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Abstract The effects of light on skin are due to various degrees of absorption of electromagnetic radiation. The visible light spectrum has a 400–760 nm wavelength. The light-tissue interaction effects are due to absorption and excitation of photons. The Intense Pulse Light is situated in the visible light of the electromagnetic spectrum. Once the light reaches the skin, part of it is absorbed, part is reflected or scattered, and part is further transmitted. Selective photothermolysis is the basic principle of Intense Pulsed Light treatment. It consists of matching a specific wavelength and pulse duration to obtain optimal effect on a target tissue with minimal effect on the surrounding tissues. The structures of the tissue that absorb the photons are known as chromophores. They have different wavelengths of absorption. The most common chromophores encountered in the skin are: hemoglobin and its derivatives, melanin, water and foreign pigmented tattoos. The main target structures for Intense Pulsed Light treatment are melanin and blood vessels. The fluence delivered to the chromophores must be high enough to destroy them. In order to enhance the photodynamic therapy effect which is based on selective photothermolysis, photosensitizers can be used as adjuvants.

The effects of light on skin are due to various degrees of absorption of electromagnetic radiation (EMR). The EMR represents the fundamental form of energy having wave and particle properties. According to Planck's law, long wavelength photons carry less energy than short wavelength photons. The EMR includes radio-waves, microwaves, infrared radiation, visible light, ultraviolet radiation and x-rays (Fig. 2.1). EMR is generally classified according to wavelength. The visible light spectrum has a 400–760 nm wavelength. The light-tissue interaction effects are due to absorption

Fig. 2.1 Electromagnetic spectrum (Printed with permission of Lumenis company, Yokneam, Israel)

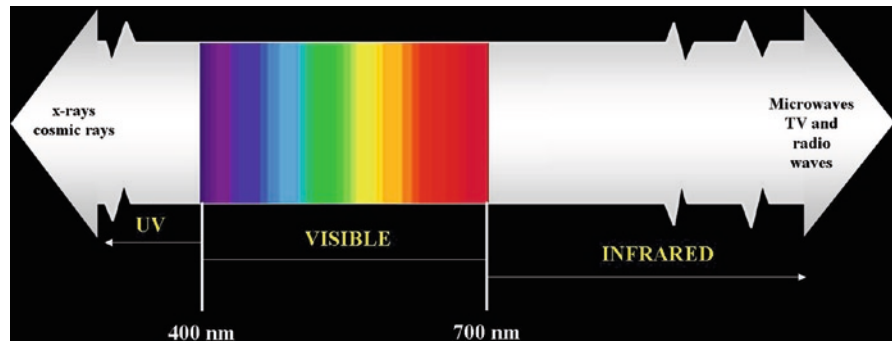
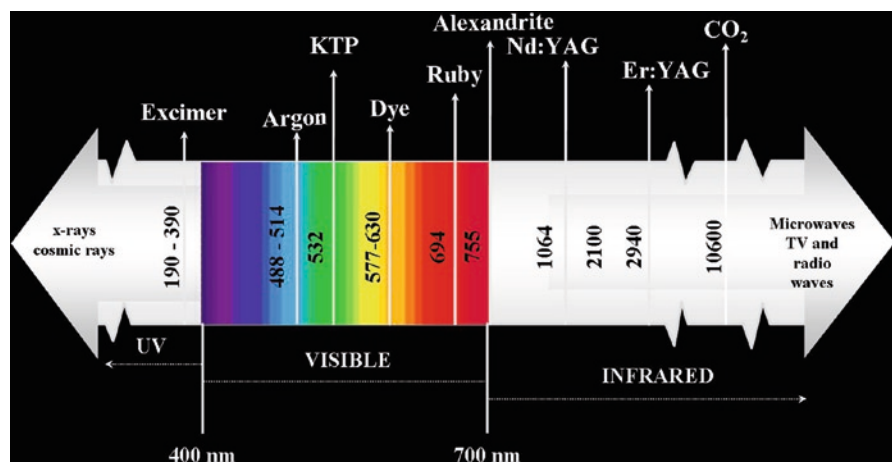


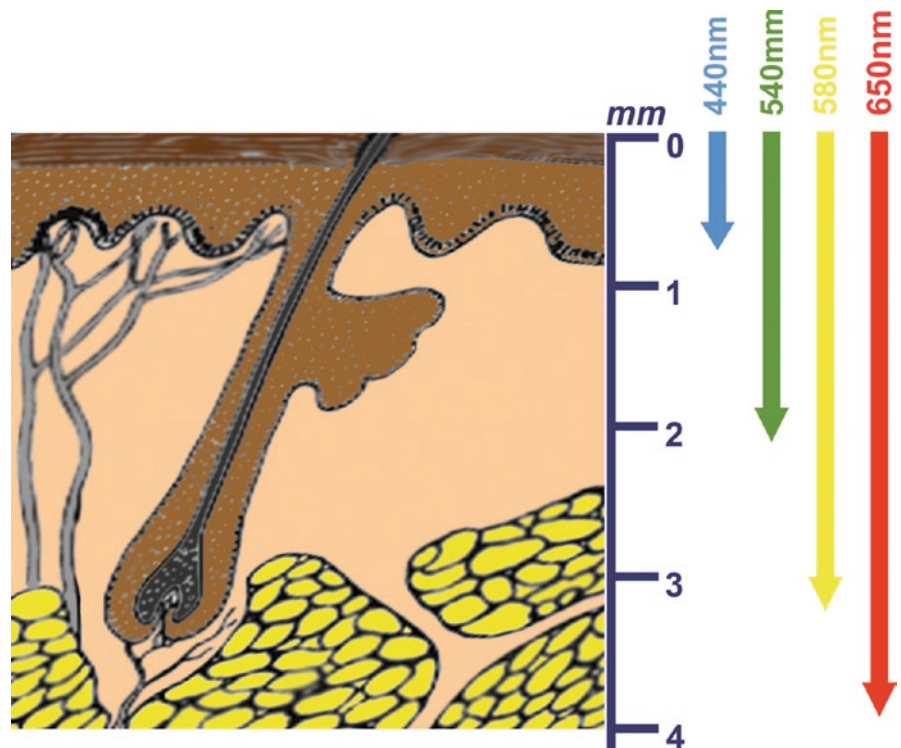
Fig. 2.2 Visible light spectrum (Printed with permission of Lumenis company, Yokneam, Israel)



and excitation of photons. The Intense Pulse Light is situated in the visible light of the electromagnetic spectrum (Fig. 2.2). To understand the effects of light on tissue, it is necessary to define some terms:

- *Fluence* (F) represents the amount of energy measured in Joules (J) per unit area, measured in cm^2 : $F = \text{J}/\text{cm}^2$.
- *Power* measured in watts (W) represents the amount of energy delivered over a certain period of time: $W = \text{J}/\text{s}$.
- *Thermal relaxation time* (TRT) is the time necessary for an object to cool down to 50% of its original temperature. TRT is further detailed in this chapter.
- *Wavelength* influences selective light absorption by a certain target and also influences the depth of tissue penetration (Fig. 2.3). The majority of light systems have different filters which allow certain wavelengths to enter the tissue, thus producing the selection of the desired light spectrum.
- *Footprint* (device spot) size has an important role in light penetration into the tissue. When a small spot size is used for light emission, only a small part will reach the deep target structures (Fig. 2.4a, b). A larger footprint offers a more planar geometry of light penetration and better efficacy (Fig. 2.5) (Keijzer et al. 1989). A spot size of about 7–10 mm is needed for maximal light penetration to the mid-dermal structures. The bigger the spot, the deeper the level of penetration (Carroll and Humphreys 2006).
- *Pulse duration*. Light can be delivered in a pulsed or continuous wave. The intense pulsed light devices

Fig. 2.3 Depth of light penetration into the skin, at various wavelengths



are based on pulsed delivery that allows more selective tissue damage. Pulse duration represents the time of exposure to the light beams. Laser and pulsed light systems enable the selection of pulse duration, which is influenced by the TRT of the target.

- *Pulse delay* represents the time that allows the skin and blood vessels to cool down between pulses, while the heat is retained inside the targets. When the pulse is shorter than the thermal relaxation time (TRT), the heat will act mainly on the target structures. When the pulse is longer than the TRT, the heat will be conducted to the surrounding structures. It is recommended that the pulse timing be higher than the skin cooling time to avoid damage to the surrounding structures.

2.1 Heating

Heating is one of the effects induced by light absorption. It is not uniformly distributed inside the skin. This process is more representative around the

target cells. The temperature is directly related to the excitation of molecules. As the temperature is raised, different changes take place at the molecular level. DNA, RNA and some proteins are affected by the heat which causes them to unwind or even melt at varying temperatures. The final result would be denaturation and coagulation of the above-mentioned structures. These effects are dependent on temperature and length of exposure. Depending on the target tissue, the light-tissue interactions will cause tissue necrosis, blood coagulation and structure alterations. Some of the heating effects are beneficial at the level of the target tissues but are dangerous to the surrounding tissue. This should always be kept in mind when choosing the treatment parameters.

The coagulation damage depends not only on the temperature but also on the exposure time. For instance, a high temperature and a short exposure can be less aggressive than a lower temperature with a longer period of exposure. The dermis, being rich in collagen and elastin, is more thermally stable than the epidermis, mainly due to elastin properties.

Fig. 2.4 (a) Light distribution of a small spot. (b) Light distribution of a large spot (Printed with permission of Lumenis company, Yokneam, Israel)

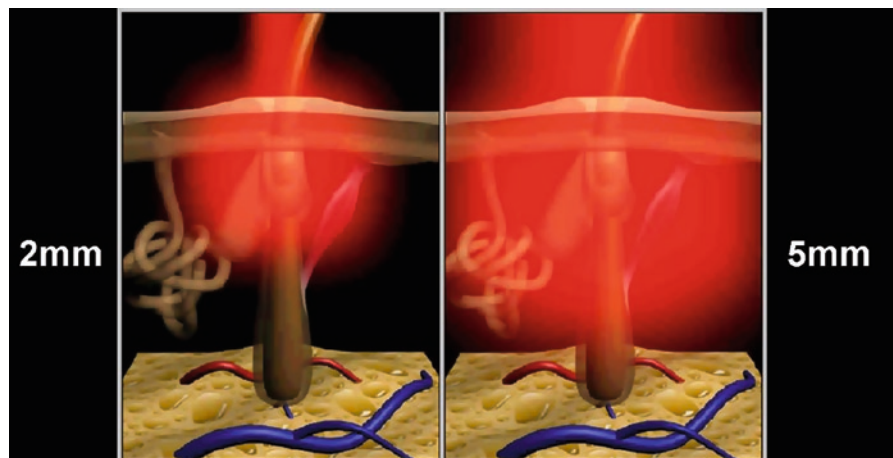
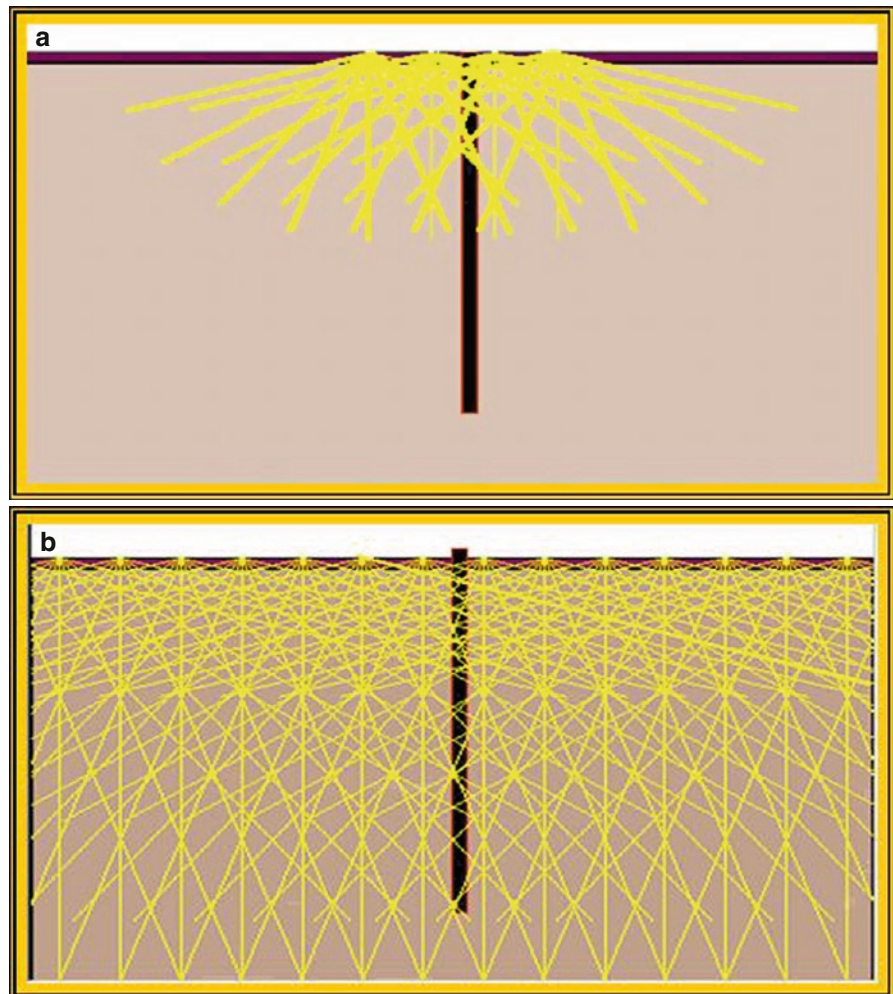


Fig. 2.5 Deeper light penetration using a large footprint (Printed with permission of Lumenis company, Yokneam, Israel)

2.2 Skin Properties Regarding Light-Tissue Interaction

Once the light reaches the skin, part of it is absorbed, part is reflected or scattered, and part is further transmitted. The scattering process takes place when the photon particles change the direction of propagation (Fig. 2.6a). This phenomenon takes place inside the skin where different structures have different indices of refraction. The scattering effect makes the light spread out and limits the depth of light penetration. It seems that the dermal collagen is responsible for most of the scattering. The amount of scattering is inversely proportional to the wavelength of the light (Herd et al. 1997). Some (4–7%) of the light is reflected, this phenomenon being produced by a change in the air and stratum corneum refractive index. The amount of light that is reflected decreases with the decreasing angle of incidence (Fig. 2.6b). The least reflection occurs when the light is perpendicular to the tissue. A very small amount of light is further transmitted (Fig. 2.6c). It has been proved that transmission of the light varies according to the skin type (Everett et al. 1966). The white dermis transmits from about 50% at 400 nm to 90% at 1,200 nm, while the black epidermis transmits less than 40% at 400 nm and 90% at 1,200 nm. In

general, there is a gradual increase in skin penetration at longer wavelengths. Most of the light is absorbed by the skin (Fig. 2.6d). This phenomenon is responsible for the desired effects on the tissue. The structures of the tissue that absorb the photons are known as chromophores. They have different wavelengths of absorption. The most common chromophores encountered in the skin are: hemoglobin and its derivatives, melanin, water and foreign pigmented tattoos (Fig. 2.7). Once the light is absorbed, the chromophores become excited. For wavelengths varying from 300–1,200 nm, melanin is the dominant absorbent.

Light-tissue effects can be grouped in:

- *Photothermal* – represented mainly by coagulation or vaporization of tissue based on absorption
- *Photomechanical* – tissue disruption often encountered by pulsed laser beams
- *Photochemical* – direct breakage of chemical tissue bonds or chemical interaction with an applied drug
- *Photobiostimulation* – tissue stimulation with very low level laser light
- *Selective photothermolysis* – The concept of photothermolysis was introduced for the first time by Parrish and Anderson in 1983 (Anderson and Parrish 1983). According to their description,

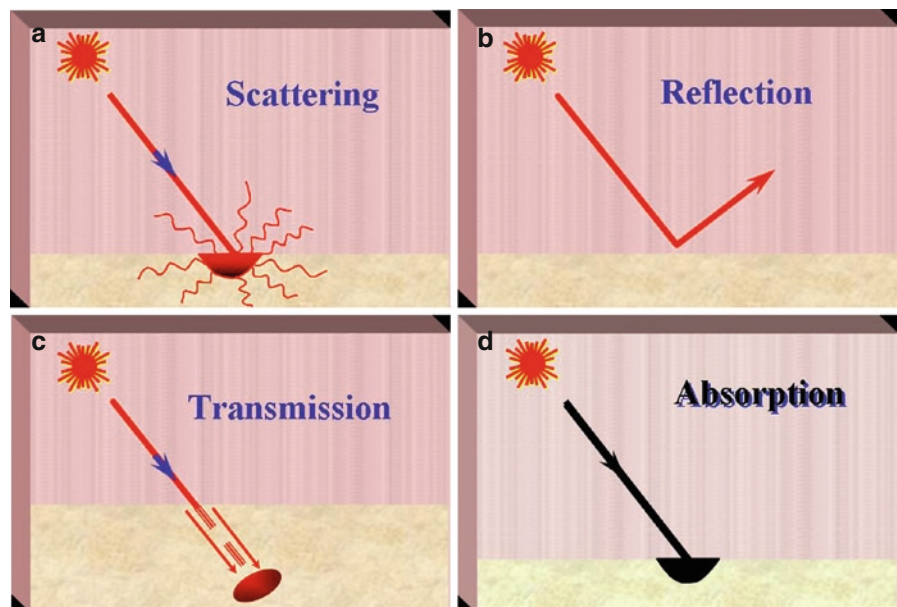
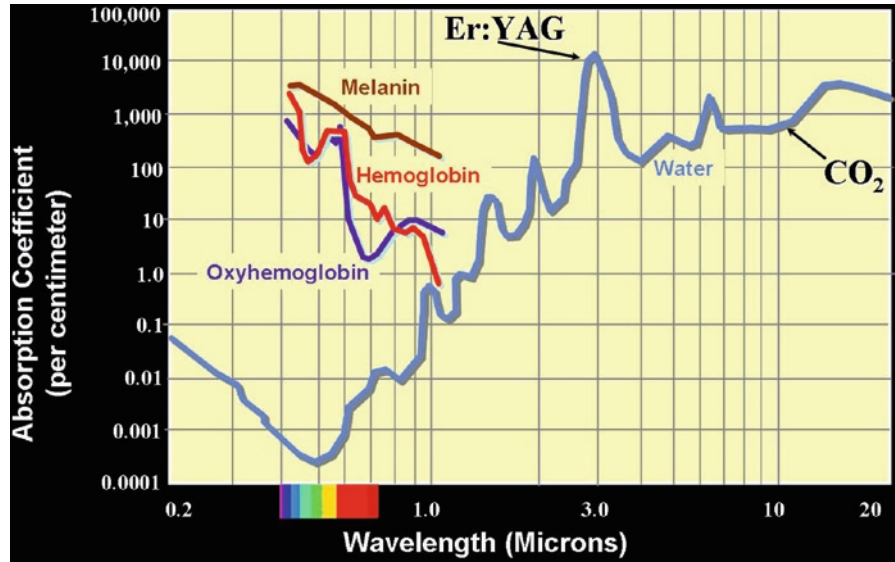


Fig. 2.6 (a) Scattering effect (printed with permission of Lumenis company, Yokneam, Israel). (b) Reflection of the light (printed with permission of Lumenis company, Yokneam, Israel). (c) Light transmission (printed with permission of Lumenis company, Yokneam, Israel). (d) Light absorption (printed with permission of Lumenis company, Yokneam, Israel)

Fig. 2.7 Light absorption for different chromophores (Printed with permission of Lumenis company, Yokneam, Israel)



three effects are necessary to produce selective photothermolysis:

- Absorption of a specific wavelength by the target structures
- The exposure time should be less than or at least equal to the time of cooling of the target structures
- There is a need for enough fluence to produce a damaging temperature within the target structures

The main target structures for Intense Pulsed Light treatment are melanin and blood vessels (Fig. 2.8a, d). To understand the relation between exposure time and extent of thermal damage, it is important to detail the “thermal relaxation time” (TRT). This represents the time required to cool a small target structure. The cooling is achieved by conduction, convection and radiation. Conduction is the main component of cooling.

Smaller objects cool faster than larger objects. The TRT is proportional to the square of the size (van Gemert and Welch 1989).

$$T = d^2 / k\alpha$$

Where: T = relaxation time

D = size of the heated object

α = thermal diffusivity (about 2×10^{-3} cm²/s for dermis)

K = geometrical factor (for a cylindrical object is 16)

To allow enough time for the epidermis and other skin structures to cool down, the pulse duration should be shorter than the cooling time of the target but longer than the cooling time of the skin. This has clinical implications especially for hair removal. The hair follicles are grossly grouped as coarse and fine. They have different sizes and consequently different TRTs. An epidermal thickness of 0.1 mm has a TRT of about 1 ms while a vessel of 0.1 mm has a TRT of about 4 ms (Goldman et al. 2005). A vessel three times bigger (0.3 mm) has a TRT of approximately 10 ms. Larger structure targets cool down slower and need increased delay time and multiple pulsing. Theoretically, most vessels smaller than 0.3 mm require only a single pulse. It is recommended that pulses be spaced at 10 ms or longer to accommodate normal epidermal TRT (Goldman et al. 2005). Patients more prone to thermal injuries should have at least 20–30 ms of TRT.

When the pulse width is greater than the TRT, non-specific thermal damage occurs because of heat diffusion. The fluence delivered to the chromophores must be high enough to destroy them.

In order to enhance the photodynamic therapy effect which is based on selective photothermolysis, photosensitizers have been introduced as adjuvants. There are topical and systemic photosensitizers. The first generation of photosensitizers was developed about 30 years ago and belongs to the porphyrin family. 5-aminolevulinic acid (ALA) and methyl aminolevulinic acid (MAL)

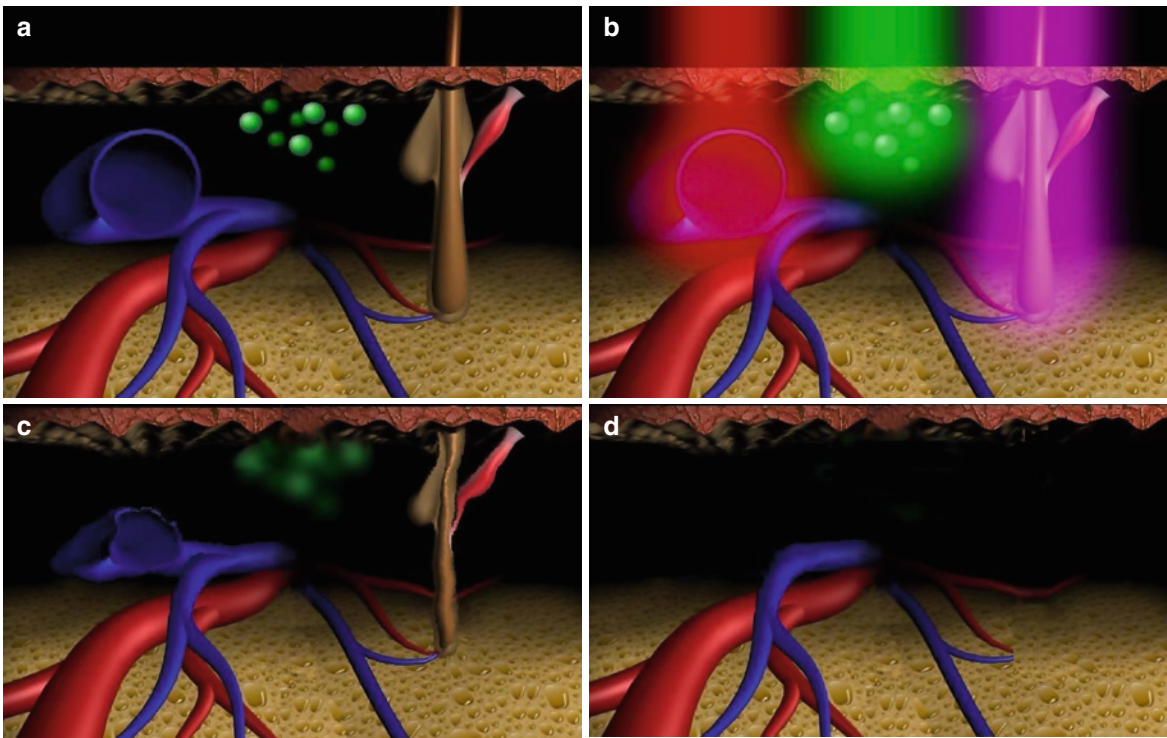


Fig. 2.8 (a) Various chromophores in the skin (printed with permission of Lumenis company, Yokneam, Israel). (b) Light interaction with various chromophores (printed with permission of Lumenis company, Yokneam, Israel). (c) Immediate response to

light–tissue interaction (printed with permission of Lumenis company, Yokneam, Israel). (d) Late response with destruction of the chromophores (Printed with permission of Lumenis company, Yokneam, Israel)

are the most common sensitizers. Second generation photosensitizers have the advantage of having a limited effective period. ALA is not a photosensitizer by itself, but it is metabolized to photosensitizing protoporphyrin IX (Piacquadio et al. 2004). The spectrum of absorption of protoporphyrin IX is in the visible spectrum. The peak of absorption is 405 nm (Nyman and Hynninen 2004). Systemic sensitizers are administered intravenously since they do not penetrate the skin. Hematoporphyrin and photofrin have been thoroughly studied (Nyman and Hynninen 2004) with regard to their peak of absorption. Applications of these photosensitizers in association with Intense Pulse Light may increase the efficacy of the treatment (Marmur et al. 2005). This concept of combining light with a photosensitizing agent known as photodynamic therapy has wider applications, including tumor treatment (Pervaiz and Olivo 2006).

2.3 Chromophores of Human Skin

The human skin has several major ultraviolet radiation absorbing endogenous chromophores. Among them are urocanic acid, aminoacids, melanin and its precursors. The chromophore identification can be done by action spectroscopy. Theoretically, an action spectrum for a given photobiological endpoint will be the same as the absorption spectrum of its chromophore. The skin chromophores have an overlying spectra (Young 1997). From all chromophores present in the skin, the melanin and hemoglobin with its derivatives are the most important regarding light pulsed treatment.

The term melanin is widely used to describe the skins red-brown pigment which resides in the epidermis. The biosynthesis of melanin within melanocytes is a complex process and is incompletely understood.

It is believed that they are polymers with multiple-monomer units linked by non-hydrolysable bonds (Young 1997). There are two major classes of natural melanins: the black-brown eumelanin and the yellow-red pheomelanin. They are differentiated by their molecular building blocks (Wakamatsu and Ito 2002; Ye et al. 2008). Eumelanin is the dominant pigment.

Human skin coloration is dependent on spatial distribution of the melanin and haemoglobin chromophores (Anderson and Parrish 1981; Zonios et al. 2001). Eumelanin plays a fundamental role in skin appearance and photoprotection. A weak correlation was noticed between the scattering properties of skin and tissue type with the average scatter size higher in patients with higher melanin content (Zonios et al. 2001). The skin has a multilayered structure. The two main chromophores in the skin, melanin and hemoglobin, are present in different layers, with the melanin found in the top layer (mainly epidermis) and the hemoglobin found in the bottom layer (vascular network of the dermis) (Figs. 2.9a, b, 2.10a, b, 2.11a, b). To avoid skin damage, higher cut-off filters, multiple pulses and increased delay time should be chosen

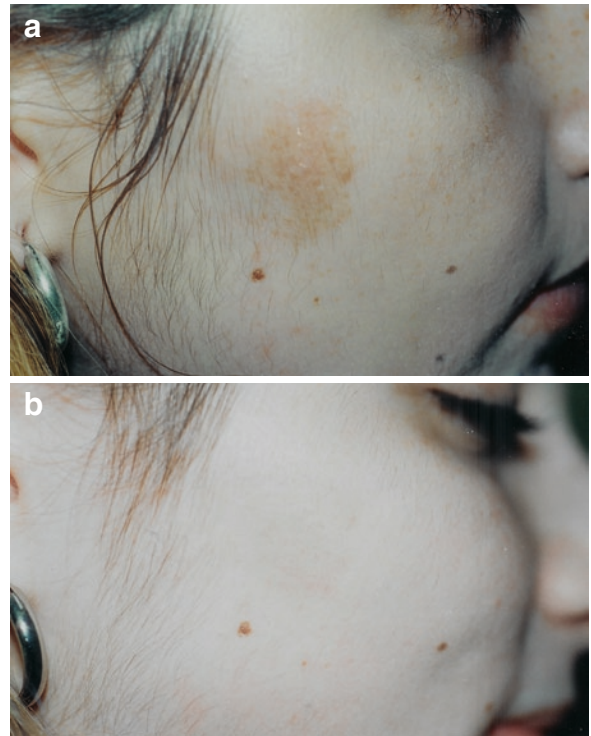


Fig 2.9 (a) Café-au lait in a young person. The melanin is the main chromophore. (b) Good result after two IPL treatments



Fig 2.10 (a) Hypertrichosis. The light energy is absorbed by the melanin (endogenous chromophore) present in the hair shaft, outer root sheath of the infundibulum and matrix area pigment from the hair bulb. (b) Good result after five IPL treatments

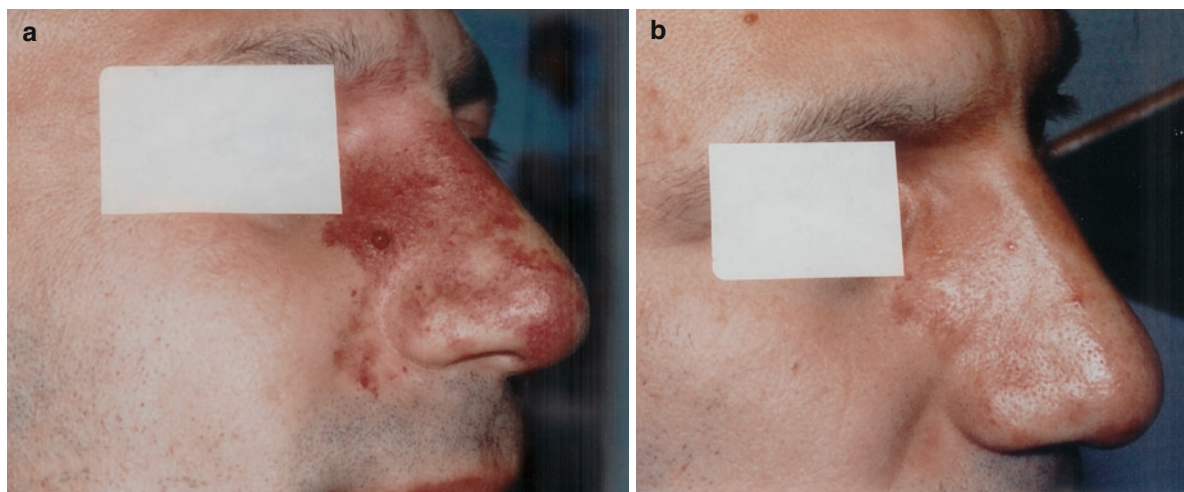


Fig 2.11 (a) PWS – adult type over the nose. The chromophore is the hemoglobin. (b) Good result after ten IPL treatments

Table 2.1 Data derived from Fitzpatrick-skin color types (Fitzpatrick 1988)

Skin type	Skin color	Susceptibility to sun burn	Susceptibility to skin cancer
Type I	Blond or red hair (freckles, fair skin, blue eyes)	Always burns easily; never tans	High
Type II	Blond or red hair (freckles, fair skin, blue eyes)	Usually burns easily; tans with difficulty	High
Type III	Darker Caucasian, light Asian	Burns moderately; tans gradually	Low
Type IV	Mediterranean, Hispanic, Asian	Rarely burns; always tans well	Low
Type V	Latin, light-skinned black, Indian	Very rarely burns; tans very easily; dark skin tone	Very low
Type VI	Dark-skinned black	Never burns; very dark skin tone	Very low

for darker skin types. The Fitzpatrick skin typing system (Table 2.1) from I to IV has different skin colors according to pigment intensity (Fitzpatrick 1988). Although it is a widely used scale, it has been criticized that human eye evaluation is subjective and confounded by the presence of hemoglobin (Matts et al. 2007). Although the human eye can distinguish adjacent brown and red colors, it is almost impossible to distinguish the relative contribution of melanin and hemoglobin when they overlay one another, as often happens in young and photoprotected skin (Matts et al. 2007).

There are elaborated methods which try to evaluate skin color objectively. These are based on spectrophotometric or colorimetric techniques. Although these methods are more objective, they still cannot completely separate the individual contributions of the chromophores (Moncrieff et al. 2002; Ito and Wakamatsu 2003; Matts et al. 2007).

Exogenous chromophores can be administered to the skin to prevent sunburn (exogenous chromophores from sunscreens) or in combination with ultraviolet radiation for therapeutic benefit (Thompson et al. 1993; Naylor et al. 1995).

Practical Points

- › The intense pulsed light is situated in the visible light of the electromagnetic spectrum.
- › Heating is an important effect induced by light absorption. This often leads to cell necrosis, blood coagulation and structure alterations.
- › The light interacts with the skin and part of it is absorbed, part reflected or scattered, and part is further transmitted. The absorption is responsible for the desired effect on the tissue.
- › The two main skin chromophores present in the skin and responsible for the light effects are melanin and hemoglobin.
- › Selective photothermolysis is the basic principle of Intense Pulsed Light treatment. It consists of matching a specific wavelength and pulse duration to obtain optimal effect on a target tissue with minimal effect on the surrounding tissues.
- › Melanin is located within the top layer of the skin (epidermis) and hemoglobin is found in the bottom layer (vascular network of the dermis).

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