

Multimodality Breast Imaging

Diagnosis and Treatment

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Contents

<i>Preface</i>	xvii
<i>List of Contributors</i>	xxi
<i>Acronyms and Abbreviations</i>	xxv

1	Detection of Architectural Distortion in Prior Mammograms Using Statistical Measures of Angular Spread	1
	<i>Rangaraj M. Rangayyan, Shantanu Banik, and J. E. Leo Desautels</i>	
1.1	Introduction	2
1.2	Experimental Setup and Database	3
1.3	Methods	5
1.3.1	Detection of potential sites of architectural distortion	6
1.3.2	Analysis of angular spread	10
1.3.2.1	Angular spread of power in the frequency domain	10
1.3.2.2	Coherence	13
1.3.2.3	Orientation strength	14
1.3.3	Characterization of angular spread	15
1.3.4	Measures of angular spread	16
1.3.4.1	Shannon's entropy	17
1.3.4.2	Tsallis entropy	18
1.3.4.3	Rényi entropy	20
1.3.5	Feature selection and pattern classification	21
1.4	Results	23
1.4.1	Analysis with various sets of features	23
1.4.2	Statistical significance of differences in ROC analysis	24
1.4.3	Reduction of FPs	25
1.4.4	Statistical significance of the differences in FROC analysis	26
1.4.5	Effects of the initial number of ROIs selected	27
1.5	Discussion	27
1.5.1	Comparative analysis with related previous works	28
1.5.2	Comparative analysis with other works	29
1.5.3	Limitations	30

1.6	Conclusion	31
	Acknowledgments	31
	References	31
2	Texture-based Automated Detection of Breast Cancer Using Digitized Mammograms: A Comparative Study	41
	<i>U. Rajendra Acharya, E. Y. K. Ng, Jen-Hong Tan, S. Vinitha Sree, and Jasjit S. Suri</i>	
2.1	Introduction	42
2.2	Data Acquisition and Preprocessing	44
2.3	Feature Extraction	45
2.3.1	Gray-level co-occurrence matrix	45
2.3.2	Run length matrix	48
2.4	Classifiers	48
2.4.1	Support vector machine	48
2.4.2	Gaussian mixture model	49
2.4.3	Fuzzy Sugeno classifier	49
2.4.4	<i>k</i> -nearest neighbor	49
2.4.5	Probabilistic neural network	50
2.4.6	Decision tree	50
2.5	Results	50
2.5.1	Performance measures	50
2.5.2	Receiver operating characteristics	51
2.5.3	Classification results	51
2.5.4	Graphical user interface	54
2.6	Discussion	54
2.7	Conclusion	57
	Acknowledgments	58
	References	58
3	Case-based Clinical Decision Support for Breast Magnetic Resonance Imaging	65
	<i>Ye Xu and Hiroyuki Abe</i>	
3.1	Introduction	65
3.2	Methodologies	68
3.2.1	Data preparation	68
3.2.2	Block diagram of our case-based approach	69
3.2.3	Features to calculate on breast MRI images	72
3.2.4	Collections for ground truth of similarity from data	75
3.2.5	Evaluation	75
3.3	Results and Discussion	76
3.4	Conclusions	80
	References	80

4	Registration, Lesion Detection, and Discrimination for Breast Dynamic Contrast-Enhanced Magnetic Resonance Imaging	85
	<i>Valentina Giannini, Anna Vignati, Massimo De Luca, Silvano Agliozzo, Alberto Bert, Lia Morra, Diego Persano, Filippo Molinari, and Daniele Regge</i>	
4.1	Introduction	86
4.2	Registration	87
4.2.1	Method	87
4.2.2	Results	88
4.3	Lesion Detection	88
4.3.1	Method	90
4.3.1.1	Breast segmentation	90
4.3.1.2	Lesion detection	91
4.3.1.3	False-positive reduction	94
4.3.2	Results	95
4.3.2.1	Subjects and MRI protocols	95
4.3.2.2	Statistical analysis	96
4.3.2.3	Results	97
4.4	Lesion Discrimination	97
4.4.1	Method	100
4.4.2	Results	102
4.5	Discussion and Conclusions	103
	References	105
5	Advanced Modality Imaging of the Systemic Spread of Breast Cancer	113
	<i>Cher Heng Tan</i>	
5.1	Staging Evaluation of Breast Cancer	113
5.2	Nodal Disease	115
5.2.1	Axillary nodes	116
5.2.2	Other draining nodes	119
5.3	Distant Metastases	120
5.3.1	Pulmonary metastases	121
5.3.2	Bone metastases	122
5.3.3	Liver metastases	124
5.3.4	Brain metastases	127
5.4	Treatment Response Evaluation: Response Evaluation Criteria in Solid Tumors (RECIST)	128
5.5	Surveillance: To Do or Not To Do?	130
5.6	Locoregional Recurrence	132
5.7	Summary	132
	References	133

6	Nuclear Imaging with PET CT and PET Mammography	143
	<i>Andrew Eik Hock Tan and Wanying Xie</i>	
6.1	Introduction	143
6.2	Breast Cancer Molecular Pathology and PET	144
6.3	Diagnosis of Primary Breast Cancers	147
6.4	Staging of Breast Cancers	150
6.4.1	Axillary nodal evaluation	150
6.4.2	Mediastinal and internal mammary nodal evaluation	151
6.4.3	Distant metastasis and overall staging impact of FDG PET	152
6.5	Response Assessment	154
6.6	Conclusion	156
	References	156
7	3D Whole-Breast Ultrasonography	165
	<i>Ruey-Feng Chang and Yi-Wei Shen</i>	
7.1	Introduction	165
7.2	3D Whole-Breast Ultrasonography Machines	166
7.3	Related Studies of 3D Whole-Breast Ultrasonography	170
7.4	Conclusion	172
	References	172
8	Diagnosis of Breast Cancer Using Ultrasound	175
	<i>Chui-Mei Tiu, Yi-Hong Chou, Chung-Ming Chen, and Jie-Zhi Cheng</i>	
8.1	Introduction	176
8.2	Instrument Requirements	177
8.2.1	Equipment and transducer	177
8.2.2	Image quality and equipment quality control	178
8.3	Examination Technique	178
8.3.1	Patient positioning	178
8.3.2	Scanning technique	179
8.3.3	Doppler imaging and contrast-enhanced US	179
8.3.4	Elastography	180
8.3.5	Image labeling	181
8.4	Grayscale Ultrasonic Criteria of Breast Disease	181
8.4.1	General criteria of interpretation	181
8.4.2	Diagnosing cysts	181
8.4.3	Differentiating solid lesions	181
8.4.4	Diagnosing carcinoma	182
8.4.5	Secondary signs of malignancy	183
8.4.6	Evaluation of breast calcifications	183
8.5	Considerations in Interpreting US Examination Results	184

8.6	Ultrasonography of Malignant Tumors	185
8.6.1	Invasive ductal carcinoma	185
8.6.1.1	Sonographic findings	186
8.6.2	Mucinous carcinoma	198
8.6.3	Medullary carcinoma	200
8.6.4	Invasive lobular carcinoma	203
8.6.4.1	Ultrasound features	203
8.6.5	Ductal carcinoma <i>in situ</i>	203
8.6.5.1	Sonographic findings	205
8.6.6	Lobular carcinoma <i>in situ</i>	207
8.6.7	Inflammatory carcinoma	208
8.6.8	Lymphoma and metastases of the breast	210
8.6.8.1	Sonographic features	211
8.7	Fibrocystic Changes and Breast Cysts	213
8.7.1	Fibrocystic changes and benign proliferative disorders	213
8.7.1.1	Benign proliferative disorders in fibrocystic changes	215
8.7.1.2	Sonographic findings	216
8.7.2	Fibroadenomas	216
8.7.2.1	Sonographic findings	217
8.7.3	Fibroadenoma variants	219
8.7.3.1	Complex fibroadenomas	219
8.7.3.2	Sonographic findings	219
8.7.4	Tubular adenomas and lactating adenomas	220
8.7.4.1	Sonographic findings	220
8.7.5	Papilloma	221
8.7.5.1	Sonographic findings	223
8.7.6	Intramammary lymph nodes	225
8.7.6.1	Sonographic findings	225
8.7.7	Hamartomas	225
8.7.7.1	Sonographic findings	226
8.7.8	Lipomas	226
8.7.8.1	Sonographic findings	227
8.7.9	Pseudo-angiomatous stromal hyperplasia	228
8.7.9.1	Sonographic findings	228
8.7.10	Hemangiomas	229
8.7.10.1	Sonographic findings	229
8.7.11	Phyllodes tumors	230
8.7.11.1	Sonographic findings	230
8.7.12	Focal fibrosis	232
8.7.12.1	Sonographic findings	232

8.7.13	Diabetic mastopathy	233
8.7.13.1	Sonographic findings	233
8.7.14	Infections and abscesses of the breast	234
8.7.14.1	Sonographic findings	235
8.8	Clinical Usefulness of US-Guided Aspiration and Biopsy	236
8.8.1	Ultrasound-guided breast aspiration	237
8.8.2	Ultrasound-guided breast biopsy	238
8.8.3	Vacuum-assisted biopsy	240
8.9	Conclusion	240
	References	242
9	Abnormal Lesion Detection from Breast Thermal Images Using Chaos with Lyapunov Exponents	255
	<i>Mahnaz Etahadtavakol, E. Y. K. Ng, Caro Lucas, and Mohammad Ataei</i>	
9.1	Introduction	256
9.2	Time Series	256
9.3	Time-Delay Embedding	257
9.4	Lyapunov Exponents	257
9.5	Computation of the Lyapunov Exponents	259
9.5.1	Polynomial model	260
9.6	Generating the Time Series	261
9.7	Experimental Results and Discussion	262
9.7.1	Fractal images	262
9.7.2	Real-world IR images	268
9.8	Conclusion	270
	References	271
10	Intelligent Rule-based Classification of Image Features for Breast Thermogram Analysis	275
	<i>Gerald Schaefer</i>	
10.1	Introduction	275
10.2	Image Features	276
10.3	Fuzzy Rule-based Classification	277
10.3.1	Classification algorithm	277
10.3.2	Experimental results	279
10.4	Ant Colony Optimization Classification	280
10.4.1	Classification algorithm	280
10.4.2	Experimental results	281
10.5	Conclusions	282
	Acknowledgments	282
	References	282

11 Infrared Imaging for Breast Cancer Detection with Proper Selection of Properties: From Acquisition Protocol to Numerical Simulation	285
<i>Luciete A. Bezerra, Marília M. Oliveira, Marcus C. Araújo, Mariana J. A. Viana, Ladjane C. Santos, Francisco G. S. Santos, Tiago L. Rolim, Paulo R. M. Lyra, Rita C. F. Lima, Tiago B. Borschardt, Roger Resmini, and Aura Conci</i>	
11.1 Introduction	286
11.2 Computer-Aided Diagnosis	287
11.2.1 Standardization in acquiring IR breast images	288
11.2.1.1 The mechanical apparatus	288
11.2.1.2 Protocol	289
11.2.2 Data storage	291
11.2.2.1 Database system	291
11.2.2.2 Patient's electronic record for research application	292
11.2.2.3 Research workflow (clinical workflow)	293
11.2.2.4 Description of the database system	293
11.2.3 Breast segmentation	294
11.2.3.1 Representation of the IR image	294
11.2.3.2 Manual segmentation based on a temperature matrix	295
11.2.4 Extracting features	296
11.2.5 Classification results	301
11.3 Several Approaches for Improving the Numerical Simulation of Temperature Profiles	303
11.3.1 Surrogate geometry of the breast	304
11.3.1.1 Acquiring surrogate geometries	304
11.3.1.2 Choice of the surrogate geometry that best fits the real breast being studied	305
11.3.2 A parametric analysis to investigate IR sensitivity	307
11.3.2.1 The mathematical model	307
11.3.2.2 A parametric study using a phantom 3D geometry	308
11.3.2.3 Calculating the temperature profile: An example of the use of breast prosthesis and parametric analysis	310
11.3.3 Estimation of some breast and tumor properties	312
11.3.3.1 The inverse method	313
11.3.3.2 Experimental validation of the methodology	315
11.3.3.3 Cases analyzed	317

11.4	Conclusions	321
	References	322
12	Diffuse Optical Imaging of the Breast: Recent Progress	333
	<i>Jun Hui Ho, Jing Dong, and Kijoon Lee</i>	
12.1	Introduction	333
12.2	Theory	335
12.2.1	Photon propagation model	335
12.2.2	Diffuse optical spectroscopy	335
12.2.3	Diffuse correlation spectroscopy	337
12.2.4	Diffuse optical tomography	339
12.3	Instrumentation	340
12.3.1	Diffuse optical spectroscopy	340
12.3.2	Diffuse correlation spectroscopy	341
12.3.3	Diffuse optical tomography	342
12.4	Clinical Applications	343
12.4.1	Breast cancer detection/characterization	343
12.4.1.1	Endogenous contrast	343
12.4.1.2	Exogenous contrast	347
12.4.2	Therapy monitoring	347
12.5	Future of DOI of the Breast	349
12.5.1	Structural illumination	349
12.5.2	Spectral derivative	351
12.5.3	New parameters	351
12.6	Conclusion	351
	References	353
13	Computer Vision Theoretic Approach for Breast Cancer Diagnosis: Commonly Perceived Diagnostic Significance of Cytological Features and Feature Usability Analysis of an Existing Breast Cancer Database	361
	<i>Hrushikesh Garud, Debdoot Sheet, Jyotirmoy Chatterjee, Manjunatha Mahadevappa, Ajoy Kumar Ray, and Arindam Ghosh</i>	
13.1	Introduction	362
13.2	Commonly Perceived Significance of Cytological Features in Breast FNAC	364
13.2.1	Overview of the survey	365
13.2.2	Opinion of the experts	366
13.3	Analysis of the Wisconsin Diagnostic Breast Cancer (WDBC) Database	370
13.3.1	Ranking of features using feature usability index	373
13.3.1.1	Homogeneity	373
13.3.1.2	Class specificity	373
13.3.1.3	Error in decision making	374

13.3.2	Feature selection	376
13.4	Conclusions	377
	References	379
14	Radiofrequency Ablation of Breast Neoplasms	383
	<i>José Luis del Cura</i>	
14.1	Introduction	383
14.2	Radiofrequency	384
14.2.1	Concept	384
14.2.2	Technical issues	384
14.3	Radiofrequency Ablation in the Breast	385
14.4	Technique of Ablation	386
14.5	Outcomes	389
14.6	Complications	393
14.7	Conclusions and Future Trends	394
	References	395
15	Minimally Invasive Thermal Ablation for Breast Cancer	399
	<i>Feng Wu</i>	
15.1	Introduction	400
15.2	Methods of Thermal Ablation Technique	401
15.2.1	Radiofrequency ablation (RFA)	401
15.2.2	Laser ablation (LA)	401
15.2.3	Microwave ablation (MWA)	403
15.2.4	Cryoablation	403
15.2.5	High-intensity focused ultrasound (HIFU) ablation	403
15.3	Scientific Principles of Thermal Ablation	404
15.4	Mechanisms of Thermal Ablation	404
15.4.1	Direct thermal and nonthermal effects on tumors	405
15.4.2	Thermal effects on tumor vasculature	405
15.4.3	Indirect effects on tumor	406
15.5	Clinical Studies on Thermal Ablation of Breast Cancer	407
15.5.1	Radiofrequency ablation	407
15.5.2	Laser ablation	410
15.5.3	Microwave ablation	412
15.5.4	Cryoablation	413
15.5.5	High-intensity focused ultrasound ablation	415
15.6	Antitumor Immune Response after Thermal Ablation	417
15.6.1	Antitumor immune response after RFA	418
15.6.2	Antitumor immune response after LA	421
15.6.3	Antitumor immune response after cryoablation	421
15.6.4	Antitumor immune response after MWA	424

15.6.5	Antitumor immune response after HIFU ablation	425
15.7	Summary	427
	References	429
16	Correlated Microwave Acoustic Imaging for Breast Cancer Detection	453
	<i>Yuanjin Zheng, Fei Gao, and Zhiping Lin</i>	
16.1	Introduction	453
16.2	Emerging Microwave-based Imaging Modality	454
16.2.1	Dielectric property of biological tissue	455
16.2.2	Microwave imaging	456
16.2.3	Microwave-induced thermo-acoustic imaging	457
16.3	Correlated Microwave Acoustic Imaging:	
	Numerical Example	459
16.3.1	Image reconstruction algorithm	460
16.3.2	Numerical simulation results	461
16.4	Preliminary Prototyping	464
16.4.1	Collecting microwaves and acoustic waves simultaneously	464
16.4.2	UWB transmitter design	466
16.5	Conclusion	470
	References	470
17	Diagnostic Sensing of Specific Proteins in Breast Cancer Cells Using Hollow-Core Photonic Crystal Fiber	475
	<i>Vadake Matham Murukeshan, Vengalathunadakal Kuttinarayanan Shinoj, Saraswathi Padmanabhan, and Parasuraman Padmanabhan</i>	
17.1	Introduction	475
17.2	Photonic Crystal Fibers	477
17.2.1	Refractive-index scaling law	478
17.2.2	Selection of fibers	480
17.3	Sensing Mechanism Based on Evanescent Waves	482
17.3.1	Conventional-fiber-based evanescent wave sensing	482
17.3.2	Evanescent wave sensing using HC-PCF	482
17.4	Materials and Methods	483
17.4.1	Cell culture and sample preparation	483
17.5	Results and Discussion	484
17.5.1	HC-PCF-based fluorescence detection	484
17.5.1.1	Spectroscopic analysis	486
17.5.1.2	Image processing method	488
17.6	Conclusion	489
	Acknowledgments	490
	References	490

18 Quality Assurance in Digital Mammography	497
<i>Kwan-Hoong Ng, Tânia Aparecida Correia Furquim, and Noriah Jamal</i>	
18.1 Introduction	498
18.1.1 Scope	498
18.2 Technical Quality Control	499
18.3 Testing by Medical Physicists and Equipment Performance	501
18.3.1 Mammography unit assembly evaluation	502
18.3.2 Compression force and thickness accuracy	502
18.3.2.1 Compression force	502
18.3.2.2 Thickness accuracy	503
18.3.3 Site technique factors for SDNR (radiographer baseline)	503
18.3.4 Automatic exposure control evaluation	504
18.3.4.1 Thickness behavior	504
18.3.4.2 Density control	505
18.3.5 Baseline for detector performance	506
18.3.6 Spatial linearity and geometric distortion of the detector	509
18.3.7 Detector ghosting	510
18.3.8 Detector uniformity and artifact evaluation	511
18.3.9 Modulation transfer function	512
18.3.9.1 High-contrast edge	512
18.3.9.2 High-contrast resolution pattern	513
18.3.10 Limiting spatial resolution	514
18.3.11 Half-value layer	515
18.3.12 Incident air kerma at the entrance surface of PMMA slabs	516
18.3.13 Mean glandular dose	516
18.3.13.1 IAEA method	517
18.3.13.2 ACR method	517
18.3.14 Collimation system	518
18.3.15 Image display quality	519
18.3.15.1 Geometric distortions	520
18.3.15.2 Luminance uniformity	520
18.3.15.3 Luminance response and contrast	520
18.3.15.4 Ambient lighting	520
18.3.16 Laser printer (where applicable)	520
18.3.17 Phantom image quality	522
18.4 Technologist Testing	522
18.4.1 Inspection, cleaning, and viewing conditions of monitors and view boxes	523

18.4.2	Laser printer	523
18.4.2.1	Sensitometry	523
18.4.2.2	Artifacts	523
18.4.2.3	Printed image quality	524
18.4.3	Phantom image quality	524
18.4.4	Digital mammography equipment daily checklist	524
18.4.5	Daily and monthly flat-field phantom image test	524
18.4.6	Visual inspection for artifacts (CR systems only)	525
18.4.7	Image plate erasure (CR systems only)	525
18.4.8	Monitor QC	526
18.4.9	Weekly QC test object and full-field artifacts	526
18.4.10	Safety and function checks of examination room and equipment	526
18.4.11	Repeat image analysis	527
18.4.12	Spatial resolution test (CR and scanning systems only)	527
Appendix 18.1	ACR Summary of Medical Physicist's and Technologist's QC Tests: General Electric	528
Appendix 18.2	ACR Summary of Medical Physicist's and Technologist's QC Tests: Hologic	530
Appendix 18.3	IAEA Safety and Function Checklist of Examination Room and Equipment	531
	References	532
	Index	535

Preface

Breast cancer is an abnormal growth of cells in the breast, usually in the inner lining of the milk ducts or lobules. It is currently the most common type of cancer in women in developed and developing countries. The number of women affected by breast cancer is gradually increasing and remains as a significant health concern. Hence, the early detection of breast cancer can improve the survival rate and quality of life. Therefore, today, newer modalities are available to more accurately detect breast cancer. Researchers are continuously working to develop novel techniques to detect early stages of breast cancer. This book covers breast cancer detection using different imaging modalities such as mammography, magnetic resonance imaging, computed tomography, positron emission tomography, ultrasonography, infrared imaging, and other modalities.

Architectural distortion is one of the major causes of false-negative findings in the detection of early stages of breast cancer. Chapter 1 presents methods for computer-aided detection of architectural distortion in mammograms acquired prior to the diagnosis of breast cancer in the interval between scheduled screening sessions. The results are promising and indicate that the proposed methods can detect architectural distortion in prior mammograms taken 15 months (on average) before clinical diagnosis of breast cancer, with a sensitivity of 0.8 at 5.2 false positives per patient.

A computer-aided system for the automated detection of normal, benign, and cancerous breasts using texture features extracted from digitized mammograms and data mining techniques is proposed in Chapter 2. The novelty of this work is to automatically classify the mammogram into normal, benign, and malignant classes using the texture features alone, with an efficiency of 93.3% and sensitivity of 92.3% using a fuzzy classifier.

Breast cancer diagnosis by combination of fuzzy systems and an ant colony optimization algorithm is proposed in Chapter 3. Results on the breast cancer diagnosis dataset from the University of California Irvine machine learning repository show that the proposed FUZZY-ACO would be capable of classifying cancer instances with a high accuracy rate and adequate interpretability of extracted rules.

Chapter 4 discusses a computer-aided diagnosis system tested on magnetic resonance datasets obtained from different scanners, with a variable temporal and spatial resolution and on both fat-sat and non-fat-sat images, and has shown promising results. This type of system could potentially be used for early diagnosis and staging of breast cancer to reduce reading time and to improve detection, especially of the smaller satellite nodules.

Imaging plays a pivotal role in the evaluation of metastatic spread of breast cancer disease. Chapter 5 gives an overview of the recent developments in breast cancer imaging, in terms of instrumentation and clinical applications. In addition, the theoretical framework behind advanced imaging modalities is highlighted to provide background knowledge to the reader, and potential future research directions are also presented.

The role of positron emission tomography is established in the practice of oncology. The advances in functional and molecular imaging techniques have increased the accuracy in the diagnostic evaluation of breast cancers and is discussed in detail in Chapter 6.

Chapter 7 discusses 3D whole-breast ultrasonography, which can provide the entire breast anatomy for later review. The 3D whole-breast ultrasound procedure and the training time are simpler and shorter than the traditional 2D US. It also provides interoperator consistency, and its reproducibility is better for follow-up studies.

Recent progress in medical ultrasound has paved the way for the evaluation of breast cancer. State-of-the-art high-resolution ultrasound can detect tiny breast lesions as small as 1–2 mm in size, and sometimes microcalcifications even less than 0.5 mm, or small carcinomas 3–6 mm in diameter. Chapter 8 presents an overview of the recent developments in ultrasound imaging of breast cancer, in terms of instrumentation and clinical applications.

Nonlinear features such as Lyapunov exponents are used to differentiate malignant and benign breast thermograms in Chapter 9. This work can be extended for classifying different stages of breast cancer. The authors are currently working toward these objectives.

A set of image features describing bilateral differences between left and right breast regions in thermograms is described in Chapter 10. These features are then used in a pattern classification stage to discriminate malignant cases from benign ones. Classification is performed by fuzzy if-then rules and applies a genetic algorithm to optimize the rule base, and secondly uses an ant colony optimization classification algorithm. Both approaches have shown good classification accuracy.

Infrared imaging has shown to be a promising technique for the early diagnosis of breast pathologies and as a screening technique. The concept of a combined diagnostic enables a high degree of specificity and sensibility in such diagnosis. Chapter 11 presents a concept of merging

information from the images with other modalities of examination, such as mammograms and ultrasound, in order to improve the early detection of breast pathologies, including cancer.

Chapter 12 discusses diffuse optical imaging, which makes use of diffuse light to probe deep tissues by taking advantage of low tissue absorption within the near-infrared wavelength range (650–900 nm). The optical measurements obtained can be used to calculate optical properties, namely absorption and scattering within tissues. This, in turn, can provide information about physiological parameters within tissues, such as oxy- and deoxy-haemoglobin, and water and lipid, all of which can be utilized in the detection, characterization, and therapy monitoring of breast cancer.

Cytopathology is a branch of pathology that studies and diagnoses diseases on the cellular level, using samples of free cells or tissue fragments. Chapter 13 describes the results of a study of the features that are used by physicians and computers to diagnose cancer based on features in fine-needle aspiration cytology images. It discusses the significance of a cytological feature in representing its true ability to discriminate benign and malignant conditions of a breast lump in the Wisconsin Diagnostic Breast Cancer database.

Only a small number of studies have been reported on breast radiofrequency ablation, and most of them have included the posterior surgical excision of the treated breast. Chapter 14 presents the future trends in the development of more-specific radiofrequency algorithms for breast cancer treatment, to improve the results, determine the setting of the specific indications for the technique, and expand the study of long-term results and survival.

Breast conserving therapy is the gold-standard option for patients with early-stage breast cancer. The surgical excision removes the entire tumor with a negative surgical margin and helps to preserve the breast tissue as far as possible. Chapter 15 explains minimally invasive ablative techniques, which may offer complete tumor ablation, with less psychological morbidity, better cosmetic results, and shorter hospital stay.

A microwave-based imaging modality is an emerging noninvasive medical imaging approach exploring the dielectric property of biological tissue that shows great potential in breast cancer detection. Chapter 16 discusses a correlated microwave acoustic imaging modality and numerical simulation using finite-difference time-domain analysis. It is clearly shown that a combination of microwave-based imaging modalities is expected to provide an efficient diagnostic method for breast cancer detection in the future.

Fluorescence-based bioassays are novel diagnostic tools that are available to clinicians for deciding future treatment and to researchers for monitoring biological functions that may lead to novel investigations.

The different aspects of photonic crystal fiber, its guiding mechanism, the refractive index law, etc. are analyzed and explained in Chapter 17. The proposed methodology is implemented in an array format of immuno recognition of specific proteins using a hollow-core photonic crystal fiber.

An overview of a quality-assurance program for digital mammography is discussed in Chapter 18. This overview includes the quality-control test procedures based on the American College of Radiology and the International Atomic Energy Agency. The role of medical physicists in the mammography quality-assurance programs, including acceptance, annual, and regular quality-control testing, is briefly presented.

In this book, we have made an honest effort to present information and methodologies for accurate diagnosis of breast cancer to help researchers, doctors, teachers, and students in biomedical science and engineering.

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Acronyms and Abbreviations

ABSN	angles between surface normals
ABVS	Automated Breast Volume Scanner
ACO	ant colony optimization
ACR	American College of Radiology
ACS	ant colony system
AEC	automatic exposure control
AI	artificial intelligence
AJCC	American Joint Committee on Cancer
ALA	5-aminolevulinic acid
ANN	artificial neural network
ANOVA	analysis of variance
APC	antigen-presenting cell
APD	avalanche photodiode
ART	algebraic reconstruction technique
AUC	area under ROC curve
AUCEC	area under the contrast-enhancement curve
B + F	base + fog
BC	breast cancer
BCDSG	Breast Cancer Disease Site Group
BEM	boundary element method
BFGS	Broyden–Fletcher–Goldfarb–Shanno (method)
BHTE	bioheat transfer equation
BIRADS [®]	Breast Imaging Reporting and Data System
BIRADS-MRI	BIRADS for MRI
bpp	bits per pixel
BRCA-1, -2	breast cancer genes
BS	bone scintigraphy
BSE	breast self-examination
BWI	bound water index
CaCo	colorectal cancer
CAD	computer-aided diagnosis
CADe	computer-aided detection
CADx	computer-aided diagnosis
CAM	combined autocorrelation method

CBE	clinical breast examination
CCD	charge-coupled device
CDS	clinical decision support
CDSS	clinical decision support system
CDU	color Doppler ultrasound
CECT	contrast-enhanced computed tomography
CFD	computational fluid dynamics
CI	confidence interval
CLS	curvilinear structure
CMAI	correlated microwave acoustic imaging
CMM	coordinate measuring machine
CMOS	complementary metal-oxide semiconductor
CNS	central nervous system
CR	computed radiography
CR	contrast response
CT	computed tomography
CTL	cytotoxic T lymphocyte
CTS	chaotic time series
CW	continuous wave
CXR	chest radiology
DC	dendritic cells
DCE-MRI	dynamic contrast-enhanced MRI
DCIS	ductal carcinoma <i>in situ</i>
DCS	diffuse correlation spectroscopy
DD	density difference
DDSM	Digital Database for Screening Mammography
del	detector element
DeTr	decision tree
DICOM	Digital Imaging and Communications in Medicine
DM	digital mammography
DMD	digital micromirror device
DMIST	Digital Mammographic Imaging Screening Trial
DOI	diffuse optical imaging
DOS	diffuse optical spectroscopy
DOT	diffuse optical tomography
DR	digital radiology
DRS	diffuse reflectance spectroscopy
DW	diffusion weighted
E-M	expectation maximization
EGFR	epidermal growth factor receptor
EI	exposure index
EM	electromagnetic
EORTC	European Organization for Research and Treatment of Cancer

ER	estrogen receptor
ESAK	entrance surface air kerma
ESF	edge spread function
EW	evanescent wave
fat-sat	fat saturated
FCC	fibrocystic change
FD	frequency domain
FDG	fluorodeoxyglucose (^{18}F)
FDM	finite-difference method
fDOT	fluorescence diffuse optical tomography
FDTD	finite-difference time domain
FEM	finite-element method
FES	fluoro-17 β -estradiol
FFDM	full-field digital mammography
FG	fibroglandular
FG	fractal geometry
FLDA	Fisher linear discriminant analysis
FN	false negative
FNA	fine-needle aspiration
FNAC	fine-needle aspiration cytology
FNN	false nearest neighbor
FP	false positive
FROC	free-response ROC
FS	feature selection
FUI	feature usability index
GLCM	gray-level co-occurrence matrix
GMM	Gaussian mixture model
GSDF	grayscale standard display function
GUI	graphical user interface
H&E	hematoxylin-eosin
HCC	hepatocellular carcinoma
HC-PCF	hollow-core photonic crystal fiber
HC/UFPE	Clinical Hospital of the Federal University of Pernambuco
HIFU	high-intensity focused ultrasound
HL7	health level 7
HNG	high nuclear grade
HRT	hormone replacement therapy
HSP	heat shock protein
HVL	half-value layer
IAEA	International Atomic Energy Agency
ICG	indocyanine-green
IDC	invasive ductal carcinoma

IFN	interferon
IG-NIRS	image-guided NIR spectroscopy
IM	internal mammary
ING	intermediate nuclear grade
IR	infrared
ITK	Insight Toolkit
IV	intravenous
JAFROC	jackknife alternative free-response ROC
JND	just-noticeable difference
k -NN	k -nearest neighbor
LA	laser ablation
LBP	local binary pattern
LC-VCO	inductor/capacitor voltage-controlled oscillator
LCIS	lobular carcinoma <i>in situ</i>
LE	Lyapunov exponent
LNG	low nuclear grade
LSM	least-square method
LTB	lesion-to-background (ratio)
LUT	lookup table
MCC	microcalcification
MD	mid-density
MGD	mean glandular dose
MGH	Massachusetts General Hospital
MIAS	Mammographic Image Analysis Society
MIP	maximum-intensity projection
MIPT	maximum-intensity projection over time
mIPT	mean-intensity projection over time
ML	maximum likelihood
MOF	microstructured optical fiber
MPV	mean pixel value
MQSA	Mammography Quality Standards Act
MR	magnetic resonance
MRI	magnetic resonance imaging
MRS	magnetic resonance spectroscopy
MTAI	microwave-induced thermoacoustic imaging
MTF	modulation transfer function
MWA	microwave ablation
MWI	microwave imaging
NADH	nicotinamide adenine dinucleotide plus hydrogen
NBC	Naïve Bayesian classifier
NICE	National Institute for Health and Clinical Excellence (UK)
NIR	near infrared

NPV	negative predictive value
OI	optical index
OO	object-oriented (model)
ORD	object-relational database
PASH	pseudo-angiomatous stromal hyperplasia
PBG	photonic bandgap
PBS	phosphate-buffered saline
PCF	photonic crystal fiber
PD	progressive disease
PEM	positron emission mammography
PET	positron emission tomography
PET-CT	PET with computed tomography
PDU	power Doppler ultrasound
PHA	phytohaemagglutinin
PMMA	poly(methyl methacrylate)
PMT	photomultiplier tube
PNN	probabilistic neural network
PO	pulse oximeter
PPIX	protoporphyrin IX
PPV	positive predictive value
PR	partial response
PR	progesterone receptor
QA	quality assurance
QAP	quality assurance program
QC	quality control
QDA	quadratic discriminant analysis
RBF	radial basis function
RECIST	response evaluation criteria in solid tumors
RF	radiofrequency
RFA	radiofrequency ablation
RI	refractive index
RI	resistivity index
ROC	receiver operating characteristic
ROI	region of interest
ROL	reference operating level
RPS	reconstructed phase space
S/C	signal-to-clutter ratio
SD	stable disease
SDNR	signal-difference-to-noise ratio
SEM	scanning electron microscope
SFM	screen-film mammography
SI	shape index
SID	source-to-image distance

SHH	Sacred Heart Hospital
SIRT	simultaneous iterative reconstruction technique
SLNB	sentinel lymph node biopsy
SMPTE	Society of Motion Picture and Television Engineers
SNR	signal-to-noise ratio
SPAD	single-photon avalanche diode
SPECT	single-photon emission computed tomography
SQP	sequential quadratic programming
std	standard deviation
STIR	short tau inversion recovery
StO ₂	tissue oxygenation or oxygen saturation
SUV _{max}	maximum standardized uptake value
SUV _{mean}	mean standardized uptake value
SVD	singular value decomposition
SVM	support vector machine
TBS	tris-buffered saline
TBST	tris-buffered saline/Tween
TD	time domain
TDE	time-delay embedding
TDLU	terminal ductalobular unit
THC	total haemoglobin concentration
THI	tissue harmonic imaging
TIL	tumor-infiltrating lymphocyte
TN	true negative
TNF	tumor necrosis factor
TP	true positive
TPSF	temporal point spread function
TS	time series
TSFC	texture shape feature coding
UCI	University of California Irvine
US	ultrasound/ultrasonography
US NCI	United States National Cancer Institute
USPIO	ultrasmall superparamagnetic iron oxide
UWB	ultrawideband
VAB	vacuum-assisted biopsy
VOI	volume of interest
WB	whole body
WDBC	Wisconsin Diagnostic Breast Cancer (database)
WFUSM	Wake Forest University School of Medicine
WHO	World Health Organization
WU	Washington University in St. Louis