Optical Properties of Human Skin

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Despite the many years since optical spectra from human skin were first obtained, only recently have quantitative models of cutaneous optics been applied. This chapter aims to present the optics of human skin conceptually and quantitatively, to examine the structures and pigments that modify cutaneous optics, and to discuss current research in this area and its applications to photomedicine. Introductory sections on the structure of skin and on optical phenomena in turbid media are included in addition to the general introduction below. This chapter does not offer an exhaustive review of all studies related to the optics of human skin, but attempts to include those reliable studies pertinent to its goals. The interested reader can find thorough and more historical reviews in (1–3).

Unlike most other organs, the skin is accessible for visual inspection. Consequently, humans have learned to judge each other, in part, on the basis of pigmentation, texture, and cosmetic appearance of skin. The accessibility of skin often allows the dermatologist to diagnose and follow its condition simply by visual inspection. Specific local or generalized changes in skin color are most often due to abnormal structures or depositions of pigmented substances within the skin. As such, an understanding of the optical properties of the skin is helpful in explaining such changes and can be useful in diagnosis of skin or systemic disease. Quantitative optical measurements of skin in vivo can be used to quantify, monitor, and diagnose certain cutaneous and systemic conditions. For example, in phototherapy or photochemotherapy, in vivo spectral measurements of diffuse reflectance (remittance) can quantify
the vascular and pigmentary responses of skin, and might also be used as an aid in determining optical dosimetry. Neonatal serum bilirubin levels can be monitored noninvasively by a similar technique. Patterns of visible auto-fluorescence of pigmented skin can be used to deduce the locality of abnormal quantities of melanin pigmentation.

In addition to making such diagnostic techniques feasible, a quantitative understanding of the optics of skin yields knowledge of the optical radiation doses received by different cell layers within the skin, by cutaneous blood, and by internal organs, when humans are exposed to optical radiation. Different wavelengths across the optical spectrum, defined here as approximately 250 nm in the ultraviolet to approximately 3000 nm in the infrared, reach vastly different depths within tissue. Because most photobiologic effects are both wavelength- and dose-dependent, the rational design and explanation of the effects of various phototherapies require knowledge of internal optical dosimetry. Our rapidly increasing knowledge of cellular and molecular photobiology gained from in vitro bacterial and tissue culture studies can in theory be related to observed responses of cells in situ by comparing the dose-related effects of optical radiation in vitro to those in vivo. Conversely, on the basis of knowing the practical upper limits of spectral radiant exposure doses experienced by cell layers, blood, or other structures in vivo, one can then concentrate on basic studies of repair, mutation, and metabolic changes induced by equivalent doses in vitro. The use of laser irradiation for selective thermal destruction of optically absorbing structures in skin, and control of the tissue depth affected by various forms of photochemotherapy, are examples in which understanding cutaneous optics allows selectivity and control of the damage induced.

Describing “the” optics of human skin is somewhat like describing “the” weather; it can be measured and understood, but cannot be considered static. The skin is a highly dynamic organ capable of withstanding, and mounting protective responses to, a host of deleterious environmental treatments and agents. As such, the optical properties of skin are also dynamic. Many different physical structures and chromophores (optically absorbing molecular structures) within different layers of the skin influence its optical properties over different spectral regions. Changes in vasodilatation, vascular permeability, oxygenation of cutaneous blood, bile pigments, carotenoids, melanin pigmentation, and thickness of any of the various layers of skin affect cutaneous optics. The simple act of bathing alters the optics of the stratum corneum to make one more sensitive to certain ultraviolet wavelengths. A 10-min exposure on a sunny day is sufficient in many persons to cause immediate pigment darkening—a photochemical oxidation reaction of melanin—subsequent delayed hyperpigmentation (tanning), and epidermal hyperplasia. Systemic and cutaneous pathologic conditions can markedly alter cutaneous optics as well.