

CHAPTER 1

INTRODUCTION

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1.1 Introduction

Photonics is a light based optical technology that is considered as the leading technology for the new millennium. During the last 50 years, there has been many breakthroughs in photonics which laid foundation for its wide range of applications in health care. Most applications of photonics in health care were based on various types of light and different types of photon-tissue interactions. Application of photonics based techniques offer several specific advantages such as rapidity, sensitivity, specificity, inexpensive and non-invasive (needle less). It has been observed that many diseases of the mouth are accompanied by characteristic changes in the tissue structure. Some of the typical examples include dental caries, non-cariou lesions in teeth, gingivitis, periodontitis, precancerous lesions and tumors of the oral tissues. Dentistry has traditionally depended on contemporary science and technology for improvement in diagnostic tools and advancement in treatment options. However, the impact of photonics in clinical Dentistry has been significantly less than in clinical Medicine and Surgery.

Current dental practice has been emphasizing more on (1) early diagnosis and preventions of common oral diseases and (2) to conserve tooth structure as much as possible during restorative procedures. Thus Atraumatic and Non Invasive Treatment (ANIT) modalities have been the key thrust in Dentistry today. Keeping in mind the tremendous

potential of optical technology to provide high sensitive tissue information non-invasively, and the ability to induce localized and specific tissue changes, this should be the foremost technology to embrace for advancement in dentistry. In addition, research has highlighted saliva as a potential source of diagnostic markers to monitor the health status of the whole body. Saliva is increasingly used as an investigational aid in the diagnosis of diseases, such as dental caries, HIV, diabetes mellitus, oral cancer and breast cancer. Saliva meets all the requirements for a non-invasive, accessible and highly efficient diagnostic medium. When compared with the procedures for collecting blood, the use of saliva is less invasive and less traumatic to the patients. The most important benefit of light based diagnostic methods is their capability to detect clinically relevant information much early before actual clinical signs and symptoms appear in the patient. This allows photonics based techniques not only to be non-invasive during application but also detect disease associated tissue changes very early. Early detection of disease process will enable clinicians to carry out preventive treatment measures or minimally invasive treatment procedures that are less traumatic and cost effective.

1.2 Definition and Significance

Photonics include all light-based (optical) technology that is hailed as the dominant technology of this millennium. Biophotonics is a multidisciplinary category under photonics, which involves the fusion of photonics and biomedical sciences. **Biophotonics** defined as the science of generating and harnessing light (photons) to image, detect and manipulate biological materials. It is applied in Medicine and Dentistry to understand, diagnosis and treatment of diseases. Biophotonics mainly involves the interaction between light with biological tissues, and is used to study biological tissues and biological processes at different scales that ranges from micro to nano-levels. Biophotonics integrates lasers, photonics, nanotechnology and biotechnology. This integrated approach provides new dimension for diagnostics and therapeutics. This rapidly growing new discipline will have a major impact on health care.

Light has been used as a therapeutic agent and experimental approach for many centuries. The major use of light for therapeutic applications in health care sciences was noticeably initiated after the development of lasers in 1960. Invention of lasers, a concentrated source of monochromatic light has revolutionized photonics. Most of the earlier clinical studies in dentistry were conducted with high energy lasers such as Ruby laser ((1963), CO₂ (1968), YAG (1974), Argon (1977), Nd:YAG (1977) and Q-switched YAG (1980).

Last decade saw the advent of semiconductor diode lasers which are referred to as soft lasers. These lasers are compact, low cost device which have very high electrical and optical efficiency. In Dentistry the soft lasers have been used for acceleration of wound healing, enhanced remodelling and repair of bone, restoration of normal neural function following injury, normalization of abnormal hormonal function and modulation of the immune system. Although low-level light offers many potential advantages in Dentistry, further research is warranted before serious clinical applications.

1.3 Classification of Biophotonics in Dentistry

Biophotonics in Dentistry is crucial for the early detection of diseases, to carry out more effective minimally-invasive targeted-therapies and to restore diseased tissues functionally and esthetically. Different applications of biophotonics in health care are shown in Fig. 1.1. Biophotonics in Dentistry can be broadly categorized into (1) research and (2) clinical applications (see Fig. 1.2). Under clinical application they can be further subdivided into (2A) diagnostics and (2B) therapeutics.

1.3.1 Diagnostic

Low-energy light interacting with tissue gives rise to a characteristic luminescence, which provides information on different clinically useful parameters such as blood flow, pH and oxygen content. In addition, it

may also provide information on the physiologically and pathologically induced biochemical changes.

1.3.2 Therapeutic

Thermal interaction: In this process heat generated by the high-energy laser light is used to disrupt tissues. This process will mechanically induce coagulation, vaporization, carbonization and melting. Ruptured blood vessels are sealed by the laser induced coagulation of blood. The heat generated by laser beam on the focused tissue can be also used to weld tissue segments instead of using sutures. Further, high energy lasers are also used to cut-through tissues.

Photodynamic Therapy: This method uses light to trigger chemical reactions in the body for therapeutic applications. A photosensitizing agent is utilized to achieve the photodynamic effect. Photodynamic therapy is also called as photoradiation therapy, phototherapy, or photochemotherapy.

Photo-biostimulation: In this method extremely low-power light is used to induce photochemical effects on tissues. A low-powered laser procedure does not produce heat and therefore does not damage biological tissues; it stimulates the tissues and promotes healing by penetrating deep into the tissues initializing the process of photochemical effect. Photo-biostimulation is applied in Dentistry for many applications such as post extraction edema, sensitive teeth, gums and benign mouth lesions.

Bioimaging: Optical and x-ray imaging has influenced the practice of dentistry dramatically. Reconstruction of images in both two and three-dimensions has allowed better visualization of models and disease processes, allowing quantification of disease changes over time, thus assisting the treatment planning decisions and improving patient care. Some of these innovations are in the research and development stage. Bioimaging finds application in oncology, inflammatory processes, wound healing, pharmacokinetics, pharmacodynamics, toxicology,

infectious disease, gene expression and more. Furthermore, new concepts of non-invasive imaging (optical biopsy) rely on better understanding of the signal's origin, both "native" and exogenous.

1.3.3 Research

Photomechanics: Much research in dentistry is directed to understand the stress-strain states in biological and artificial structures (restorations and prosthesis). Photomechanical experiments are optics based experiments used to study the material property gradients in biological materials and the stress-strain distribution in tooth and supporting bone structures. These high sensitive experimental techniques are used to extrapolate clinically relevant material properties within dental structures and within biological interfaces. Photoelasticity, Moiré interferometry and Electronic Speckle pattern interferometry are some of the most commonly employed optical techniques in dental biomechanics. In the past analyzing optical fringes to deduce clinically useful experimental data was considered tedious and time consuming. However, with the recent advances in digital image processing systems, analysis of optical fringes has been robust and efficient.

Spectroscopy: A spectrum is a representation of the electromagnetic radiation which is absorbed or emitted by a sample. The qualitative applications of absorption spectrometry depends on the fact that a given molecular species absorbs light only in the specific region of the spectrum, and in varying degrees, characteristic of that particular species. Such a display is called an absorption spectrum of that molecular species and serves as a fingerprint for identification purpose. UV-Visible spectroscopy monitors the electronic states of the molecules, while an infrared spectroscopy determines changes in the vibrational states of the molecules. These techniques are very valuable for the non-invasive testing (without needles) of biochemical substances for diagnostic and therapeutic purposes. Raman spectroscopy, which is based on Raman scattering, measures the inelastic scattering when high-energy photon interact with a molecule (or crystal lattice). This analytical technique is finding significant application in pharmaceutical industry. There is a

growing interest in single cell, tissue, organ level measurements as applied to basic physiology, non-invasive diagnostics, and in vivo studies.

Fiber-optic sensors: Optical fibers in health care sciences have come a long way; however, they still need further improvements. Fiber optics offers the advantage of flexibility of beam manipulation. In the past fiber optics was used mostly as an optical conduit to illuminate inaccessible regions and to conduct high-energy lasers to specific tissue site for cutting. Recently, many fiber optic based sensors are being developed with intentions to provide a safe, rapid and non-invasive testing of clinically relevant physiological variables. The fiber optic based sensor offers advantages such as electrical isolation, physical flexibility and needless of electrical power for driving the sensor unit. Additionally, they find application in designing customized probes that are tailored for specific applications. These probes combine the advantage of spectroscopic techniques with fiber optics.

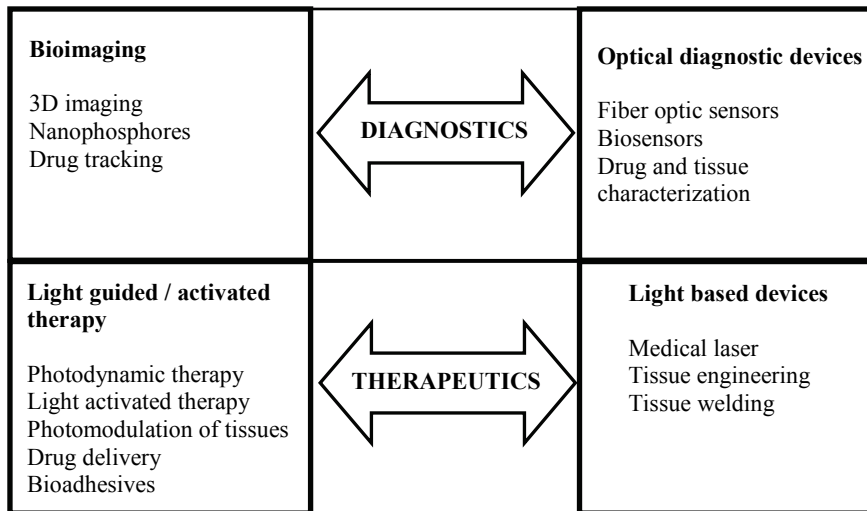


Fig. 1.1. Applications of biophotonics for health care.

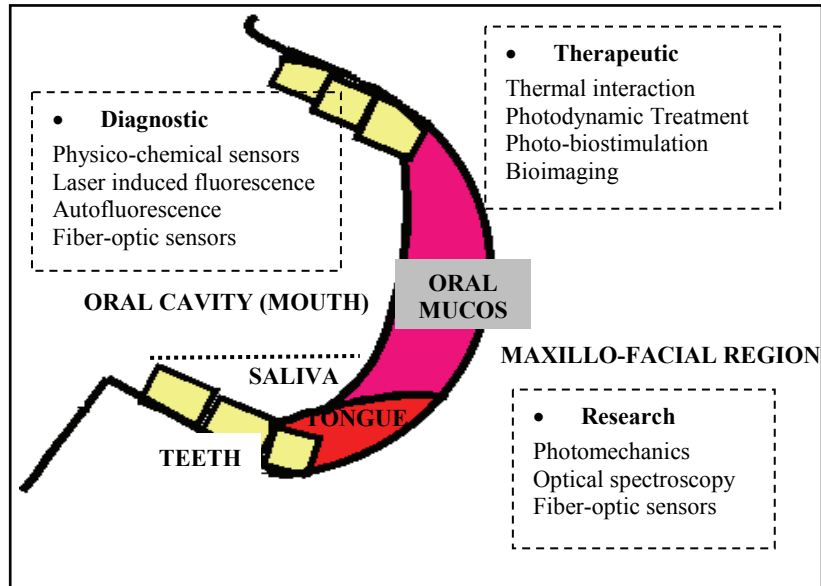


Fig. 1.2. The comprehensive multidisciplinary scope of biophotonics in dentistry.

1.4 Future Opportunities

Dental practitioners have been traditionally plagued with different problems pertaining to the diagnosis and treatment of oral diseases. Biophotonics is an emerging technology that promises to have a broad and significant impact on health care. In the past decade, key technologies such as (a) compact lasers, (b) CCD detectors, (c) volume holographic elements and (d) easy-to-use computing platforms combined with fiber-optic coupled instrumentation has developed many diagnostic and therapeutic instruments in health care. Rapid detection and non-invasive tissue modulation are the most important advantages of photonics based methods. These methods allow early detection of diseases and implementation of preventative or minimally invasive treatment regimes that avert drastic tissue damage. Currently, biophotonics is entering a new era of rigorous clinical testing and evaluation. As photonics find major application in health care, it is particularly important that the basic principles and potential pitfalls of technology is also understood. Although optical spectroscopy may one

day replace some of the conventional clinical techniques, it is important to combine the advantages of photonics with lessons learned by the clinicians in the past. This approach will enable us to develop clinically useful technologies for better health care management.

Biophotonics offers remarkable prospectus for both clinical applications and fundamental research. In the future biophotonics is anticipated to play a major role in creating new technologies for significant health care benefits and immense commercial potential for different biomedical industries. Future opportunities with biophotonics are: development and testing of multiple-analyte based nano-probes, optical biosensors for infections and cancers, in vivo optical biopsy, tissue welding, tissue contouring and regeneration, in vivo imaging of human subjects, real-time monitoring of drug delivery and action. All these technological aids should be supported by long-term clinical evaluations.

1.5 Scope of this Book

The aim of this book is to provide a basic understanding of broad range of topics for individuals from different backgrounds to acquire minimum knowledge for research and development in biophotonics. The chapters in this book is sorted under two major categories, the first category describes the fundamental aspects of photonics such as Photomechanics, Biomedical Imaging, Lasers and laser-tissue interaction, spectroscopy and Photodynamic therapy. The second category describes the applications of biophotonic, especially with relevance to dentistry. Dental Photobiomechanics, Raman Spectroscopy, dental tissue optics and fiber optic diagnostic sensors are dealt under this category.

References

1. G.A. Catone, C.C. Alling, *Laser applications in Oral and Maxillofacial Surgery*, WB Saunders Company: London (1997).
2. A. Katzir. *Lasers and optical fibers in medicine*, Academic Press, Inc: New York (1993).
3. P.N. Prasad. *Introduction to Biophotonics*. Wiley Interscience Inc., New Jersey (2003).