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Biomedical Imaging: Principles and Applications

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Book Reviews

Biomedical Imaging: Principles and Applications

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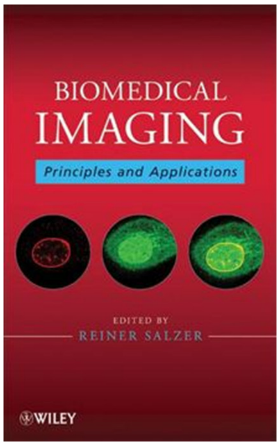

Biomedical Imaging: Principles and Applications, edited by Reiner Salzer, PhD, is a new book recently published by John Wiley & Sons. Of the 28 contributing authors, 25 are from Europe, 2 are from Canada, and 1 is from the United States. The authors have put together a comprehensive set of both well-established and emerging imaging technologies currently used in the laboratory and clinical practice. The text is well written with plenty of references and illustrations. In my opinion, it will help educate a wide audience coming into the field of biomedical imaging from various disciplines of science and engineering.

First, I present some background about the field of biomedical imaging, its importance, the clinical issues and problems it faces today, the book's strength and weakness, and finally why the book is important to the research community, with a few suggestions for its future improvement.

The importance and scope of the field of biomedical imaging can be judged by the fact that just 12 years ago a new institute, the National Institute of Biomedical Imaging and Bioengineering (NIBIB), was established within the National Institutes of Health in the United States. NIBIB's website describes its pivotal role in medicine and human health as follows: "Biomedical imaging is an indispensable tool for the diagnosis and treatment of a variety of diseases. In the early twentieth century, incremental advances in imaging were achieved at a relatively slow rate. However, in the last 40 years, improvements and new discoveries in imaging technology have occurred much more rapidly. The x-rays of over 100 years ago have been replaced by imaging (MRI). Now, researchers and physicians can choose to image not only the entire body or individual organs, but even specific cells or molecules within an organ or tissue." There is also an increasing awareness in Third World countries to acquire biomedical imaging technologies to allow physicians to make better and well-informed health-care decisions for their patients. For example, according to the World Health Organization, "a significant portion of all abdominal surgical interventions (explorative laparotomy) may have been avoided if simple diagnostic imaging services such as ultrasound had been available."

Our understanding of disease was greatly advanced by the introduction of microscopes to pathologists in the 19th century. Microscopes were helpful in identifying the causes or etiology of a disease, its progression, morphological changes at the tissue-to-cellular level, and finally the clinical implications. Since then, thanks to many technological advances in various fields of science and engineering, more powerful imaging modalities are continuously expanding our understanding of a number of diseases and their treatment by early detection of mechanisms of injury at the cellular and molecular levels. For example, the phenomena of necrosis, inflammation, oxidative stress, wound healing, and neoplasia can now be observed and studied.

Today, millions of x rays, MRI, and CT scans are taken every day in clinics all around the world. Even though they play an important role in saving lives, these well-established and routinely used techniques seem to have serious problems in data quality and interpretation. Safety issues are another concern. I illustrate this point with a few typical examples. The debate on the impact of both false positives and false negatives on patients undergoing mammography is yet to be settled. A new study on mammography recently presented by A. Bleyer and H.G. Welch in the *New England Journal of Medicine* (November 22, 2012) points to overdiagnosis of new breast cancers and unneeded cancer treatments. From the engineering point of view, problems dealing with artifacts in image quality require innovative solutions. Talcum powder, lotion, and deodorant female patients wear during mammography can be viewed as calcium spots in mammograms, sounding false alarms and subjecting them to more tests, including painful biopsies. Image quality is severely degraded by the amount of scattered radiation due to multiple scattering as x rays penetrate deeper into tissue. Important issues in almost all imaging techniques dealing with both ionizing and nonionizing radiation include the time to process an imaging session, patient fatigue, patient movement (prevention of "motion blur"), and minimizing the radiation dose. MRI, CT, and other similar imaging modalities have their share of limitations and serious side effects. In MRI, these include radiofrequency energy effects, acoustic noise, peripheral nerve stimulation, claustrophobia, and patient discomfort, to name a few. Gadolinium-based MRI contrast agents have also been linked to the development of nephrogenic systemic fibrosis in individuals with kidney insufficiencies. The Food and Drug Administration in the United States has identified CT scan problems with patients exposed to dangerous levels of ionizing radiation. Ultrasound imaging is relatively safe, but its safety should not be taken for granted, especially in cases of pregnancy when high-intensity sound waves are used to image the fetus. Containing the ever-increasing cost of medical imaging is also an important issue in developing effective and cost-competitive technologies. Hence, the field of biomedical imaging is continuously evolving and embracing new technological advances from almost every field of science, computation and data compression, and engineering. This offers the young generation of researchers a unique opportunity to make these technologies truly noninvasive, accurate, and safe.

The book *Biomedical Imaging: Principles and Applications* gives the reader an appreciation of how diverse concepts in the physical and biological sciences are connected in developing new imaging technologies to help improve human health by diagnosis of disease (pathology). The book describes well-established techniques of x ray, MRI, CT, and tracer imaging and the emerging techniques of fluorescence and Raman spectroscopy, coherent anti-Stokes Raman scattering (CARS) microscopy, sonography, and acoustic microscopy. The book covers a diverse set of technologies in the areas of anatomical imaging and spectroscopic imaging using ionizing and nonionizing radiation. Some of these are established and routinely used clinical technologies, and others are in their infancy or in translational stages. Even the established and routinely used technologies are affected by interpretations from radiologists requiring second opinions and discussions. The book addresses this area and discusses various efforts in making subjective decisions on a more objective foundation. If the focus of modern medicine is to prevent disease and not to wait until a full-blown effect is manifested into something that can be imaged, then it is too late to intervene except perhaps to perform surgery. This idea is now picking up momentum in monitoring or "imaging" a disease at the molecular level via spectroscopic means. The later chapters of the book offer a good perspective on this approach.

Some of the highlights of individual book chapters are as follows. The first chapter, "Evaluation of Spectroscopic Images," provides an overview of existing analytical methods, which include mathematical and statistical approaches for data analysis in image visualization such as pattern recognition and clustering and their application to the detection of brain tumors. It also highlights their limitations, challenges, and future directions. The second chapter, "Evaluation of Tomographic Data," gives an overview of the data analysis techniques used in the image reconstruction and its resolution in x-ray CT, MRI, single photon emission tomography (SPECT), and positron emission tomography (PET). The third chapter, "X-ray Imaging," describes in detail the instrumentation aspects and clinical applications in dentistry, mammography, and angiography. The fourth chapter, "Computed Tomography," describes the instrumentation aspects of CT scanning and measurement techniques of axial and helical scanning with examples of clear separation and blurring in spiral interpolation approach. Case studies in cardiac imaging and tumor staging (lymphoma) are discussed with future directions for image acquisition. Chapter 5 discusses MRI. Image creation and reconstruction techniques along with image resolution and signal-to-noise ratios are defined and discussed. The instrumentation is also discussed with the outlook for its future development. Multimodality imaging (combining two or more microscopic imaging techniques) is the topic of discussion in Chap. 6. It discusses correlative light and electron microscopy (CLEM). The benefit is that light microscopy (LM) provides fast scanning of large sample areas while electron microscopy (EM) provides very high resolution images of a selected area of the same sample, making it possible to study dynamic processes. Sample preparation techniques, tagging of molecules, and detection methods are discussed in detail with practical examples and future directions. Chapter 7 presents the technique of tracer imaging or imaging with radio-labeled molecules, which yields important information on blood flow, metabolic rates, and physiological processes in the animal and human body. PET and SPECT imaging devices and instrumentation are discussed with a few examples of imaging biomarkers in neuroscience. The technique of fluorescence imaging and its role in visualizing proteins, DNA molecules, and small animal organs in laboratory and preclinical settings is discussed in Chap. 8. Chapter 9 discusses infrared (IR) and Raman spectroscopic imaging. These emerging techniques can be used in several medical applications. The instrumentation aspects, data analysis, and image evaluation are nicely presented with clear charts in tabular form with color illustrations to applications in cell biology, neuroscience, and dermatology. Chapter 10, on CARS microscopy, demonstrates its potential for real-time chemical imaging in living biological cells. The established technique of ultrasound imaging is discussed as biomedical sonography in Chap. 11, emphasizing basic principles, instrumentation, and several color illustrations from clinical applications. Some of these include blood flow in the carotid artery, fetal umbilical cord, thyroid, and 3-D rendering of fetal face and arm. Finally, acoustic microscopy (AM) is discussed in Chap. 12. It can provide shape and mechanical information of biological specimens. Examples of AM images in an isolated rat cardiomyocyte, HaCaT cells, and endothelial cell (XTH-2) in culture are presented.

One of the book's weaknesses is that the individual chapters lack a consistent format. For example, while some chapters discuss the future outlook of their imaging modality, others do not. It would be helpful to newcomers in the field of biomedical imaging if every chapter in the book would discuss advantages and disadvantages and identify technology gaps and research needs for future development of their respective technologies. I also think the book omits a few important technological developments. From the standpoint of recent developments in biophotonics/biomedical optics and given the enormous popularity and promise of optical coherence tomography (OCT) in both basic and multidisciplinary clinical research, I find it surprising that the book does not cover this noninvasive imaging technique. Chapter 2 summarizes OCT in one short sentence: "Owing to the usually high absorption and scattering of light in tissue, the application of optical tomographic methods is generally restricted to investigations of near-surface structures such as the skin or the eye." The authors' focus therefore remains on x ray CT, MRI, SPECT, and PET. Similarly, discussion of the important imaging technique of functional near-infrared spectroscopy (fNIRS) as presented in Sec. 9.6.3 (Diagnosis of Hemodynamics) is very brief. Given its many applications and promise in diverse areas of clinical research, the topic should be expanded into a full chapter. At the very least, a comparison of fNIRS with fMRI (Sec. 5.11, Chap. 5) should have been included. A discussion of the fast-emerging photoacoustic technology should have also been included. Inclusion of these technologies in a future edition of the book would be helpful to a wider community of biophotonics/biomedical optics researchers and clinical instrument developers.

In my opinion, the book gives a broad overview of biomedical imaging and research methods. It can benefit graduate students, postdoctoral fellows, medical residents, and researchers to improve their research designs and help develop their projects or new technologies. It can complement, but it is not a substitute for, a well-designed medical imaging training program at the university level. I therefore agree with the book's back cover comments: "Geared to non-experts looking for quick guidance on what modalities to choose for their work without getting bogged down in technical details, the book discusses technical fundamentals, molecular background, evaluation procedures, and case studies of clinical applications." This book passes with flying colors on this score. The editor and the contributing authors are to be congratulated on achieving this goal. However, I would suggest including chapters on the promising modalities of OCT, fNIRS, and photoacoustic imaging in a future edition of this book. Another suggestion is to include a summary chapter comparing imaging modalities and their strengths and weaknesses.

In conclusion, the field of biomedical imaging has seen tremendous growth in new knowledge in recent years. However, there is plenty of room to improve these technologies to be truly noninvasive and safe. A future edition of this book should identify technology gaps in capabilities and research needs. Perhaps a road map can be produced to make these technologies better, faster, cheaper, and safer for the next generation of users. This would be highly beneficial to scientists and engineers seeking careers in biomedical imaging.

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