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Using Light in Dermatology: An Update on Lasers, Ultraviolet Phototherapy, and Photodynamic Therapy

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It was just over a century ago that Niels Finsen was awarded the 1903 Nobel Prize in Medicine for establishing the scientific basis for using light to treat skin disease [1]. Despite the medical use of light in dermatology throughout the twentieth century, the fundamental mechanisms of action for its therapeutic effects have been systematically explored and clinically exploited only in the last couple of decades. This article highlights some of the most important advances in therapeutic photomedicine over the last decade with a focus on lasers, intense pulsed light (IPL), ultraviolet light (UV) phototherapy, and photodynamic therapy (PDT). Although these treatment modalities have each evolved quite independently of the others, there has been a convergence of interests among clinical practitioners and investigators who use light to treat diseased skin. For example, two very different photonic approaches have been introduced into clinical practice based on the concept that selective wavelengths within the UV light B (UVB) region are more effective for treating psoriasis: narrowband fluorescent lamps and pulsed excimer lasers. What unifies these two examples, and any other dermatologic light sources, is the fact that in essence all they really do is deliver external energy to the skin for therapeutic purposes. Regardless of the device or dermatologic indication, specific biophysical laws govern how all light affects the skin.

The key to developing and refining any type of light-based therapy is to understand how to deliver this energy to cutaneous structures efficiently and effectively in a highly targeted fashion so as to limit collateral light-induced damage to normal tissue. Treating the skin with light can be considered in two stages: understanding how selectively to deliver photons to specific structural targets in the skin (ie, tissue optics), and understanding the biologic processes that occur after a skin target absorbs light photons (ie, photobiologic reactions). Most refinements to phototherapeutic devices exploit either one or both of these two aspects, and the advances highlighted in this article are discussed using this mechanistic perspective.

Understanding tissue optics and photobiologic reactions

A detailed explanation of tissue optics and photobiologic reactions is beyond the scope of this article, but certain basic biophysical principles warrant a brief summary. The interaction of light with tissue is governed by three basic processes that can occur when a photon of light reaches the skin: (1) reflection, (2) scattering, and (3) absorption. Light that is reflected from the skin and perceived by the

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human visual system provides the means for diagnosing skin disease, but reflected light does not itself result in any direct therapeutic effect. In the absence of an absorption event (see later), the forward propagation of light deeper within the skin is influenced by the degree to which its direction of travel has been scattered by tissue structures. Tissue scattering of UV, visible, and near infrared light is wavelength-dependent, and in general longer wavelength light penetrates the skin more deeply. Targets that are deeper in the skin require the use of devices that can deliver longer wavelength light.

Absorption is an important biophysical event that involves the transfer of energy from light to tissue. Without photon absorption, energy is not taken up by the skin and no biologic or therapeutic effect occurs. The absorption of photons by specific molecules within the skin also influences light penetration because any photon that is absorbed is no longer capable of propagating through the skin, because that particular photon no longer exists. Like scattering, absorption is wavelength-dependent, but in a somewhat more complicated manner because it depends on the absorption profile or "spectrum" of the light-absorbing molecule, which in this context is usually referred to as the "chromophore." With the possible exception of UVB phototherapy the specific chromophores for most light-based therapies are precisely known and include hemoglobin; melanin; water; exogenous dyes (ie, tattoo pigment); and photosensitizing drugs (ie, psoralens and PDT photosensitizers). It is ironic that although UVB light is the oldest and most widely used form of phototherapy, the precise chromophore and subsequent biologic tissue reactions for this modality remain unclear at this time.

In summary, both scattering and absorption determine the depth to which light penetrates the skin, but only absorption can lead to photobiologic and phototherapeutic effects. All phototherapeutic applications must by definition be mediated by chromophores present in the skin. For a given photon to have a clinical effect it must actually reach the target structure within the skin and then be absorbed by a specific chromophore within that target. Whether or not these events occur and the degree to which they occur is dependent on the wavelength of light used, the structure of the skin, the presence and location of chromophores, and the preferential ability of diseased tissue to absorb light more efficiently than normal unaffected skin. In clinical parlance, there is often an undue preoccupation with the technical specifications for a given light device rather than a well-grounded understanding of the desired underlying photobiologic and phototherapeutic end points. The reality is that for any clinical indication a multiplicity of possible photonic devices are often available. This simply reflects the fact that from the point of view of the tissue and its chromophores, the exact source of the photons (eg, laser versus IPL versus light-emitting diode versus fluorescent lamp) matters far less than whether the photons are of the appropriate wavelength and delivered to the target in sufficient quantity to cause irreversible tissue changes. As with any therapeutic modality, the ultimate arbiters for the bewildering array of competing light-based therapies and devices are well-designed and rigorously executed controlled clinical studies.

Once the photon is absorbed by the chromophore, the source's light energy is transferred to the skin either to generate heat or drive photochemical reactions. The former scenario encompasses most lasers and IPLs in dermatology, all of which in essence involve the selective and irreversible alteration of tissue using heat [2]. In contrast, UV phototherapy and PDT do not primarily involve the use of light to generate heat, but rather rely on photon absorption to energize photochemistry. In the case of UV therapy it is now generally accepted that the therapeutically useful photochemical reactions culminate in cutaneous immunosuppression, although the exact sequence of reactions is less clear. In PDT the first two photochemical reactions are very clearly defined. The energy of the excited chromophore is first transferred to molecular oxygen to form singlet oxygen, which then reacts with a diverse range of biomolecules. The everexpanding indications for PDT partly mirrors the multiple ways by which singlet oxygen generated by light can affect the skin.

Using lasers and intense pulsed light to heat the skin

Because most lasers in dermatology are used precisely to heat the skin, the advances for these applications are related to increasing the selectivity of these devices by fine tuning the wavelength and pulse duration (ie, the time over which the laser energy is delivered) [3], and simultaneously cooling the skin during light exposure. These modifications have increased the safety and efficacy for photothermal lasers in dermatology, particularly for targeting larger or deeper skin structures, such as larger blood vessels and hair follicles. Another driving force in the evolution of lasers and IPL has been the need to minimize downtime from postprocedure purpura and elaborate wound care protocols.