Lasers in Dermatology and Medicine

Dermatologic Applications

Keyvan Nouri
Editor

Second Edition

Springer

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Editor
Keyvan Nouri
Leonard M. Miller School of Medicine
University of Miami
Miami, FL
USA

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Foreword—And Forward!

This, Nouri's book, is a thorough, recent, practical, and refreshing one that puts "laser dermatology" into a broader perspective; it is a pleasure to update my brief contribution for this edition. Almost immediately after the first laser was created in 1960, a handful of visionary physicians recognized the potential for surgical applications, starting with the organ systems readily accessible to light. Lasers in laryngology, ophthalmology, and dermatology are so fully adopted now that the standards of care have forever been changed. Now, light is marching inside the body. Laser lithotripsy is widely practiced all over the world. Know-how about lasers and biomedical optics is jumping between medical specialties. Optical coherence tomography, a rapid form of live microscopy invented for retinal imaging, is starting to impact dermatology while making a larger splash for upper GI tract and coronary artery diagnostic imaging. Dermatology was the first to figure out how to target individual pigmented cells with laser pulses, a capability later adopted into ophthalmology for glaucoma treatment. Recently, the various optical nanoparticles developed for laser photo-thermal cancer therapy are being used in dermatology for acne treatment.

How did we get such a wide, almost dazzling, variety of treatment lasers in dermatology? (Because, we need them for different uses in various practice settings; lasers are the most tissue-specific surgical tools in existence.) Do we really need so many? (Well, we need most all of them. Only a few are interchangeable.) Are the mechanistic, clinical, safety, ethical, and practice-related chapters of this book worthy of study? (Yes.) Can't we just learn which buttons to push, in courses provided by the more reputable device manufacturers just after a laser is purchased? (This approach is foolish beyond words, yet such fools exist). Even more foolish are those who purchase a used laser and start using it without any training whatsoever.

A great asset of this book is the breadth of its practical, clinical discussions. There is no substitute for hands-on training, which cannot be obtained even from this practical book. If you use lasers in practice, talk with your colleagues and attend medical laser conferences in which you are free to ask questions to faculty who are not trying to sell something. Many laser companies provide useful information, but are inherently biased. Laser companies are restricted from discussing off-label indications. FDA clearance of a device for a particular indication cannot be taken as assurance that it will work safely and effectively enough to satisfy you and your patients, while lack of FDA clearance for a specific indication cannot be taken as assurance that it will not work safely and effectively. Some of the best uses for dermatological lasers are not FDA-labeled indications, and probably never will be.

It is remarkable what lasers already can do for our patients, yet this field is clearly still in its youth. What comes next? With the advent of fiber laser technology, various industries and telecommunications now have extremely powerful, efficient, wavelength-versatile lasers that operate reliably for decades with little or no maintenance. Those have begun to make their way into dermatology, and may ultimately do better what we do now, plus add wholly new capabilities. Fractional lasers have taught us how amazingly tolerant skin is, to a large volume of micro-injury. Up to 30% of skin can be killed or removed in random, full-thickness wounds that heal rapidly without scarring. The caveat is that every little wound must be less than about 0.4 mm wide. Given that, is it possible to “target” anything in the skin that can be localized, regardless of its optical or thermal properties? If we knew where various things are in the skin, can’t we just aim at them? Yes, we could! Image-guided smart fractional lasers will be used to selectively treat structures and lesions not now addressed with lasers—and with that, we will have software-programmable laser targeting. For example, all three cutaneous glands—eccrine, sebaceous, and apocrine—are reasonable targets, as well as nerves, lymphatics, sensory end organs, mast cells, antigen-presenting cells, and other components of normal skin. Microscopy-driven ablative lasers may even rival conventional microscopic margin-controlled tumor surgery, some day. When laser microscopy and laser tissue ablation are finally married, surgical oncology in general may be impacted. This new era is coming sooner than you think.

I have been fortunate to play a role in launching many aspects of laser dermatology, starting with some fundamental understanding of skin optics, the concept of selective photothermolysis, lasers specifically designed for dermatological use, permanent laser hair removal, scanning confocal laser microscopy, and “fractional” laser treatments. Each of these arose from trying to understand or solve one clinical problem, but now the panoply of clinical laser applications far exceeds the initial effort. For example, fractional lasers arose as a safer alternative to fully ablative laser skin resurfacing, a safer way to induce skin remodeling. We had no idea that tissue so grossly abnormal as a hypertrophic wound scar could be stimulated to normalize itself this way. Fractional ablative lasers also offer a new way for delivery of topical agents, including very high molecular weight macromolecules, particles, and even cells. The current widespread and diverse use of lasers in dermatology attests not so much to new technology, as to the extreme value of astute clinical observations made by dedicated dermatologists. Nouri’s text is aimed exactly at achieving that. So please be a gourmet laser chef, not a short-order cook. Contribute to an amazing and evolving part of dermatology.

Thank you, Dr. Nouri and the many authors involved in this text, for your excellent contribution.

R. Rox Anderson

Preface

Laser technology is quickly evolving with the presence of newer lasers, along with new indications, that are constantly being introduced. The use of lasers has become a major discipline and is currently practiced in a variety of fields of medicine today. This book specifically offers a comprehensive literature covering the different ways lasers are being used in the field of dermatology. The authors of *Lasers in Dermatology and Medicine* are well known in their respective fields and have attempted to cover each topic in the most comprehensive, readable, and understandable format. Each chapter consists of an introduction and summary boxes in bulleted formats with up-to-date information highlighting the importance of each respective section, enabling the reader to have an easy approach towards reading and understanding the various topics on lasers. This book has been written with the sincere hope of the editors and the authors to serve as a cornerstone of laser usage in dermatology, ultimately leading to better patient care and treatments. Lasers in dermatology have clearly expanded. The areas or laser treatments include port wine stains, vascular anomalies and lesions, pigmented lesions and tattoos, hair removal and hair re-growth, acne, facial rejuvenation, psoriasis, hypopigmented lesions and vitiligo, and treatment of fat and cellulites, among others. The lasers are also being used for treatment and diagnosis of skin cancers.

We anticipate that this book will be of interest to all the physicians in the field of dermatology who use or are interested in using lasers in their practice. We are extremely grateful to our contributing authors. This book will serve as a potential study source for physicians that would like to expand their knowledge in lasers and light devices.

Miami, FL, USA Keyvan Nouri

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I would also like to acknowledge the publishing staff Mr. Grant Weston, Ms. Tracy Marton, Mr. Leo Johnson, and the entire Springer Publishing team for having done a superb job with the publication. It has been a pleasure working with them and this excellent project to compile the textbook.

Lastly, I would like to sincerely thank all the authors of this textbook. These individuals are world-renowned in their respective specialties and without their time and energy, writing this book would have not been possible. These individuals have made this a comprehensive, up-to-date, and reliable source on *Lasers in Dermatology and Medicine*. I truly appreciate their hard work and thank them for their contributions.

Keyvan Nouri

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Contributors

Murad Alam Department of Dermatology, Otolaryngology, and Surgery, Northwestern University, Chicago, IL, USA

Department of Dermatology, Northwestern University, Chicago, IL, USA

Mana ALHarbi Department of Dermatology, College of Medicine, Al Imam Muhammad Ibn Saud Islamic University (IMSIU), Riyadh, Kingdom of Saudi Arabia

Ibrahim Abdullah Omair ALOmair Department of Dermatology, College of Medicine, Al Imam Muhammad Ibn Saud Islamic University (IMSIU), Riyadh, Kingdom of Saudi Arabia

Tina S. Alster Georgetown University Medical Center, Washington Institute of Dermatologic Laser Surgery, Washington, DC, USA

Marc R. Avram Department of Dermatology, Massachusetts General Hospital, Harvard Medical School, Boston, MA, USA

Mathew M. Avram Department of Dermatology, Massachusetts General Hospital, Harvard Medical School, Boston, MA, USA

Ehsan Azimi Department of Dermatology, Cutaneous Biology Research Center, Massachusetts General Hospital, Charlestown, MA, USA

Ashish C. Bhatia Department of Dermatology, Northwestern University – Feinberg School of Medicine, Chicago, IL, USA

Oak Dermatology, Schaumburg, IL, USA

Peter Bjerring Department of Dermatology, Swansea University, Swansea, Wales, UK

Navid Bouzari South Shore Skin Center, Plymouth, MA, USA

Lori A. Brightman Laser & Skin Surgery Center of New York, New York, NY, USA

R. Glen Calderhead Research Division, VP Medicoscientific Affairs, Clinique L, Goyang-shi, Gyeonggi-Do, South Korea

Shields Callahan Department of Dermatology, Virginia Commonwealth University School of Medicine, Richmond, VA, USA

Isabella Camacho School of Medicine, Georgetown University, Washington, DC, USA

Caroline V. Caperton Miller School of Medicine, University of Miami, Miami, FL, USA

Jessica Cervantes Department of Dermatology, University of Miami Miller School of Medicine, Miami, FL, USA

Rawat Charoensawad Rawat Clinic, Bangkok, Thailand

Biophile Training Center, Bangkok, Thailand

Sonal Choudhary Department of Dermatology and Cutaneous Surgery, Miller School of Medicine, University of Miami, Miami, FL, USA

Kåre Christiansen Molholm Research, Molholm Hospital, Vejle, Denmark

Brienne D. Cressey Department of Dermatology, New York Presbyterian-Weill Cornell Hospital, New York, NY, USA

Stephen C. Davis Department of Dermatology and Cutaneous Surgery, University of Miami, Miami, FL, USA

Alpesh Desai Heights Dermatology and Aesthetic Center, Houston, TX, USA

Shraddha Desai Dermatology Institute, DuPage Medical Group, Naperville, IL, USA

Tejas Desai Heights Dermatology and Aesthetic Center, Houston, TX, USA

Roberto Diaz Department of Neurosurgery, University of Miami, Miami, FL, USA

Alaleh Dormishian Department of Dermatology and Cutaneous Surgery, University of Miami Miller School of Medicine, Miami, FL, USA

Jeffrey S. Dover Department of Dermatology, Yale University School of Medicine and Brown University, Chestnut Hill, MA, USA

Meghan Dubina Department of Dermatology, Northwestern University, Chicago, IL, USA

Ariel E. Eber Department of Dermatology and Cutaneous Surgery, University of Miami, Miller School of Medicine, Miami, FL, USA

Yun Ehrlich Department of Dermatology and Cutaneous Surgery, University of Miami, Miami, FL, USA

Ronda S. Farah Department of Dermatology, University of Minnesota, Minneapolis, MN, USA

Nkanyezi Ferguson Department of Dermatology, University of Iowa Hospital and Clinics, Iowa City, IA, USA

Elizabeth A. M. Frost Mount Sinai Medical Center, New York, NY, USA

Julie A. Gayle Department of Anesthesiology, LSUHSC School of Medicine, New Orleans, LA, USA

Roy G. Geronemus Laser & Skin Surgery Center of New York, New York, NY, USA

Department of Dermatology, New York University Medical Center, New York, NY, USA

Michael C. Giovingo Department of Ophthalmology, Stroger Hospital of Cook County, Chicago, IL, USA

Michael Howard Gold Gold Skin Care Center and Tennessee Clinical Research Center, Nashville, TN, USA

Mercedes E. Gonzalez Department of Dermatology, University of Miami Miller School of Medicine, Miami, FL, USA

Salvador González Department of Medicine and Medical Specialities, Alcalá University, Madrid, Spain

Department of Dermatology, Memorial Sloan-Kettering Cancer Center, New York, NY, USA

Hospital Ramón y Cajal, Alcala University, Madrid, Spain

Emmy M. Graber Dermatology Institute of Boston, PC, Boston, MA, USA

Michael S. Graves Southwest Skin Cancer & Vein Clinic, Austin, TX, USA

Ramez I. Haddadin Department of Ophthalmology, Feinberg School of Medicine, Northwestern University, Chicago, IL, USA

Molly B. Hirt Department of Dermatology, University of Minnesota, Minneapolis, MN, USA

Vincent M. Hsu Department of Dermatology and Cutaneous Surgery, University of Miami Miller School of Medicine, Miami, FL, USA

Ran Huo Broward Dermatology Clinic, Pembroke Pines, FL, USA

Sofia Iglesia Department of Dermatology and Cutaneous Surgery, University of Miami Miller School of Medicine, Miami, FL, USA

Viacheslav Iremashvili Department of Urology, Jackson Memorial Hospital, Miami, FL, USA

Michael E. Ivan Department of Neurological Surgery, University of Miami Hospital, Jackson Memorial Hospital, and Jackson South Hospital, Miami, FL, USA

Sanjana Iyengar Department of Dermatology, Feinberg School of Medicine, Northwestern University, Chicago, IL, USA

Hana Jeon Laser & Skin Surgery Center of New York, New York, NY, USA

Jayne Joo Department of Dermatology, Davis and Sacramento VA Medical Center, University of California, Sacramento, CA, USA

Laura Jordan Kansas City University Consortium, Tri-County Dermatology Residency Program, Cuyahoga Falls, OH, USA

Julie K. Karen Department of Dermatology, CompleteSkinMD, NYU Langone Medical Center, New York, NY, USA

Alan David Kaye Department of Anesthesiology, Louisiana Health Sciences Center, School of Medicine, New Orleans, LA, USA

Ashley Keyes Department of Dermatology, Weill Cornell Medicine, Lincoln Medical Center, Bronx, NY, USA

Suzanne Kilmer Laser & Skin Surgery Center of Northern California, Sacramento, CA, USA

Department of Dermatology, Davis Medical Center, University of California, Sacramento, CA, USA

William T. Kirby Laseraway Hermosa Beach, Hermosa Beach, CA, USA

Ricardo J. Komotar Department of Neurosurgery, University of Miami, Miami, FL, USA

Sailesh Konda Department of Dermatology, University of Florida College of Medicine, Gainesville, FL, USA

Raymond J. Lanzafame Raymond J. Lanzafame, MD PLLC, Buffalo, NY, USA

School of Dental Medicine, State University of New York at Buffalo, Buffalo, NY, USA

Hans-Joachim Laubac Dermatologische Abteilung, Universitäre Krankenhäuser von Gen, Genf, Schweiz

Ken K. Lee Dermatologic and Laser Surgery, Oregon Health and Sciences University, Portland, OR, USA

Angel Leiva Department of Dermatology and Cutaneous Surgery, Miller School of Medicine, University of Miami, Miami, FL, USA

Yakir S. Levin Department of Dermatology, Massachusetts General Hospital, Boston, MA, USA

Wellman Center for Photomedicine, Massachusetts General Hospital, Boston, MA, USA

Amanda Abramson Lloyd Skin and Vein Institute, Encinitas, CA, USA

Maren C. Locke Department of Dermatology, MetroHealth System, Cleveland, OH, USA

Robert Magno Department of Dermatology, University of Miami, Toms River, NJ, USA

Dieter Manstein Wellman Center for Photomedicine, Massachusetts General Hospital, Harvard Medical School, Boston, MA, USA

Robert Marcovich Department of Urology, University of Miami, Miami, FL, USA

Juan-Carlos Martinez Dermatologic and Laser Surgery, Oregon Health and Sciences University, Portland, OR, USA

Daniel Michael Department of Dermatology, Laser and Skin Surgery Center of Northern California, University of California, Davis, Medical Center, Sacramento, CA, USA

Summer Moon Dermatology Specialists of West Florida, FL, USA

Rachael L. Moore Dermatology Specialists of West Florida, Oregon Health and Sciences University, Portland, OR, USA

Girish S. Munavalli Dermatology, Laser, and Vein Specialists of the Carolinas, Charlotte, NC, USA

Timothy G. Murray Department of Ophthalmology/Ocular Oncology, Retina Vitreous Diseases/Pediatric Ophthalmology, Medical Arts Surgery Center Baptist, Nicklaus Children's Hospital, Miami, FL, USA

Vic A. Narurkar Bay Area Laser Institute, San Francisco, CA, USA

Keyvan Nouri Dermatology, University of Miami, Miami, FL, USA

Ophthalmology, University of Miami, Miami, FL, USA

Otolaryngology, University of Miami, Miami, FL, USA

Dermatologic Surgery, University of Miami, Miami, FL, USA

Department of Dermatology and Cutaneous Surgery, University of Miami Medical Group, University of Miami, Miami, FL, USA

Dermatology Services at Sylvester Comprehensive Cancer Center, University of Miami Hospital and Clinics, Miami, FL, USA

MOHS, Dermatologic and Laser Surgery, University of Miami, Miami, FL, USA

Surgical Training, University of Miami, Miami, FL, USA

Mahnaz Nouri Boston Eye Group, Brookline, MA, USA

Peter O'Kane Dorset Heart Centre, Royal Bournemouth Hospital, Bournemouth, Dorset, UK

Carolyn Orgain Department of Otolaryngology, University of California, Irvine, Orange, CA, USA

Steven Parker , Harrogate, North Yorkshire, UK

Krishna B. Patel Department of Ophthalmology, John H. Stroger Hospital of Cook County, Lombard, IL, USA

Shalu S. Patel Department of Dermatology and Cutaneous Surgery, Miller School of Medicine, University of Miami, Miami, FL, USA

Robert Perez Department of Dermatology and Cutaneous Surgery, Miller School of Medicine, University of Miami, Miami, FL, USA

Marina Perper Department of Dermatology and Cutaneous Surgery, University of Miami Hospital, Miller School of Medicine, Miami, FL, USA

Roberto Pineda Department of Ophthalmology, Massachusetts Ear and Eye Hospital, Boston, MA, USA

Ali Rajabi-Estarabadi Department of Dermatology and Cutaneous Surgery, University of Miami Miller School of Medicine, Miami, FL, USA

John Rawlins Dorset Heart Centre, Royal Bournemouth Hospital, Bournemouth, UK

Douglas J. Rhee Department of Ophthalmology and Visual Science, University Hospitals, Cleveland, OH, USA

Department of Ophthalmology and Visual Sciences, Case Western Reserve University School of Medicine, Cleveland, OH, USA

Cornelia Selma de Riese Department of Obstetrics and Gynecology, Texas Tech University Health Sciences Center, Lubbock, TX, USA

Nicole E. Rogers Hair Restoration of the South, Metairie, LA, USA

Edward Victor Ross Department of Dermatology, Scripps Clinic, San Diego, CA, USA

Vanessa Rothholtz Pacific Coast Ear Nose and Throat, Beverly Hills, CA, USA

R. Rox Anderson Department of Dermatology, Massachusetts General Hospital, Harvard Medical School, Boston, MA, USA

Wellman Center for Photomedicine, Massachusetts General Hospital, Harvard Medical School, Boston, MA, USA

Ryan Rubin Department of Anesthesiology, Louisiana Health Sciences Center, New Orleans, LA, USA

Fernanda Hidemi Sakamoto Department of Dermatology, Massachusetts General Hospital, Harvard Medical School, Boston, MA, USA

Wellman Center for Photomedicine, Massachusetts General Hospital, Harvard Medical School, Boston, MA, USA

Amy C. Schefler Department of Ophthalmology, Bascom Palmer Eye Institute, Miami, FL, USA

Gonzalo Segurado-Miravalles Department of Dermatology, Ramón y Cajal Hospital, Madrid, Spain

Pablo Fernández-Crehuet Serrano Department of Dermatology, Alto Guadalquivir de Andújar, Andújar, Jaén, Spain

Brian Simmons Department of Dermatology and Cutaneous Surgery, University of Miami, Miami, FL, USA

Anita Singh Montefiore Medical Center, Albert Einstein College of Medicine, Bronx, NY, USA

James M. Spencer Spencer Dermatology and Skin Surgery Center (Spencer Dermatology, Carillon Outpatient Center), St. Petersburg, FL, USA

Joseph Stuto Department of Dermatology, Weill Cornell Medical Center, New York, NY, USA

Amit Todani Department of Ophthalmology, Goodman Eye Medical & Surgical Center, Milford, MA, USA

Allyne Topaz Hackensack University Medical Center, Hackensack, NJ, USA

On Topaz Asheville VA Medical Center, Asheville, NC, USA

Abel Torres Department of Dermatology, Loma Linda University School of Medicine, Loma linda, CA, USA

John Tsatalis Department of Dermatology and Cutaneous Surgery, University of Miami Miller School of Medicine, Miami, FL, USA

Elizabeth Uhlenhake The Dermatology Group, Mason, OH, USA

Voraphol Vejjabhinanta Department of Dermatology and Cutaneous Surgery, Leonard M. Miller School of Medicine, University of Miami, Miami, FL, USA

Department of Dermatology, Siriraj Hospital, Mahidol University, Bangkok, Thailand

Sebastian H. Verne Department of Dermatology and Cutaneous Surgery, University of Miami Miller School of Medicine, Miami, FL, USA

Victor M. Villegas Bascom Palmer Eye Institute, Miami, FL, USA

Rungsima Wanitphakdeedecha Department of Dermatology, Faculty of Medicine Siriraj Hospital, Mahidol University, Bangkok, Thailand

Molly Wanner Department of Dermatology, Massachusetts General Hospital, Harvard Medical School, Boston, MA, USA

Robert A. Weiss Department of Dermatology, Maryland Dermatology Laser Skin and Vein Institute, University of Maryland School of Medicine, Hunt Valley, MD, USA

Andrew Whittaker Department of Cardiology, Dorset Heart Centre, Royal Bournemouth Hospital, Bournemouth, Dorset, UK

Heather Woolery-Lloyd Department of Dermatology and Cutaneous Surgery, Miller School of Medicine, University of Miami, Miami, FL, USA

Brian J. F. Wong Department of Otolaryngology, University of California, Irvine, Orange, CA, USA

Christopher Wong Miller School of Medicine, University of Miami, Miami, FL, USA

Charles C. Wykoff Department of Ophthalmology, Bascom Palmer Eye Institute, Miller School of Medicine, University of Miami, Miami, FL, USA

Roger B. Yandell Department of Obstetrics and Gynecology, Texas Tech University Health Sciences Center, Lubbock, TX, USA

Laser-Tissue Interactions

1

Amanda Abramson Lloyd, Michael S. Graves,
and Edward Victor Ross

Abstract

The best gauge of laser interactions is the tissue response, and experiment is the most realistic manner to address medical treatment challenges. However, theoretical models are helpful in planning treatment approaches and laser parameters. In this chapter we discuss basics of lasers, their non laser counterparts, and laser-tissue interactions.

Many physicians choose laser settings out of habit (or reading it off of a label attached to the side of the machine—a "cheat" sheet with skin-type specific parameters), using tissue endpoints to confirm the appropriateness of the parameters. For example, when treating a tattoo with a Q-switched laser, the operator looks for immediate frosty whitening. Like driving a car (where the operator may have no idea about nature of the drive train components), successful laser operation does not demand a complete understanding of the machine or the details of the light-tissue interaction. However, a comprehension of first principles allows for a logical analysis of final clinical outcomes—furthermore, more creative uses of equipment should follow. For example, with an education in laser tissue interactions (LTIs) and tissue cooling, one can deploy the alexandrite (long pulse) laser either as a hair removal device, vascular laser, or to remove lentigines.

The reader should note that although the title of this chapter is "Laser Tissue Interactions", the introduction of many new and diverse technologies make the term somewhat obsolete. We will continue to use the term, but a more appropriate term is "energy–tissue interactions." As both radiofrequency and ultrasound are increasingly applied in medicine. We will use both terms interchangeably in the remainder of the text.

Keywords

Laser · Radiofrequency · Ultrasound · Skin · Lentigines · Hair removal · Vascular · Dermatology

A. A. Lloyd
Skin and Vein Institute,
Encinitas, CA, USA

M. S. Graves
Southwest Skin Cancer and Vein Clinic,
Austin, TX, USA

E. V. Ross (✉)
Laser and Cosmetic Dermatology, Scripps Clinic,
San Diego, CA, USA
e-mail: ross.edward@scrippshealth.org

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Introduction

1. Light represents one portion of a broader electromagnetic spectrum.
2. Light-tissue interactions involve the complex topics of tissue optics, absorption, heat generation, and heat diffusion
3. Lasers are a special type of light with the characteristics of monochromaticity, directionality, and coherence.
4. Coagulation/denaturation is time and temperature dependent
5. Proper selection of light parameters is based on the color, size, and geometry of the target
6. Wound healing is the final but not least important part of the laser tissue sequence (the epilogue)
7. Laser-tissue interactions are fluid—the operator should closely examine the skin surface during all aspects of the procedure
8. Pulse duration and light doses are often as important as wavelength in predicting tissue responses to laser to irradiation

The best gauge of laser interactions is the tissue response, and experiment is the most realistic manner to address medical treatment challenges. However, theoretical models are helpful in planning treatment approaches and laser parameters. In this chapter we discuss basics of lasers, their non-laser counterparts, and laser-tissue interactions [1].

Many physicians choose laser settings out of habit (or reading it off of a label attached to the side of the machine—a "cheat" sheet with skin-type specific parameters), using tissue endpoints to confirm the appropriateness of the parameters. For example, when treating a tattoo with a Q-switched laser, the operator looks for immediate frosty whitening. Like driving a car (where the operator may have no idea about nature of the drive train components), successful laser operation does not demand a complete understanding of the machine or the details of the light-tissue interaction. However, a comprehension of first principles allows for a logical analysis of final clinical outcomes—furthermore, more creative uses of equipment should follow. For example, with an education in laser tissue interactions (LTIs) and tissue cooling, one can deploy the alexandrite (long pulse) laser either as a hair removal device, vascular laser, or to remove lentigines [2].

The reader should note that although the title of this chapter is "Laser Tissue Interactions", the introduction of many new and diverse technologies make the term somewhat obsolete. We will continue to use the term, but a more appropriate term is "energy–tissue interactions." As both radiofrequency and ultrasound are increasingly applied in medicine. We will use both terms interchangeably in the remainder of the text.

Light

Light represents one portion of a much broader electromagnetic spectrum. Light can be divided into the UV (200–400 nm), VIS (400–700 nm), NIR "I" (755–810 nm), NIR "II" (940–1064 nm), MIR (1.3–3 μm), and Far IR (3 μm and beyond). On a macroscopic level, light is adequately characterized as waves. The amplitude of the wave is perpendicular to the propagation direction. Light waves behave according to our "eyeball" observations in day-to-day life. For example, we are familiar with refraction and reflection. The surface of a pond is a partial mirror (reflection); a fish seen in the pond is actually deeper than it appears (refraction) [3]. Normally, the percentage of incident light reflected from the skin surface is determined by the index of refraction difference between the skin surface (stratum corneum $n = 1.55$) and air ($n = 1$) [4]. This regular reflectance is about 4–7% for light incident at right angles to the skin [3, 5]. The angle between the light beam and the skin surface determines the % of reflected light. More light is reflected at "grazing" angles of incidence. It follows that, to minimize surface losses, in most laser applications, one should deliver light approximately perpendicular to the skin [3, 6]. One can deliberately angle the beam, on the other hand, to decrease penetration depth and also attenuate the surface fluence by "spreading" the beam. One can reduce interface losses by applying an alcohol solution (n = 1.4), water (n = 1.33), or a sapphire crystal (n = 1.55 μm). This allows for optical coupling (vide infra). On the other hand, the surface of dry skin reflects more light because of multiple skin–air interfaces (hence the white appearance of a psoriasis plaque).

Light penetrates into the epidermis according to wavelength dependent absorption and scattering (vide infra) [1, 6–8]. Because of scattering, much incident light is remitted (remittance refers to the total light returned to the environment due to multiple scattering in the epidermis and dermis, as well as the regular reflection from the surface). In laser surgery, light reflected from the surface is typically "wasted". This "lost" energy varies from 15% to as much as 70% depending on wavelength and skin type. For example, for 1064 nm, 60% of an incident laser beam may be remitted. One can easily verify this by holding a finger just adjacent to the beam near the skin surface. Warmth can be felt from the remitted portion of the beam.

To describe laser tissue interactions at the molecular/microscopic level, light is considered as a stream of "particles" called photons, where the photon energy depends on the wavelength of light.

$$E_{photon} = hc / \lambda \tag{1.1}$$

Where h is Plank's constant (6.6×10^{-34} J -s), and c is the speed of light (3×10^{10} cm/s) [9].

Types of Light Devices

In principle, many non-laser devices could be used for heating skin [9]. Most properties of laser light (i.e., coherence) are unimportant insofar as the way light interacts with tissue in therapeutic applications. And although collimation (lack of divergence) of the incident beam might increase the % of transmitted light with laser versus IPL, the increasing use of filtered flash lamps in dermatology suggests that losses from IPL beam divergence are not critical. In lieu of lasers, some thermal sources can be used in skin surgery (i.e., nitrogen plasma device) for resurfacing (Portrait, Rhytec, MA). The critical features of any device are controlling the device–tissue interaction time to allow for precise heating (vide infra).

Lasers are useful because they allow for precise control of where and how much one heats [10]. There are four properties that are common to all laser types (1) Beam directionality (collimation), (2) Monochromaticity, (3) Spatial and temporal coherence of the beam, and (4) High intensity of the beam [11]. The intensity, directionality, and monochromaticity of laser light allow the beam to be expanded, or focused quite easily. With non-laser sources like flashlamps directed toward the skin surface, the light intensity at the skin surface cannot exceed the brightness of the source lamp. With many lasers, a lamp similar to the intense pulsed light (IPL) flashlamp pumps the laser cavity [12]. The *amplification of light* within the laser cavity sets laser light apart from other sources.

For most visible light applications, laser represents a conversion from lamplight to an amplified monochromatic form [13]. The high power possible with lasers (especially *peak power*) is achieved through *resonance* in the laser cavity. For many dermatology applications requiring ms or longer pulses delivered to large skin areas, IPLs are either adequate or preferable to lasers. The scientific principle on which lasers are based is *stimulated emission*. With spontaneous emission, electrons transition to the lower level in a random process. With stimulated emission, the emission occurs only in the presence of photons of a certain energy. The critical point is maintaining a condition where the population of photons in a higher state is larger than that in the lower state. To create this population inversion, a pumping energy must be directed either with electricity, light, or chemical energy.

All lasers contain four main components, the lasing medium, the excitation source, feedback apparatus, and an output coupler. With respect to lasing media, there are diode lasers, solid-state lasers, dye, and gas lasers. Most solid state and dye lasers use optical exciters (lamps), whereas gas and diode lasers use electrical excitation (i.e., CO_2 and RF). The feedback mechanism consists of mirrors where one mirror reflects 100% and the other transmits a small fraction of light [14].

An example of a solid-state laser is the alexandrite laser. A solid-state laser consists of a rod that is pumped by a flashlamp. The lamp pumps the rod for stimulated emission. The rod and lamp assembly must also be designed for adequate cooling. Lasers typically are finicky because all of the components are driven near their damage thresholds (like redlining your car all the time). As an example of this concept, consider the pulsed dye laser (PDL). As the dye degrades, the lamps must work harder to generate higher pulse energies from the dye. Also, mirrors become contaminated over time such that the lamps must work harder and harder. These demands stress the power supply. Thus, eventually, the dye kit, the power supply, lamps, and dye are all working at their maximal output. Often people speak of a tunable dye laser. In fact many dye lasers are tunable; the manufacturers have simply chosen one wavelength. An example of a tunable laser was the Sclero-plus pulsed dye laser (tunable from 585 to 600 nm in 5 nm increments) from Candela (Candela, Wayland, MA).

Laser systems differ with regard to duration and power of the emitted laser radiation. In continuous wave lasers (CW mode) with power outputs of up to 10^3 W, the lasing medium is excited continuously. With pulsed lasers, excitation is effected in a single pulse or in on-line pulses (free-running mode). Peak powers of 10^5 W can be developed for a duration of 100 µs–10 ms. Storing the excitation energy and releasing it suddenly (Q-switch mode or mode-locking) leads to a peak power increase of up to 10^{10}–10^{12} W, and a pulse duration of 10 ps–100 ns [13].

Light emitting diodes (LEDs) are becoming commonplace in dermatology (Fig. 1.1). Primarily used as a PDT light source, they are also used in biostimulation. LEDs are similar to semiconductor (aka diode) lasers in that they use electrical current placed between two types of semiconductors. However, they lack an amplification process (no mirrors). LEDs do not produce coherent beams but can produce monochromatic light. Semiconductor (diode) lasers contain an LED as the active gain medium. A current passes through a sandwich of two layers consisting of compounds (called p type and n type). Below threshold, there is no oscillation and the semiconductor LASER acts like an LED. This emission is very similar to the visible emission of light emitting diodes. If one adds mirrors it operates as a tiny laser instead of an LED. The overall efficiency of semiconductor lasers is quite high, approximately 30% and among the highest available for any laser types. Most semiconductor (diode) lasers are operated in CW mode but can be pulsed. New visible light semiconductor lasers are available, and also laser diode arrays are available where scientists have created large numbers of semiconductor lasers on one substrate. Some diode lasers are housed separate from the handpiece and delivered by fiber optics. Others are configured with the laser diodes in the handpiece as arrays. Modern diode lasers achieve higher powers than in the past, but their peak powers are still lag behind most pulsed solidstate lasers [14].

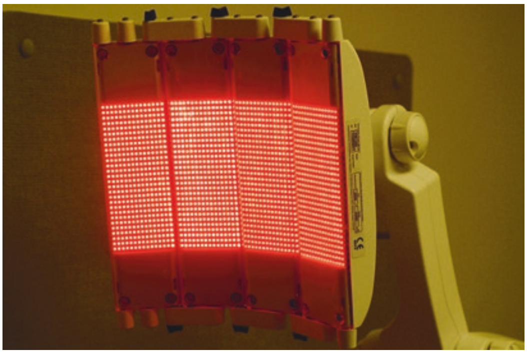

Fig. 1.1 A *red LED* (OmniLux, Phototherapeutics, Inc.)

Excimer lasers emit UV light and are used for photomodulation of the immune system. They have also been used in surgery. The possible mutagenicity of these lasers has not been well studied. Materials such as the KTP crystal can be used to generate harmonics with lasers. The KTP crystal is used to convert 1064 nm radiation to 532 green light. Also quality (Q) switching is used for generating short pulses. Much of the electrical energy used to create laser emissions is wasted as heat, which is why water is used for cooling most lasers. Air cooling is used for some high-powered flash lamps and many diode lasers. In the future, free electron lasers might be useful but presently they are too cumbersome and only generate small amounts of energy per unit wavelength.

Intense pulsed light devices are becoming increasingly comparable to lasers that emit ms domain pulses [15]. Absorption spectra of skin chromophores show multiple peaks (HgB) or can be broad (melanin) [16], and therefore a broadband light source is a logical alternative to lasers. Proper filtration of a xenon lamp tailors the output spectrum for a particular application. Some concessions are made with direct use of lamplight. For example, rapid beam divergence obliges that the lamp source be near the skin surface. This subsequent requirement makes for a typically heavier handpiece compared with most lasers (Fig. 1.2) (the exception being some diode arrays where the light source is also housed in the handpiece-(i.e., Light Sheer, Lumenis, CA)). Also IPL cannot be adapted to fibers for subsurface delivery. High energy short pulses (Q-switched ns pulses) are not possible with flashlamps. They can, however, be used to pump a laser, and some modern IPLs feature a laser attachment where the flashlamp and laser rod are in the handpiece. In general, the size, weight, and cost of both laser and flashlamp technology are steadily decreasing.

Light Device Terminology

Basic parameters for light sources are power, time, and spot size for continuous wave lasers, and for pulsed sources, the energy per pulse, pulse duration, spot size, fluence, repetition rate, and the total number of pulses [17]. Energy is measured in joules (J). The amount of energy delivered per unit area is the fluence, sometimes called the dose or radiant exposure, given in J/cm^2. The rate of energy delivery is called power, measured in watts (W). One watt is one joule per second (W = J/s). The power delivered per unit area is called the irradiance or power density, usually given in W/cm^2. Laser exposure duration (called pulse width for pulsed lasers) is the time over which energy is delivered. Fluence is equal to the irradiance times the exposure duration [10]. Power density is a critical parameter, for it

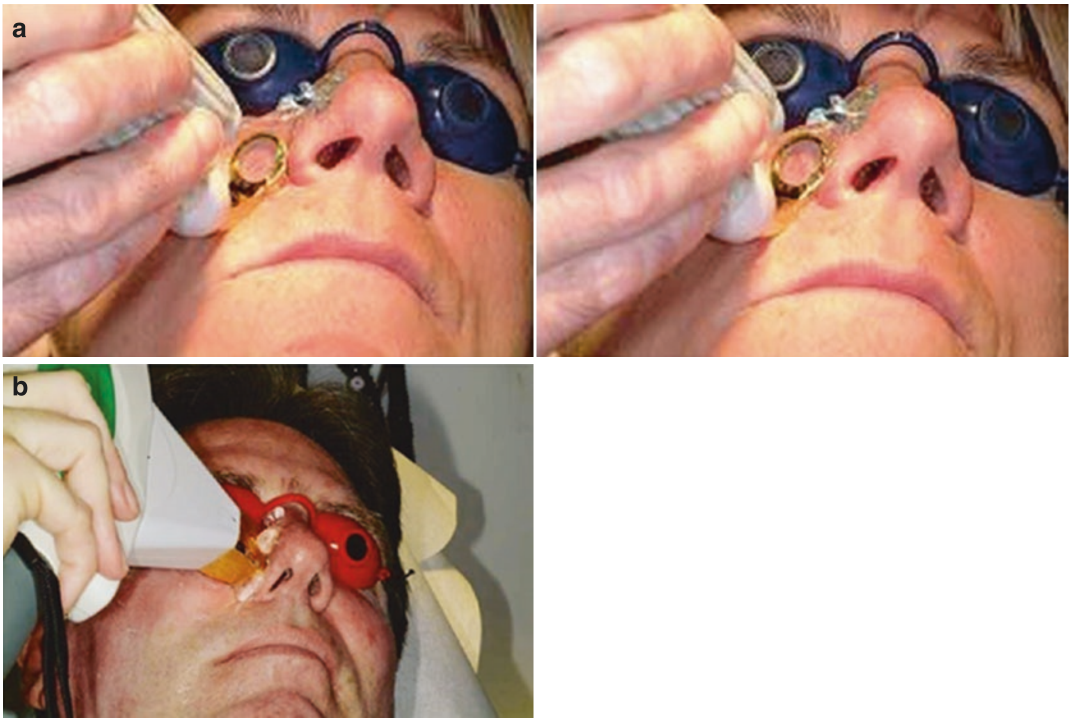

Fig. 1.2 IPL and *green light laser*—note smaller size of laser handpiece

often determines the action mechanism in cutaneous applications. For example, a very low irradiance emission (typical range of 2–10 mW/cm^2) does not heat tissue and is associated with diagnostic applications, photochemical processes, and biostimulation. On the other extreme, a very short ns pulse can generate high peak power densities associated with shock waves and even plasma formation [18]. Plasma is a "spark" due to ionization of matter.

Another factor is the laser exposure spot size (which can greatly affect the beam strength inside the skin). Other characteristics of importance are whether the incident light is convergent, divergent, or diffuse, and the uniformity of irradiance over the exposure area (spatial beam profile). The pulse profile, that is, the character of the pulse shapes in time (instantaneous power versus time) also affects the tissue response [19].

Many lasers in dermatology are pulsed, and the user interface shows pulse duration, fluence, spot size and fluence. Some multi-wavelength lasers also allow for wavelength selection. Some older lasers, for example a popular CO_2 laser, showed only the pulse energy on the instrument panel, or in continuous wave (CW) mode, the number of watts. In these cases one uses the exposure area and exposure time to calculate the total light dose (fluence).

$$\text{Fluence} = \frac{\text{Power} \times \text{time}}{\text{area}} \tag{1.2}$$

With the exception of PDT sources and CW CO_2 lasers, most aesthetic lasers create pulsed light. In many CW applications (i.e., wart treatment with a CO_2 laser), the fluence is not of great importance in characterizing the overall tissue effect. A more important parameter is power density (where higher power densities achieve ablation and lower power densities cause charring), and the physician stops the procedure when an appropriate endpoint is reached. On the other hand, in PDT applications with CW light where the clinical endpoint might be delayed, the total fluence *and* power density are important predictors of the tissue response.

In CW mode, CO_2 lasers are used with a focusing (noncollimated) handpiece such that the physician can control spot size and tissue effects simply by moving the handpiece tip toward or away from the skin. The subsequent rapid changes in power density offer "on the fly" flexibility and control.

A thorough knowledge of a specific laser's operation and quirks is imperative for optimal and "safe" lasering. Vendors are creating lasers that are more intuitive to operate. Increasingly, manufacturers have added touch screen interfaces with application-driven menus and skin-type specific preset parameters. Some devices permit patient laser parameters to be stored for future reference. Most lasers are designed such that the handpiece and instrument panels are electronically interfaced. It follows that the laser control module "knows" what spot size is being used. Typically this "handshake" occurs when one inserts the handpiece into the calibration port, or through a control cable from the handpiece to the laser "main frame". With others, one selects the spot-size on the display, and the laser calculates the fluence accordingly. For example, one of our erbium YAG lasers possesses interchangeable lenses for 1, 3, 5, and 7 mm spots. However, there is no feedback from the handpiece to the laser control board. The user "tells" the laser which lens cell is inserted, and the laser calculates the fluence based on the selected spot and selected pulse energy. In this case, if one changes the spot size (for example, by exchanging the 7 mm for the 3 mm lens cell), the laser still "thinks" the 7 mm spot is being used, and the actual surface fluence is now ~5× the fluence on the panel. The resulting impact on the skin surface (the wound depth and diameter) should alert the enlightened user to reassess his parameter selection.

Most lasers calibrate through a system where the end of the handpiece is placed in a portal on the base unit (Fig. 1.3). This configuration allows for interrogation of the entire system, from the "pumping" lamps to the fiber/articulated arm to the handpiece optics. For example, if a fiber is damaged, the laser will fail calibration, and an error message appears. Other systems measure the output within the distal end of the handpiece using a small calibration module that "picks off" a portion of the beam.

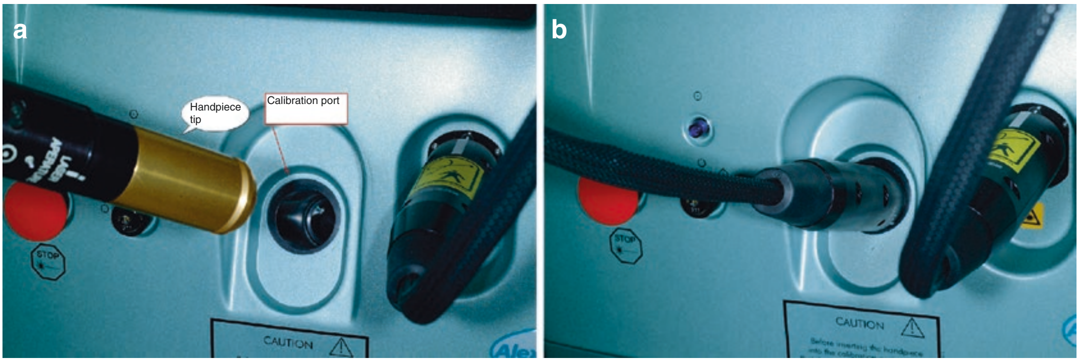

Fig. 1.3 Figures show handpiece before and during insertion into calibration port of a Q switched alexandrite laser

There are some simple ways to interrogate for system integrity. One can examine the aiming beam as it illuminates a piece of white paper, checking that the beam edges are sharp—this suggests that the treatment beam is also sharp and the profile is according to the manufacturer's specifications. Also, burn paper can be used—here the laser is used with a low energy and the spot is checked for uniformity from beam edge to edge. By checking the impact pattern, one can uncover damaged mirrors in the knuckle of the articulated arm, or a damaged focusing lens that renders the laser unstable or unsafe. Likewise, for scanners, one can ensure that skin coverage will be uniform.

1. LEDs are becoming commonplace in biomedical applications
2. Solid state lasers generally achieve the largest peak powers among laser types
3. The laser operator should know every nook and cranny of a laser's features to optimize patient outcomes and safety
4. Power density determines the mechanism for many LTIs

Beam Profiles: Top Hat Versus Gaussian

Laser beam profiles vary based on intercavity design, lasing medium, and the delivery system. A common profile is Gaussian or bell-shaped. For many lasers, this profile represents the fundamental optimized "mode" of the laser. This shape is usually observed when the beam has been delivered through an articulated arm. For some wavelengths, this is an effective way to deliver energy (CO_2 and erbium). The disadvantage of the rigid arm is limited flexibility, the typically short arm length, the possibility of misalignment from even minor impact, and a tendency for non-uniform heating across the spot [20]. For example, in treating a lentigo with a Q-switched alexandrite laser equipped with a rigid articulated arm, one may observe complete ablation of the epidermis at the center of the "spot", but only whitening at the periphery. On the other hand, sometimes a bell-shaped profile is desirable, for example, when applying a small spot FIR beam with a scanner. In this scenario, the wings of the beam allows for some overlap without delivering "too much" energy at points of overlap.

The Gaussian profile can be modified outside the cavity, which is desirable in many applications. With a fiber equipped delivery system, the beam is mixed within the fiber and can be shaped to be more flat-topped. The lentigo then is more likely to be uniformly heated (so long as the lesion itself if uniformly colored!). Although fiber delivery systems are usually preferred by physicians, some laser beams are difficult to deliver through a fiber. Examples include far IR wavelengths and very short pulses (i.e., few ns with typical Q switched Nd YAG lasers whose high peak power exceeds the damage threshold of most fibers).