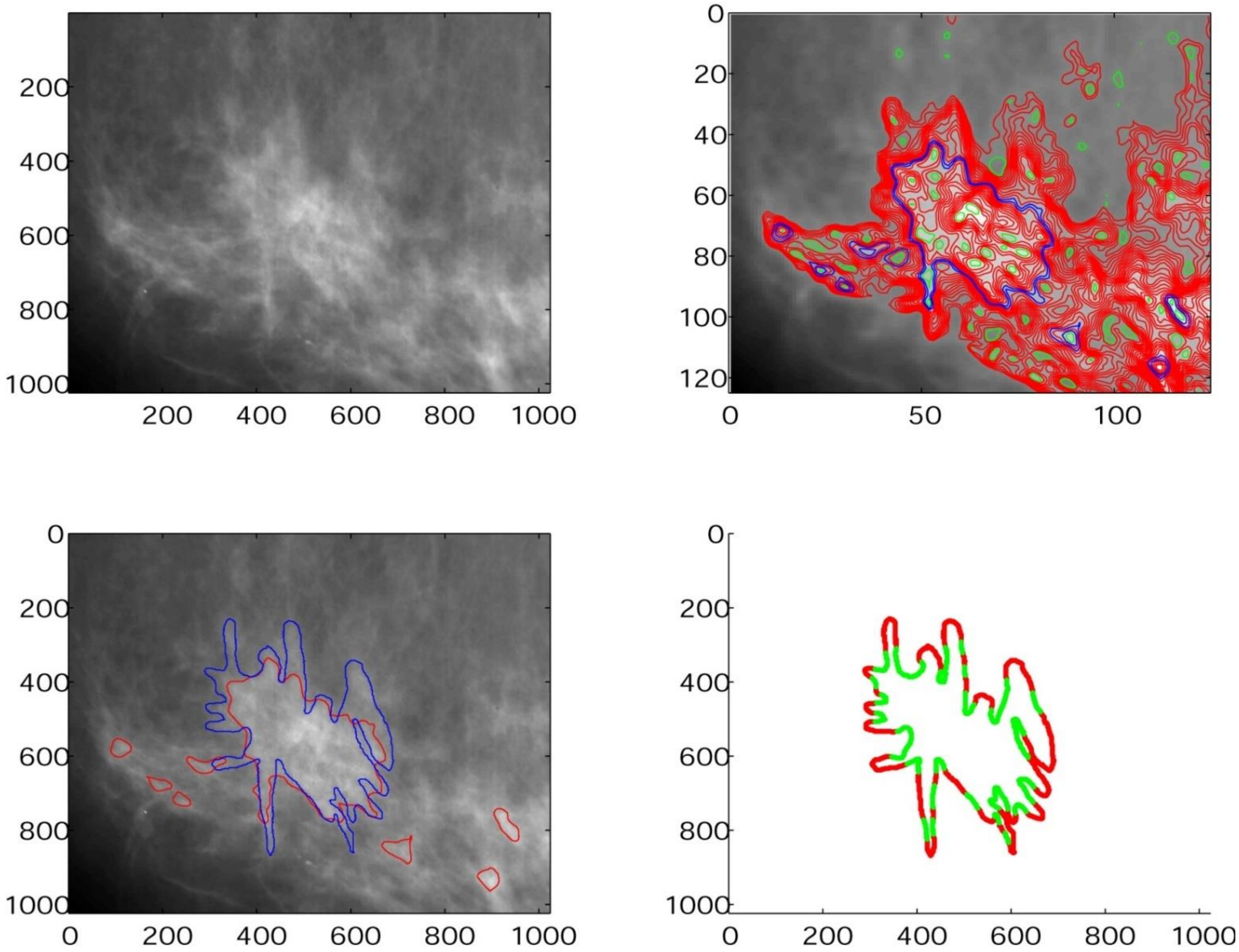
(a) Part of original mammogram

(b) Seeds detected using prediction error



(c) Calcifications detected by region growing

Detection of Breast Tumors in Mammograms



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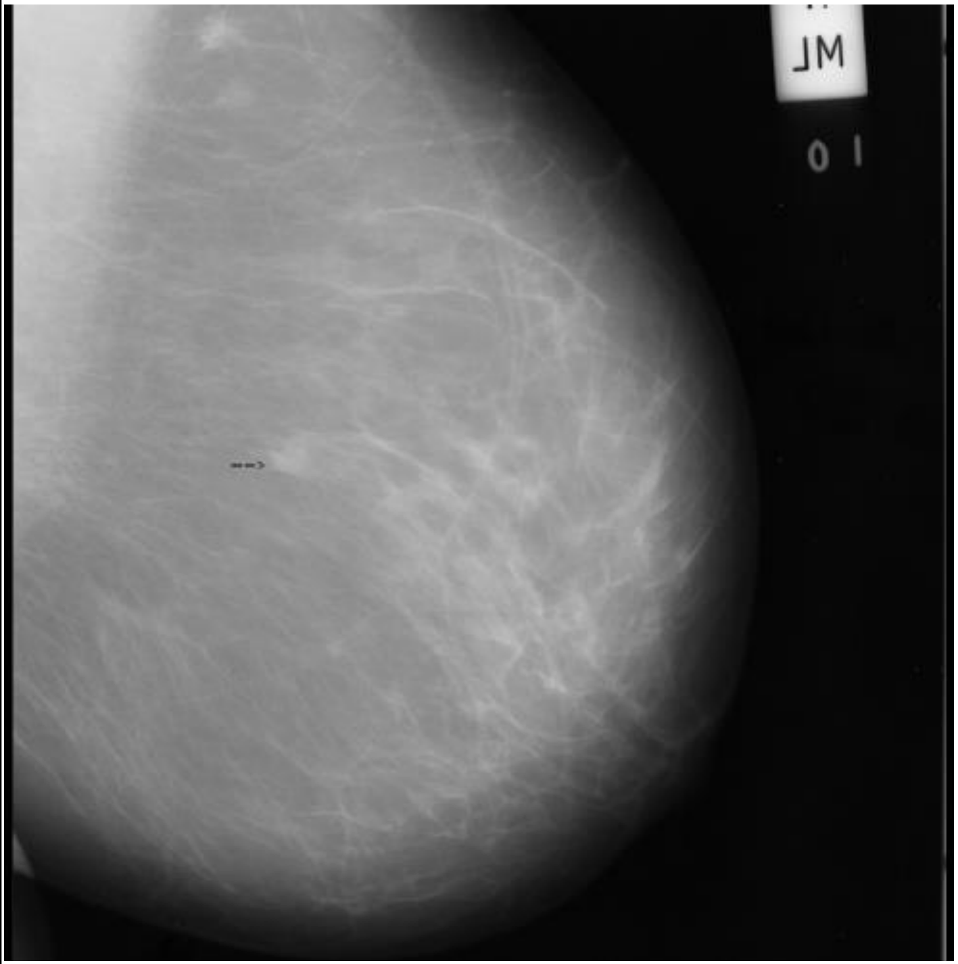
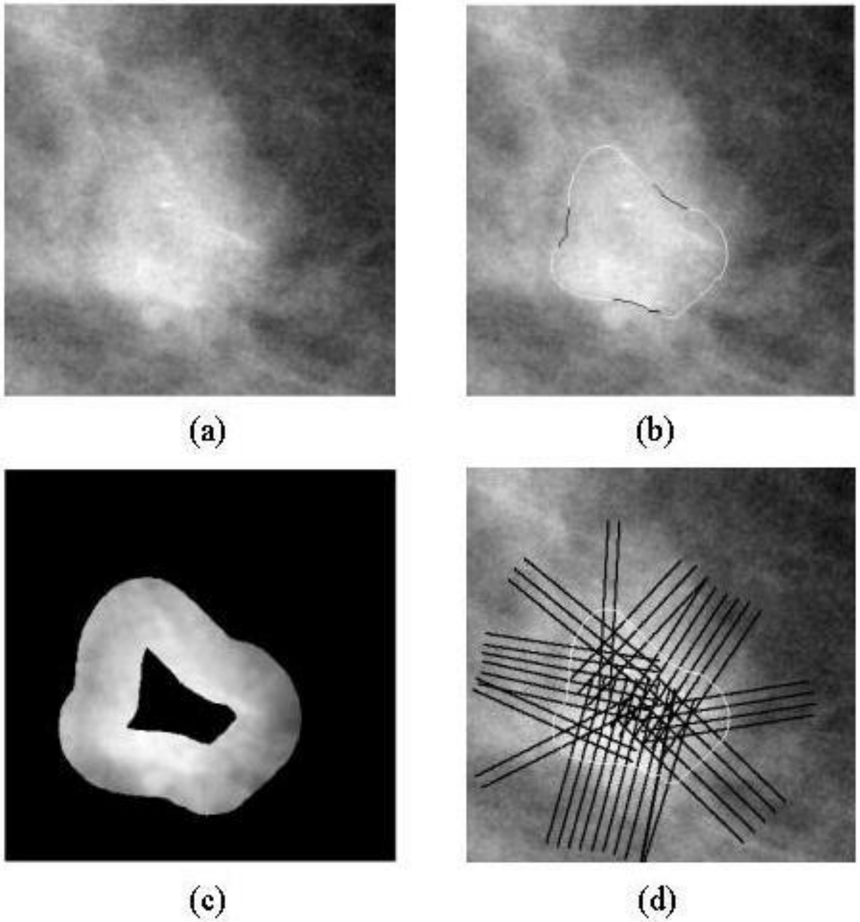
Detection of Breast Tumors: The Problem of False Positives



Analysis of Breast Masses: Feature Extraction

Mass region

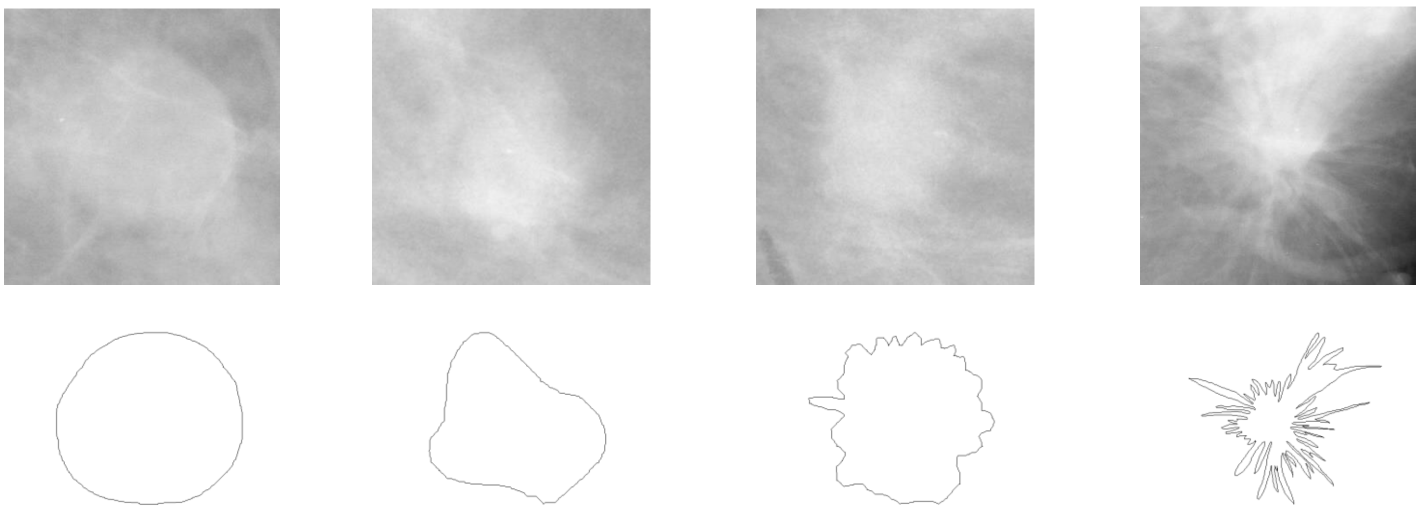
Ribbon for computation of texture features



Shape analysis: Fractional concavity

Normals to contour for computation of edge sharpness (acutance)

Objective Representation of Breast Masses



(a) b145lc95
F_{cc} = 0.00
A = 0.07
F_8 = 8.11

benign circumscribed

(b) b164ro94
F_{cc} = 0.42
A = 0.08
F_8 = 8.05

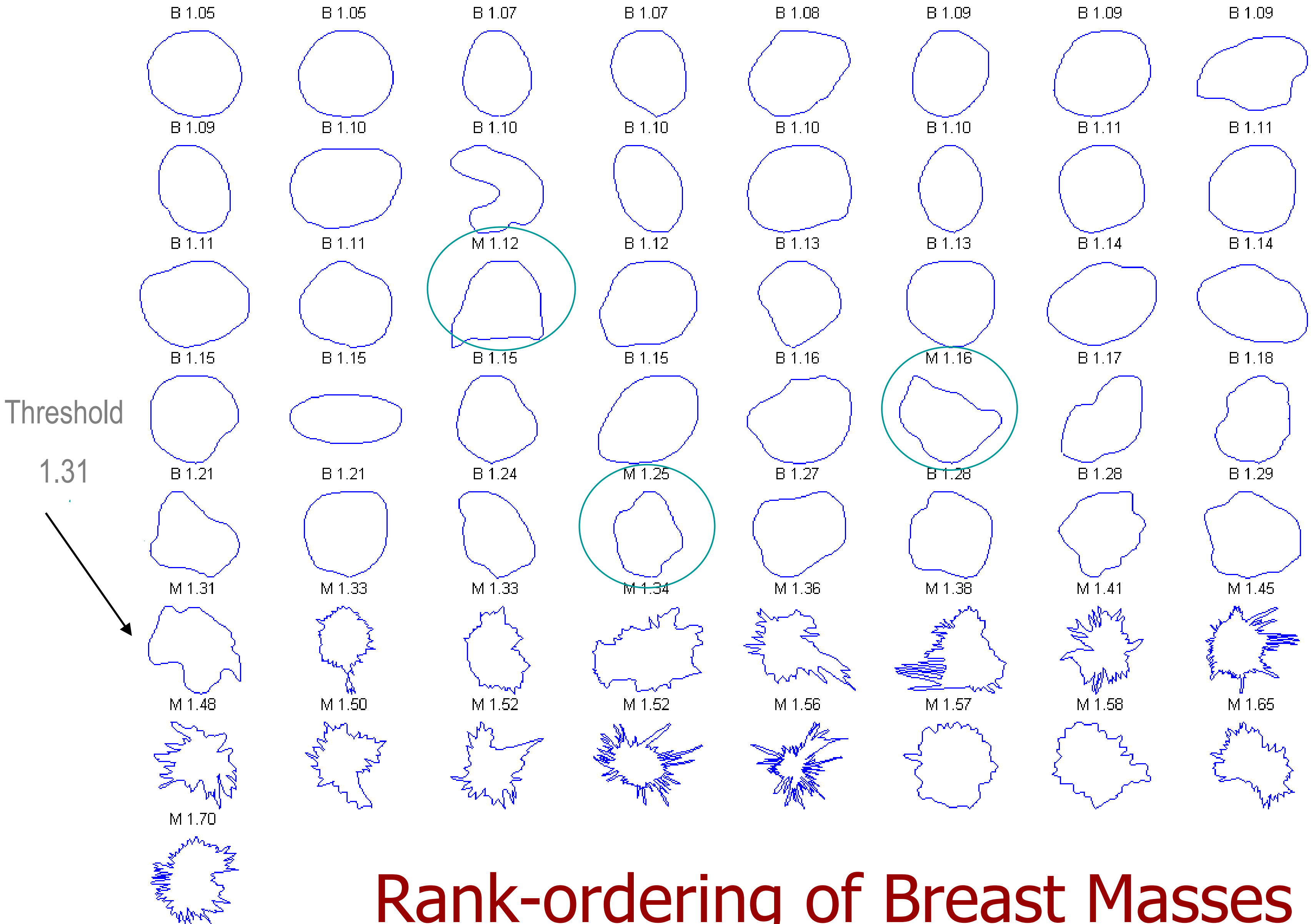
benign macrolobulated

(c) m51rc97
F_{cc} = 0.64
A = 0.09
F_8 = 8.15

malignant microlobulated

(d) m55lo97
F_{cc} = 0.83
A = 0.01
F_8 = 8.29

malignant spiculated

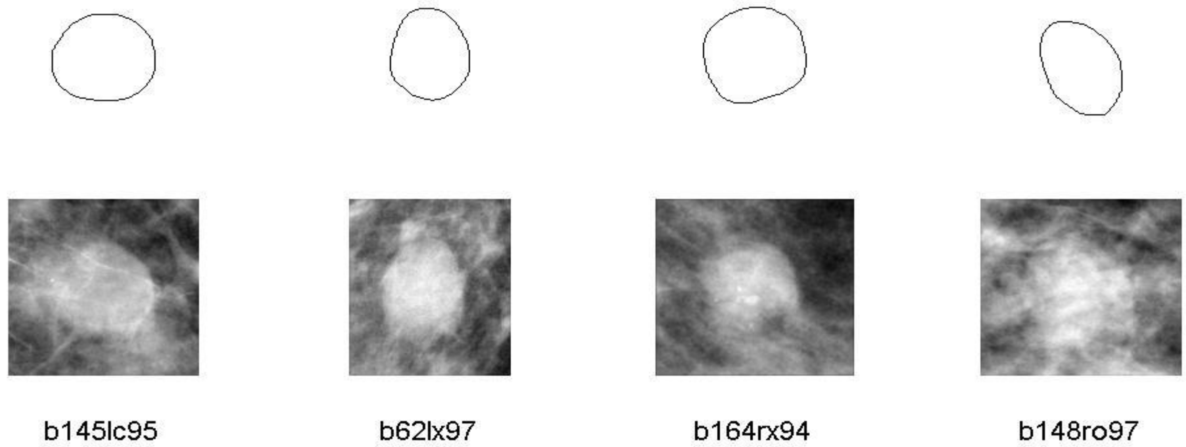


Rank-ordering of Breast Masses using Shape Factors

Content-based Image Retrieval: Benign Mass

Query | Retrieved samples

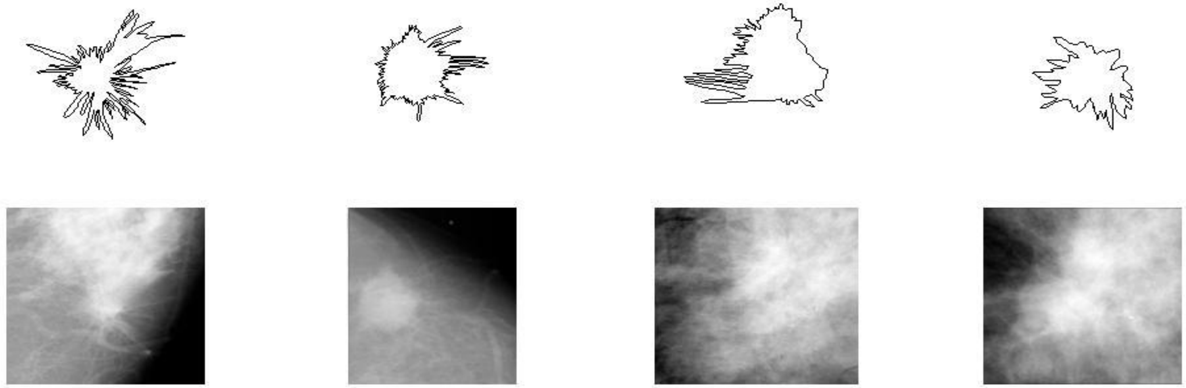
Rank 1 | Rank 2 | Rank 3



Content-based Image Retrieval: Malignant Tumor

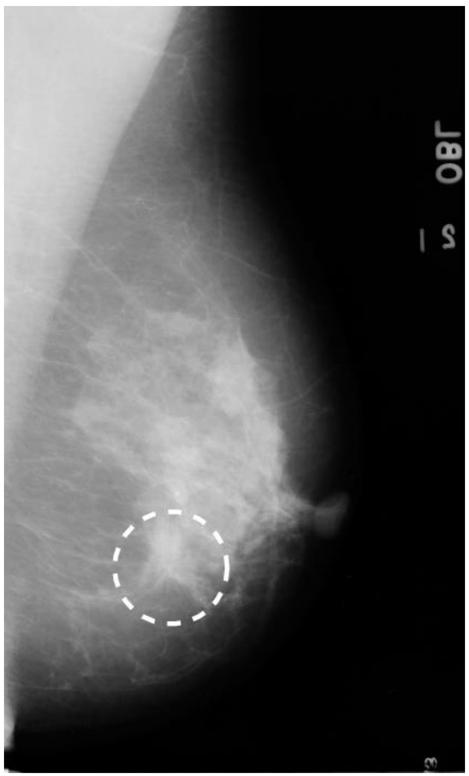
Query | Retrieved samples

Rank 1 | Rank 2 | Rank 3

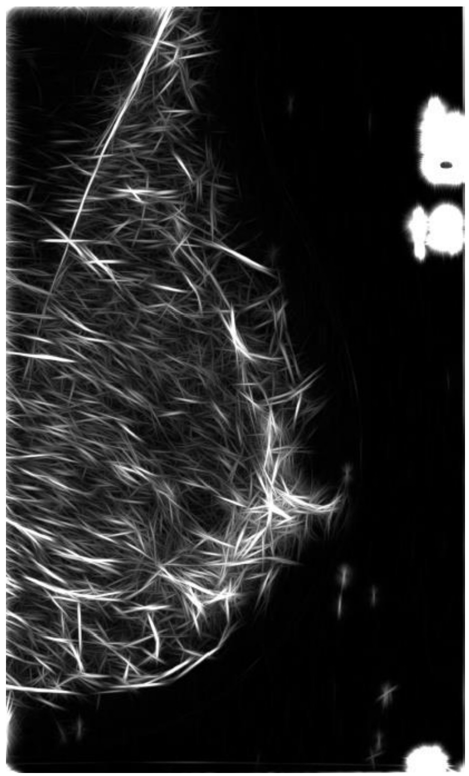


m55lo97 | m58rc97 | m61lo97 | m55lc97

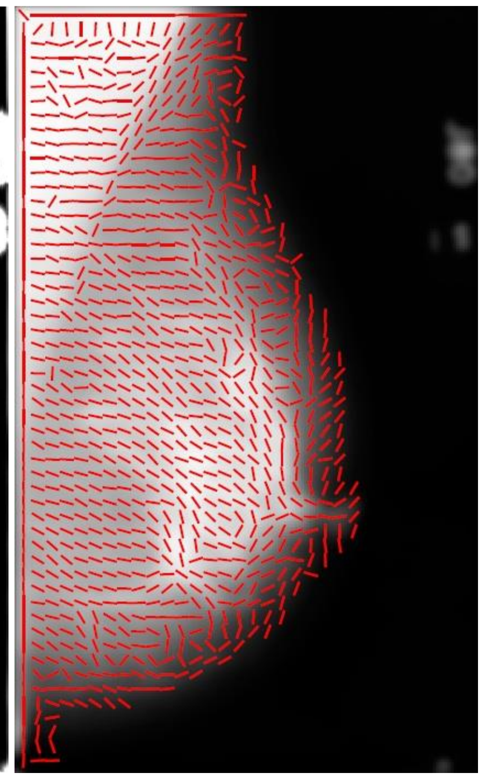
Subtle Sign of Breast Cancer: Architectural Distortion



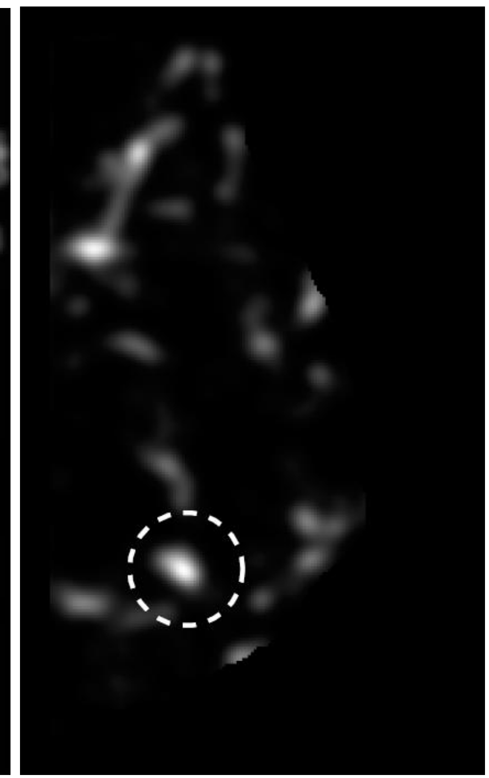
Mammogram



Gabor Magnitude

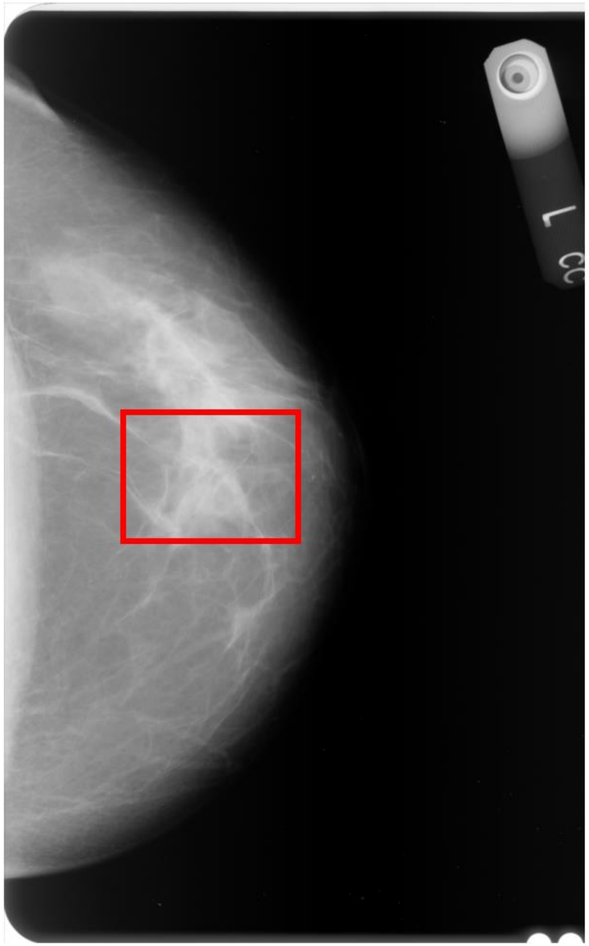


Angle Response

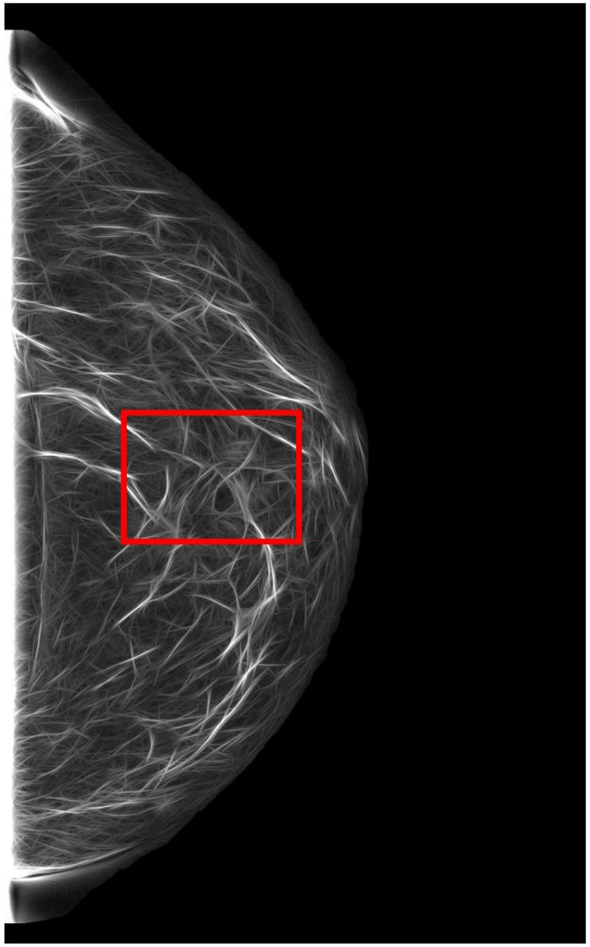


Node Map

Prior Mammogram of Interval Cancer

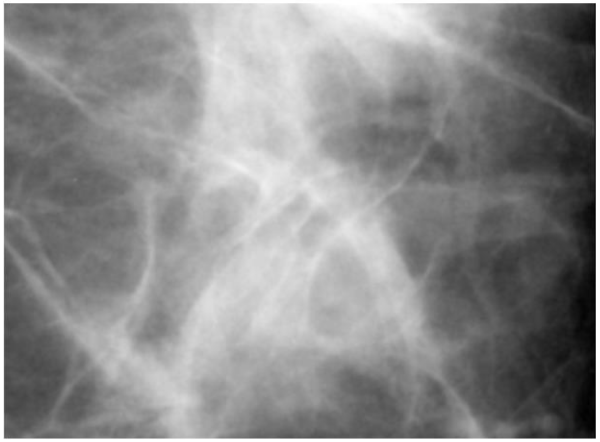


Mammogram

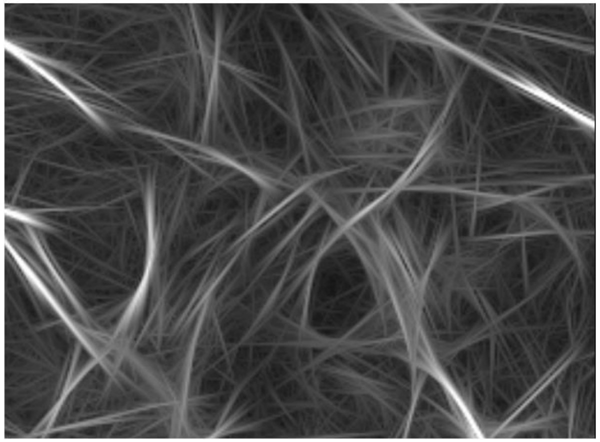


Gabor Magnitude

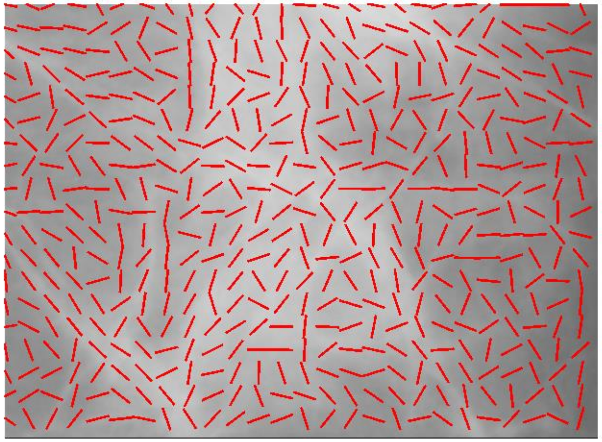
Site of Architectural Distortion



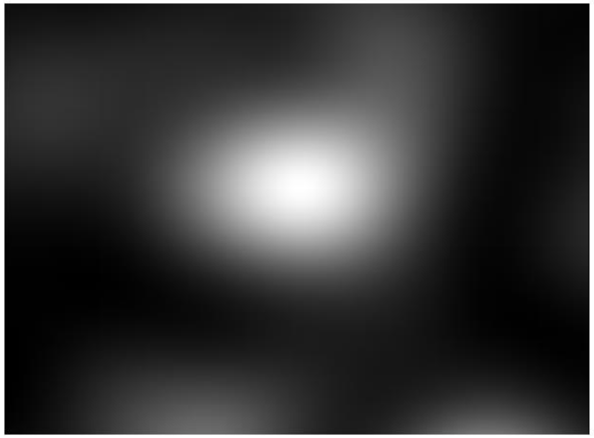
Mammogram



Gabor magnitude

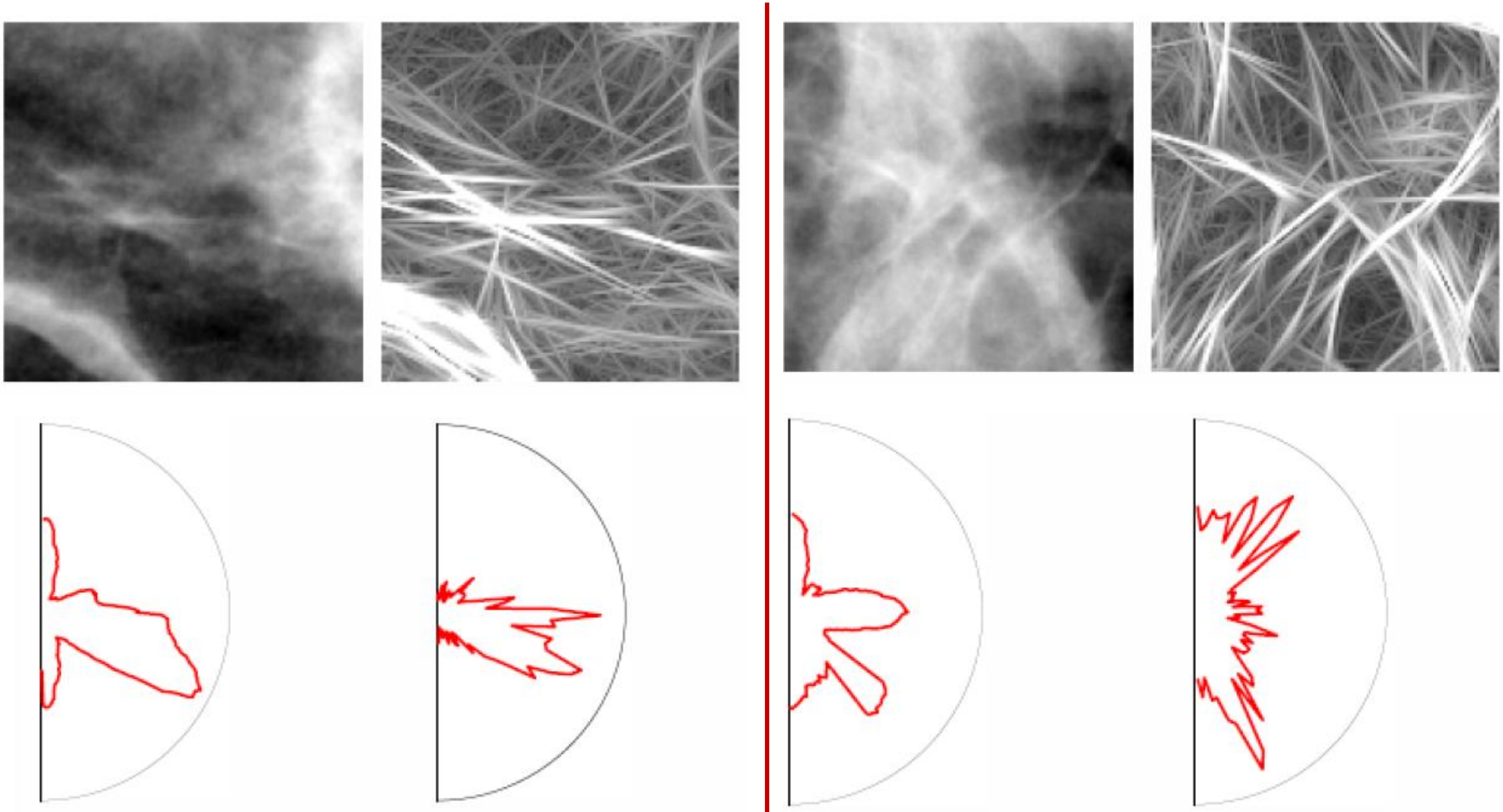


Orientation field



Node map

Analysis of Angular Spread: Normal vs Architectural Distortion



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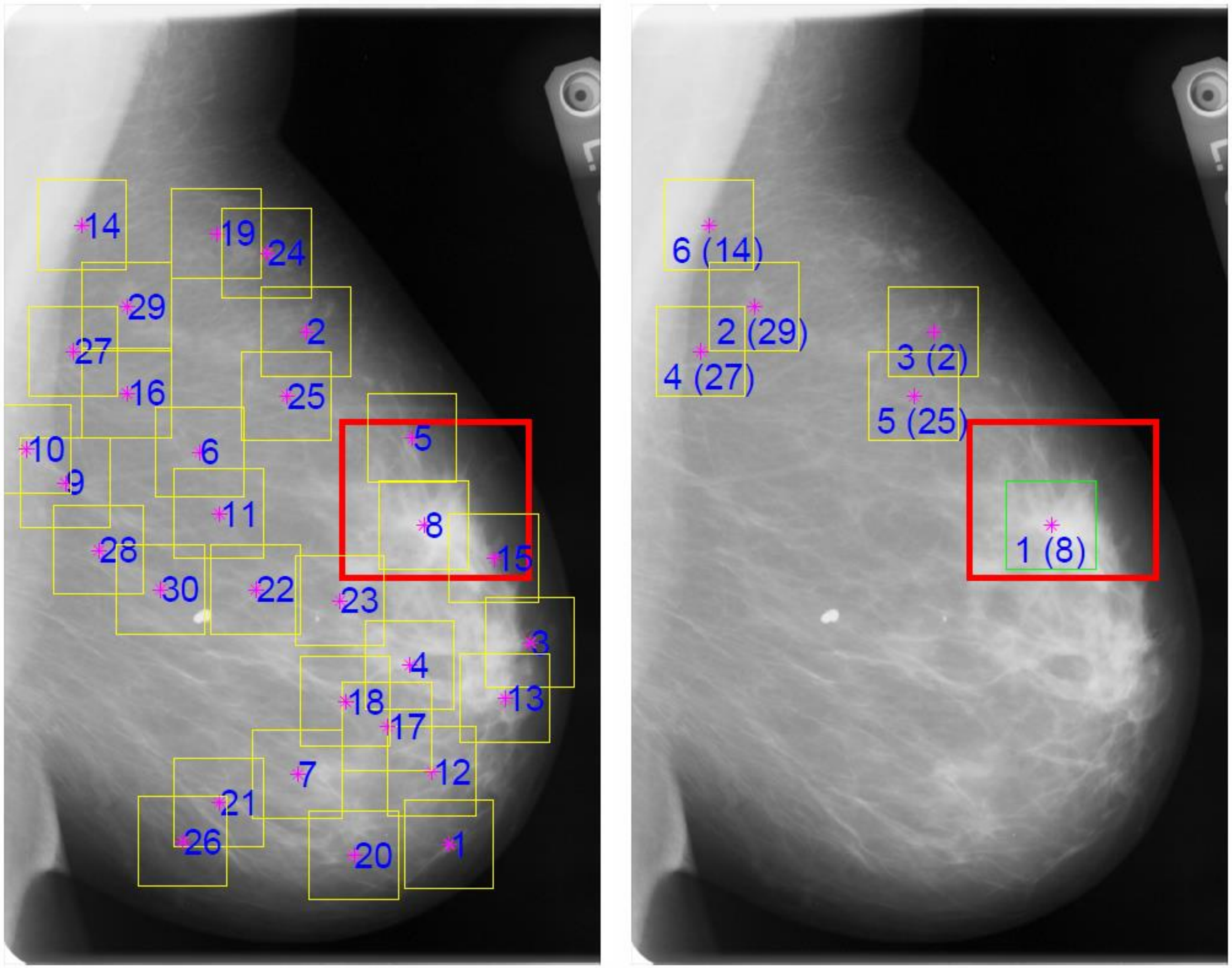
Reduction of False Alarms

via Design of Attributes and Pattern Classification Algorithms



CAD of Breast Cancer

"Our methods can detect early signs of breast cancer 15 months ahead of the time of clinical diagnosis with a sensitivity of 80% with fewer than 4 false positives per patient"


Let’s
CAD!?

Objectives of Computer-aided Analysis of Medical Images

- Enhancement of image quality
- Detection of subtle signs of disease
- Quantitative analysis of diagnostic features
- Objective aids to diagnostic decision
- Accurate, consistent, reproducible analysis
- *Earlier detection of breast cancer!*
- *Reduced morbidity and mortality!*

Why CAD?

Manual analysis of medical images, even by experts, is susceptible to

- Intraobserver errors or inconsistencies
- Interobserver errors or inconsistencies
- Limitations of manual analysis

Intraobserver errors

- Inconsistent application of knowledge
- Subjective and qualitative nature of analysis
- Environmental effects and distraction
- Fatigue due to workload and repetitive tasks

Interobserver errors

- Inconsistencies in knowledge and training
- Subjective and qualitative nature of analysis
- Differences in opinion and preferences

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Limitations of Manual Analysis

- Inconsistencies in identifying landmarks in images
- Errors in landmark locations due to limited dexterity
- Extensive time and effort required for manual marking and measurement of intricate details
- Limitations in the precision and reproducibility of manual measurement and calculations
- Subjective and qualitative nature of analysis

Benefits of CAD

- Consistent application of established rules and methods
- Objective and quantitative analysis
- Numerical precision, accuracy, and speed of computation
- Ease of repeatability and reproducibility
- Immunity to effects of work environment, fatigue, and boredom

The CAD Way to Improve Medical Diagnosis

Move from	Via	To
Qualitative analysis	Computation of measures, features, and attributes using digital image processing techniques	Quantitative analysis
Subjective analysis	Development of rules for diagnostic decision making using pattern classification techniques	Objective analysis
Inconsistent analysis	Implementation of established rules and robust procedures as computational algorithms	Consistent analysis
Interobserver and intraobserver errors	Medical image analysis, medical image informatics, and CAD	Improved diagnostic accuracy

Main Steps of CAD

1. Preprocessing of a given image for further analysis
2. Detection and segmentation of regions of interest
3. Extraction of features for quantitative analysis
4. Selection of the best set of features or related measures
5. Training of classifiers and development of decision rules
6. Pattern classification and diagnostic decision making

Measures of Performance: Comparison with Truth

	Disease is present	Disease is absent	Measures of performance
Test is positive	TP: True positive	FP: False positive	Positive predictive value PPV = TP / (TP + FP)
Test is negative	FN: False negative	TN: True negative	Negative predictive value NPV = TN / (TN + FN)
Measures of performance	Sensitivity TP / (TP + FN)	Specificity TN / (TN + FP)	Prevalence of disease (TP + FN) / All
Numbers of subjects	TP + FN With disease	TN + FP Without disease	All = TP + FN + TN + FP All subjects

Measures of Performance: Comparison with Truth

Truth Table

Test Result / Truth	Positive	Negative
Positive	True positive	False Negative
Negative	False Positive	True Negative

Measures of Performance: Comparison with Truth

Truth Table for Classification of Vibroarthrographic Signals as Normal or Chondromalacia Using Time-frequency Distributions

Actual Group	No. of Signals	Predicted Group	
		N	Ch
N	51	40 78.4%	11 21.6%
Ch	20	5 25%	15 75%
Total	71	Overall Accuracy 77.5%	

Measures of Performance: Comparison with Truth

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Confusion Matrix

in Classification of Vertebral Compression Fractures

Predicted classification			True classification
Malignant VCFs	Benign VCFs	Normal vertebral bodies	
39	5	5	Malignant VCFs
13	35	5	Benign VCFs
4	1	84	Normal vertebral bodies

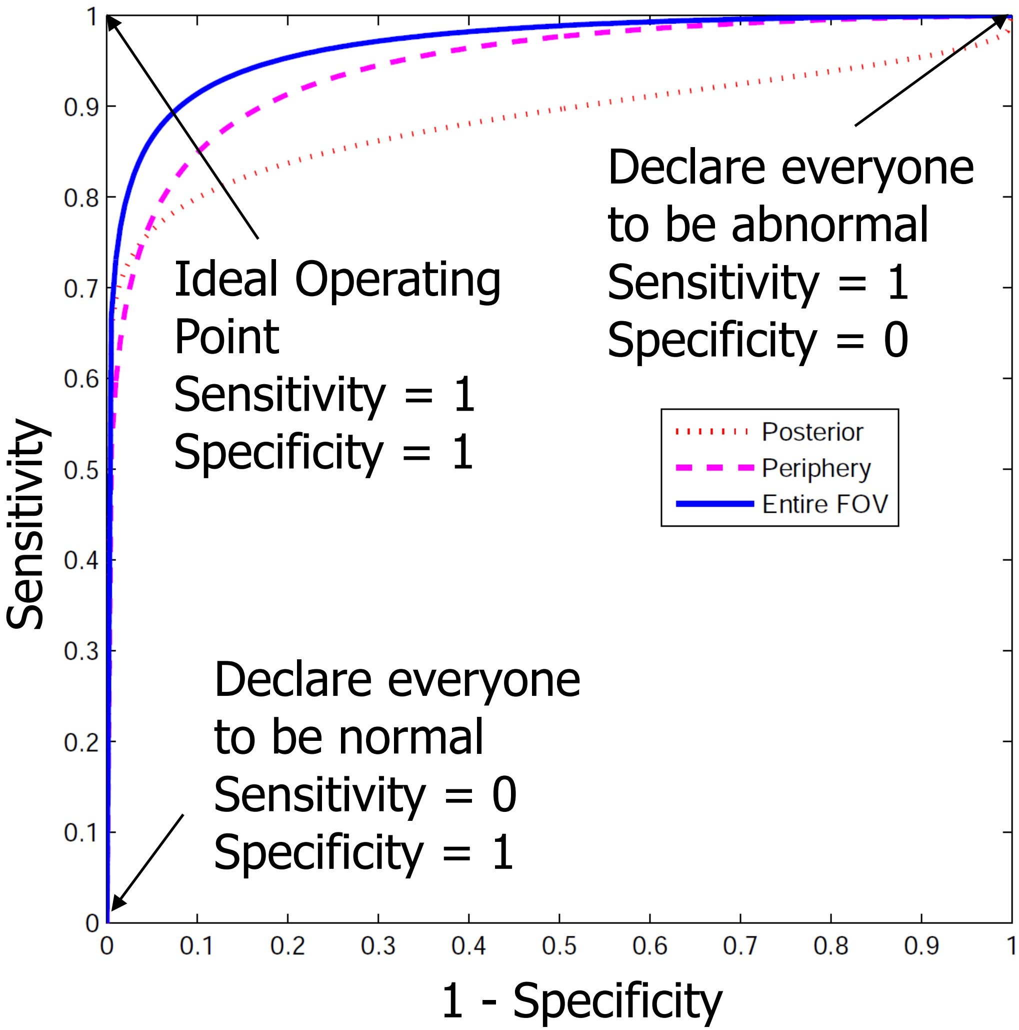
Measures of Performance:
Receiver Operating Characteristics (ROC)

Areas under the ROC curve A_z for the diagnosis of plus disease using the total length of tortuous vessels in various regions of fundus images

posterior $A_z = 0.90$

periphery $A_z = 0.95$

full image $A_z = 0.98$

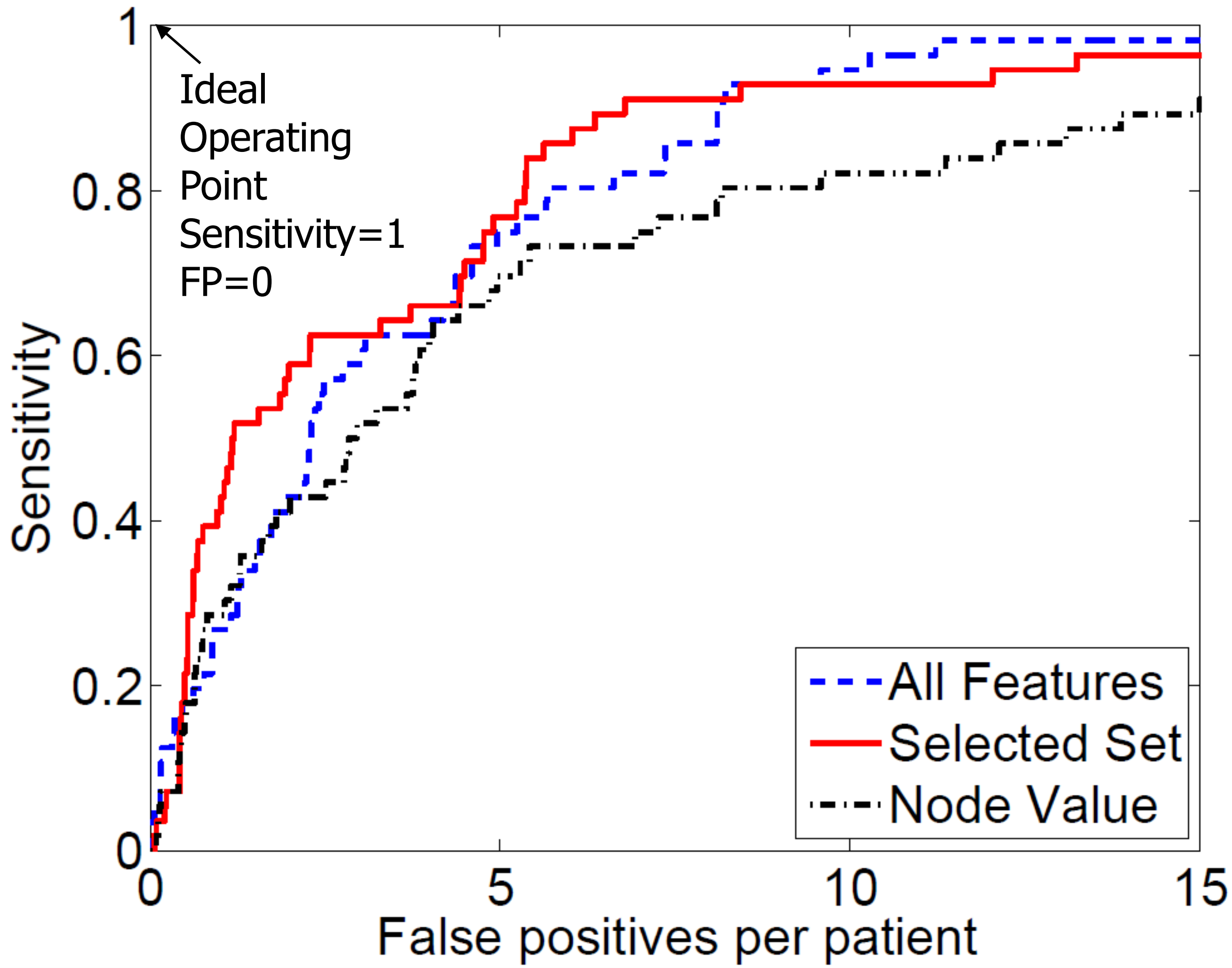


Measures of Performance:
Free-response ROC (FROC)

Detection of architectural distortion in prior mammograms:

Sensitivity = 80% at 5.3 FP/patient

90% at 6.3 FP/patient



Limitations of CAD

- Difficulty in translating methods of visual analysis into computational procedures
- Difficulty in translating clinical observations into numerical features
- Difficulty in dealing with large numbers of features in a classification rule: curse of dimensionality
- Substantial requirements of computational resources and annotated clinical databases
- Large numbers of false alarms or false positives: increased recall rate
- Difficulty in integrating CAD systems into established clinical workflows and protocols

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Popular Themes and Techniques

***BIG** data*

Information Technology

Convolutional Neural Networks

Machine Learning

Medical Informatics

Radiomics

Deep *Learning*

Information & Communication Technology

~~Artificial~~ Computational Intelligence

Committee Machine

...?

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Essentials of Engineering

- Scientific investigation and analysis: Quantitative and objective analysis
- Mathematical modeling
- Design of components, systems, and processes
- Synthesis
- Project management
- Solutions to practical problems
- Innovation and creativity

The Multidisciplinary Field of Biomedical Engineering

- From building bridges to implanting artificial ligaments
- From electrical power plants to cardiac pacemakers
- From railway engines to prosthetic limbs
- From chemical and petroleum plants to artificial tissues and organs
- From computers to lab on a chip and control systems to manage diabetes and other diseases
- From communication and control systems to CAD

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Broad Background Required for Biomedical Engineering

- Physics and Chemistry
- Mathematics and Statistics
- Biology, Anatomy, Physiology, and Pathology
- Biochemistry
- Material Science
- Sensors and Instrumentation
- Principles of Engineering
- Knowledge of Medical Diagnosis and Therapy
- Information Processing and Analysis

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Subject Areas Contributing to Computer-aided Diagnosis

- Biomedical Engineering and Medical Physics
- Diagnostic Medical Imaging and Radiology
- Digital Signal and Image Processing
- Biomedical Signal and Image Analysis
- Statistical Analysis and Pattern Recognition
- Computer Vision
- Computer and Software Engineering
- Information and Communication Technology
- Control Systems and Diagnostic Decision Making

… but is CAD Artificial Intelligence?

CAD incorporates, encodes, and encapsulates the knowledge, intelligence, and expertise of several professionals from multiple disciplines:

- Radiology and Diagnostic Medical Imaging
- Engineering and Computer Science
- Physics and Mathematics …

This is a *natural human collaborative endeavor*

and the label "artificial" is demeaning!

We should recognize, admire, and respect the contributing professionals and their subject areas!

Beyond CAD …

- Computer-aided therapy and surgery
- Computer analysis of response to therapy
- Computer-aided prognosis
- Computer-aided risk assessment
- Computer-aided patient management
- Computer-aided clinical management
- Computer-aided treatment protocol
- Computer-aided personalized medicine

Integrating the Healthcare Enterprise: IHE and Clinical Workflow

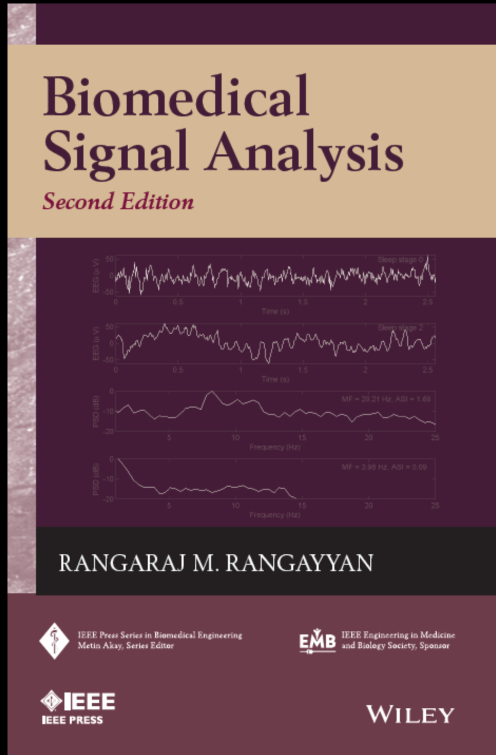
- CAD: Computer-Aided Diagnosis
- CAS: Computer-Aided Surgery
- CBIR: Content-Based Image Retrieval
- HIS: Hospital Information System
- RIS: Radiology Information System
- PACS: Picture Archival and Communication System
- DICOM: Digital Imaging and Communications in Medicine
- DBMS: Data Base Management System
- EHR: Electronic Health Record
- HL7: Health Level-7
- ISO: International Standards Organization
- OSI: Open Systems Interconnection

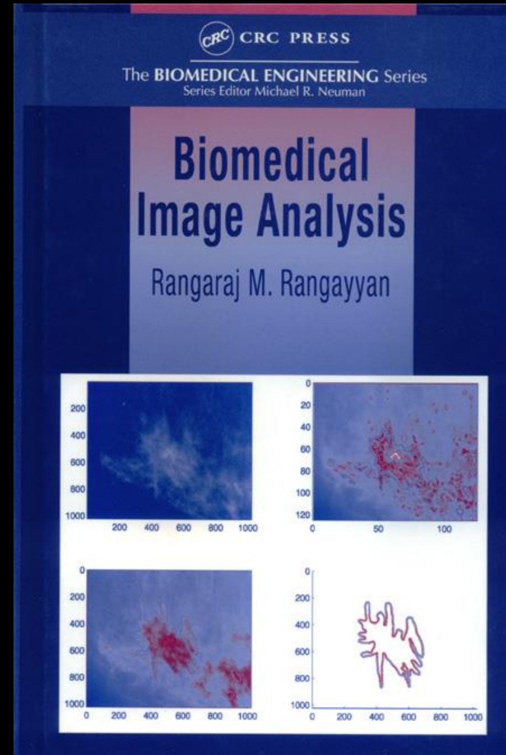
Opportunities

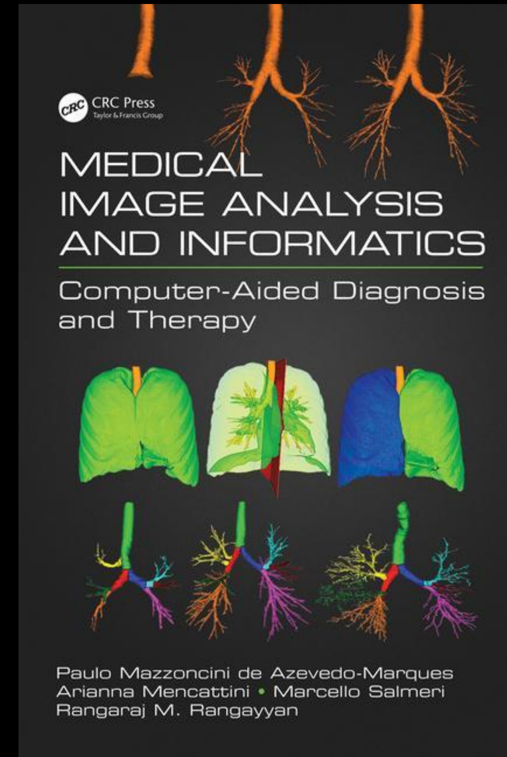
- Learn new areas of application of engineering
- Collaborate with professionals in other fields of research and investigation
- Contribute to another field with significant applications and benefit to the public
- Develop multidisciplinary perspectives and problem-solving skills
- *Contribute to the well-being of people!*

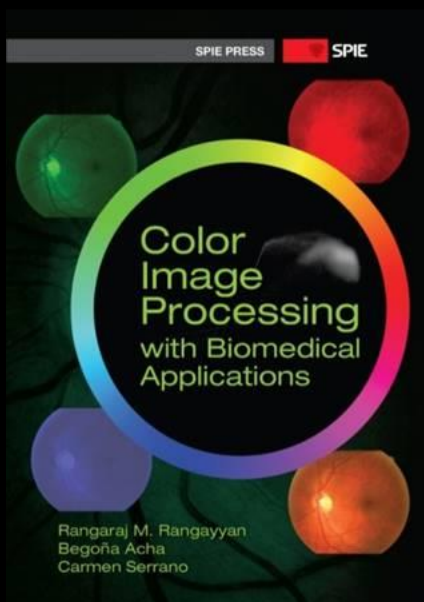

Do you believe in CAD?
Paola Casti

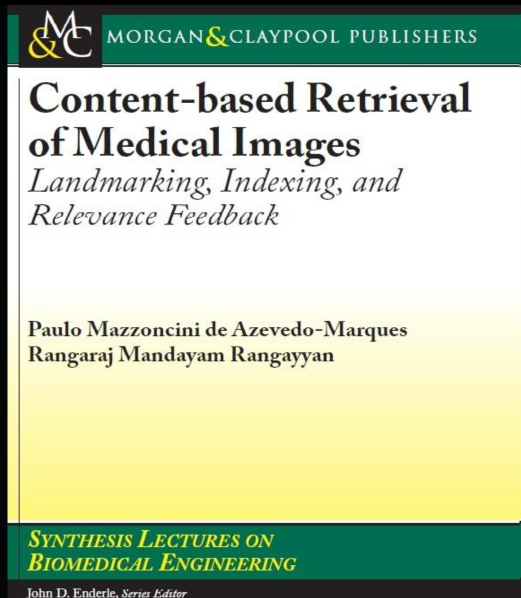
If in doubt try ...

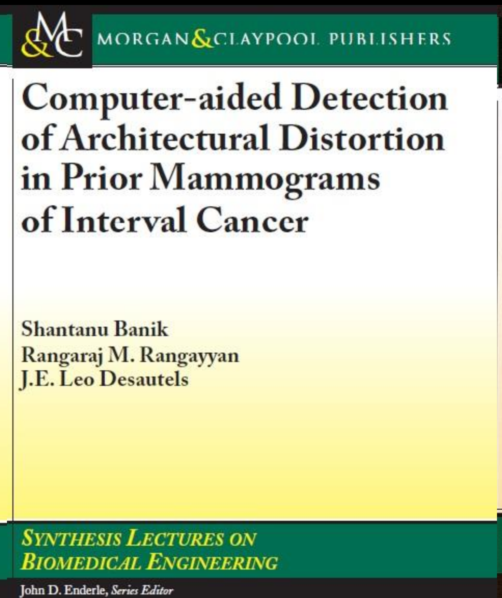


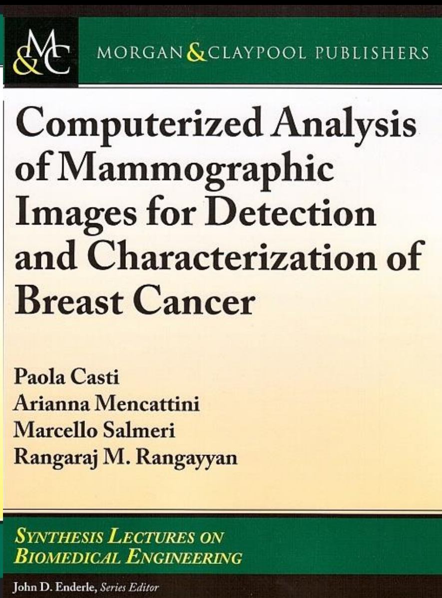












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Thank You!

- Natural Sciences and Engineering Research Council of Canada
- Alberta Heritage Foundation for Medical Research
- Canadian Breast Cancer Foundation
- Screen Test: Alberta Program for the Early Detection of Breast Cancer
- Kids Cancer Care Foundation, Calgary
- My students and collaborators

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