Electro-Optical Synergy (ELOSä) Technology for Aesthetic Medicine Advantages and limitations of various forms of electromagnetic energy for safe and effective hair removal

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Introduction

Hair removal treatment can be accomplished by causing irreversible damage to hair follicles [1]. Long-term removal of the plurality of hairs is critical for treatment of large body sites. Most of the methods intended for long-term hair removal are based on thermal destruction of the hair shaft and follicle using optical energy. Several technologies are currently used for this application, as outlined below:

Laser - In recent years, laser-based hair removal has become one of the most popular methods for hair removal [1-4]. The treatment involves applying laser pulses to the skin surface. Laser light energy is selectively absorbed by the hair shaft at skin depth of a few millimeters.

IPL - Intense Pulse Light technology takes advantage of the broad spectrum, in contrast to a monochromatic laser light. Output wavelengths can be tuned to achieve better results by filtering out some parts of the spectrum generated by the light source in accordance with skin pigmentation level [5-7].

One of the main limitations of laser and IPL treatments is the fact that the light energy has to penetrate through the epidermis before it can reach the depth necessary to cause damage to the hair. The epidermis, being rich in melanin, creates a major barrier for penetration of light. When high energies of light are used in order to create enough heating of the hair follicles, there is a high risk of overheating the epidermis, which can cause adverse effects such as burns and hyper-pigmentation. The more sophisticated devices include a cooling system that decreases heating of the epidermis. In a typical hair removal case, there is a small gap between the strength of energy pulse required for effective treatment and the strength that can cause adverse effects. Dark skin types however challenge the technology limitation of photo-epilation, and in many cases skin damage occurs before hair follicle coagulation.

Principal of selective photothermolysis

The mechanism of long-term photo-epilation is based on light absorption by the hair shaft and thermal damage to the bulge and follicle. This occurs as a result of heat transfer from the shaft to the surrounding layer of tissue.

Selective photothermolysis of hair is based on three fundamental principles [5]:

- Light penetration depth should be enough to reach the hair bulge and bulb.
- Light absorption in the hair should be higher than absorption in the surrounding tissue.
- Pulse duration should be less then the hair follicle thermal relaxation time

Light in the range of 630nm to 1300nm penetrates into the tissue deep enough to be used for hair removal. Light absorption by dark hair shafts exceeds light absorption by the dermis in the full range of wavelengths, but the most optimal spectrum is in the ranges of 680-980nm and 1020-1100nm. The wavelength range of 980-1020nm is less useful than the other wavelengths because of peak water absorption, which decreases treatment selectivity. Light penetration depth as a function of wavelength is presented in Figure 1.

Light-tissue interaction is controlled by three major phenomena: reflection, absorption, and scattering [8,9]. A significant portion of light (up to 50% of incident light) is reflected from the skin surface [11]. The rest of the light is absorbed by tissue chromophors, which are melanin, contained in the epidermis and hair shafts, and hemoglobin, contained in the blood [9-12]. The main problem of light-based hair removal is the fact that both hair and epidermis have the same absorber melanin. Thus, wavelengths that are more efficiently absorbed by the hair shaft, are also absorbed more efficiently by the epidermis.

Light transfer through the skin is mainly governed by scattering. As the light penetrates to the depths of few tens of microns, photons already lose their initial direction due to scattering. Scattering leads to the spattering of a significant part of the light in the periphery of the treated zone.

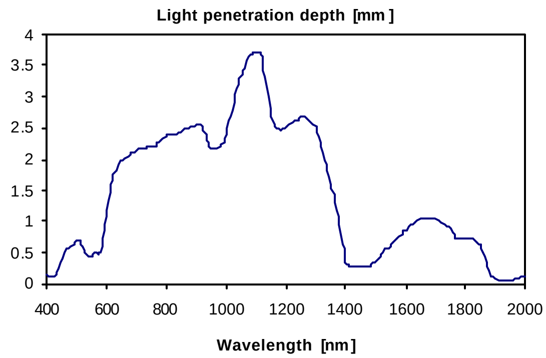

Figure 1. ***Skin penetration depth of light***

Light energy applied to the skin is measured in fluence units J/cm^2. The part of the energy absorbed in the treated zone is usually significantly lower because of the loss to reflection and scattering. In fact, energy absorbed in the treated zone can be 30% of incident energy, but the exact quantity cannot be determined because of the strong variations in the optical properties of different types of skin.

To summarize, light-based treatment offers a good alternative for hair removal in the dark hair/light skin combination. In all other cases, the risk of adverse effects is higher while treatment efficacy is lower. Improving hair removal treatment requires the following:

- Reduce light energy to the level that is safe for the epidermis, in all skin types.
- Compensate for the lack of light by applying another type of energy that satisfies the following conditions:
  a) Selectively affects the hair follicle but not the epidermis.
  b) Penetrates the tissue to a depth of a few millimeters.

Conducted Radio-Frequency Energy

Conducted radio-frequency (RF) energy has been used for almost a century for electro-surgery and coagulation. The thermal effect of the RF energy depends on the electrical properties of the tissue, but not on the optical properties. RF current streaming through the tissue generates heat that is proportional to the square of the current density.

$$H = \frac{j^2}{R} \qquad \textbf{(1)}$$

Where ***R*** is the impedance of tissue and ***j*** is the RF current density. RF current density and the energy deposited in the skin are completely independent of skin color and have no epidermal barrier like the one encountered by light that is heavily absorbed by melanin in the epidermis.

The distribution of RF current density between two electrodes coupled to the skin surface is shown schematically in Figure 2.

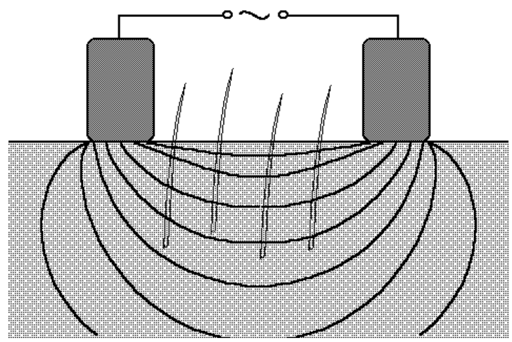

Figure 2. ***Distribution of RF current generated in tissue by a bipolar system.***

The distribution of RF current depends on the geometry of electrodes and the distance between them. RF energy penetration is approximately equal to half the distance between the electrodes. For example, when the distance between electrodes is 8mm, penetration depth is about 4mm.

Selectivity mechanism for RF energy

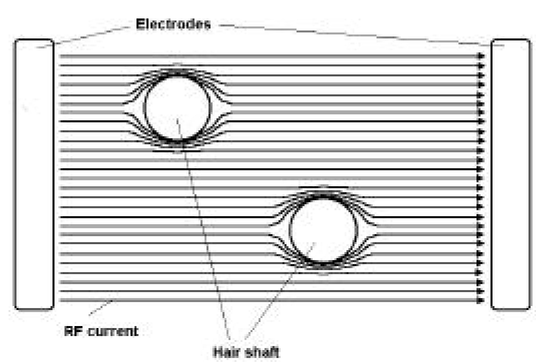

Figure 3. ***Current density distribution around the hair shaft.***

The next question to consider is the influence of RF energy on the hair and follicle. The hair shaft is an isolating material and does not conduct RF current well. Electrical current created between electrodes streams around the hair shaft, concentrating in the layer of 20-40 microns around the hair, as shown in Figure 3.

Current density in the tissue zone adjacent to the hair shaft is twice the current density in other parts of the skin. According to equation 1, skin heating around the hair is four times higher than in the dermis. The part of the skin coupled to the hair shaft comprises the follicle and bulge, which must be destroyed for long-term hair removal. Therefore, RF current selectively heats the hair follicle. Unlike selective photothermolysis, RF current heats the hair follicle and bulge directly, and not through heat dissipation from the hair shaft. Therefore, the procedure is not sensitive to skin color at all.

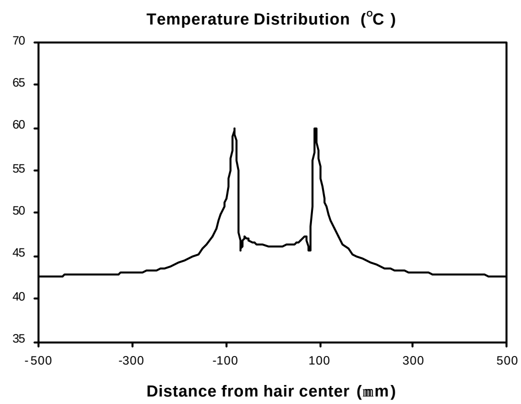

Figure 4. ***Heat distribution around the hair shaft.***

Figure 4 demonstrates the calculated static temperature created by RF current around the hair at a depth of 2mm. Maxwell equations with empirical coefficients for tissue were used in the calculation [13]. One can see that RF current selectively heats the hair follicle without affecting the hair shaft. In our calculation, hair shaft diameter was assumed to be as large as 150 microns. RF energy density deposited is equal to 25 J/cm^3.

A very important property of RF energy is the negligibility of reflection and the scattering of energy in a bipolar electrode system. In contrast to light, the energy can be deposited only in the skin, since the basic requirement for delivering RF energy is conductive media. This enables very good control of the amount of energy deposited because all of it is deposited in the skin. Also, in contrast to light, direct, measurement of the current and the voltage on the electrodes provides an online measurement of the energy deposited in the skin, using the simple

$$E = V\ I\ t \qquad \textbf{(2)}$$

Where $\boldsymbol{V}$ is the voltage applied to the electrodes, $\boldsymbol{I}$ is the current that is conducted between the electrodes and $\boldsymbol{t}$ is the pulse duration, (assuming that $\boldsymbol{V}$ and $\boldsymbol{I}$ are constant during the pulse).

Taking into the account that penetration depth ($\boldsymbol{l}$) is about 4mm, heating of the dermis can be estimated using dimensional analysis, as follows:

$$T = \frac{E}{c\,S\,l} \qquad \textbf{(3)}$$

Where $\boldsymbol{E}$ is RF energy applied to the skin, $\boldsymbol{S}$ is treated area and $\boldsymbol{c}$ is the specific heat of tissue (c=3.6J/g/K) and $\boldsymbol{l}$ is the depth of penetration of the RF energy. For the energy of 24J and spot size of 3cm^2, the maximum temperature increase of the skin is equal to 5.6^{o}C, while follicle heating is four times higher, reaching 22^{o}C.

In summary, the advantage of RF energy is its selectivity in that it directly impacts the hair-supporting tissue (follicle and bulge), with skin pigmentation not forming an obstacle for the treatment.

Electro-Optical Synergy (ELOS ä)

Neither RF current nor light energy provides complete treatment of the hair structure. While light is selectively absorbed by the hair shaft, including the hair root, RF energy heats the hair follicle. There is a small energy difference between an effective treatment and adverse effects, when using light energy.

The Aurora DS is the only machine available today that implement the ELOS™ technology. Hair from two-treated areas on human skin was pulled and presented in Figure 5.

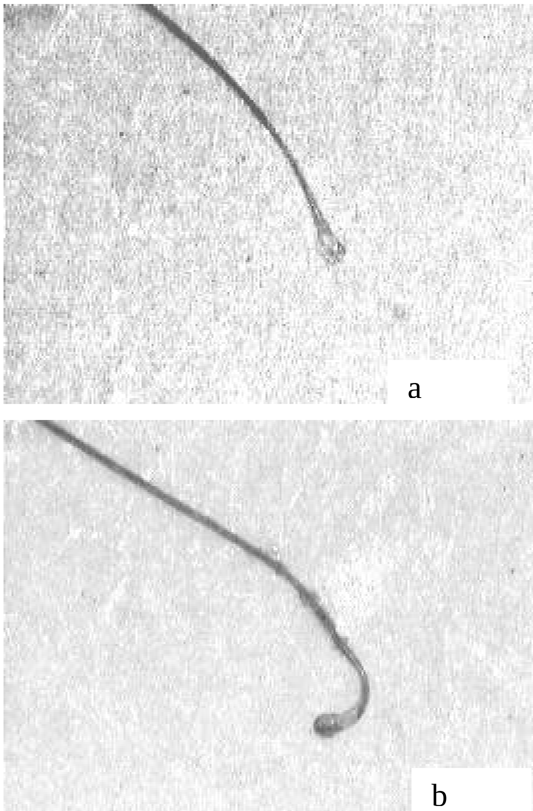

Figure 5 Treated hair a) ***optical pulse at 20J/cm^2 with no additional RF energy. b) optical pulse at 20J/cm^2 and RF energy of 20J/cm^3.***

Optical energy of 20 J/cm^2 is a safe level for the skin in the infrared range, however no damage to the hair shaft is observed, and therefore the treatment is not expected to be effective. In Figure 5b, 20 J/cm^3 of conducted RF were applied simultaneously with the same amount of optical energy. It is clearly seen that the root of the hair, (the part of the hair which is inside the skin), is burned, but the upper part is not. Such treatment parameters are as safe as the pervious one, but the result is expected to be distraction of the hair follicle.

The combination of electrical and optical energy creates the following possibilities for improving efficacy and safety of treatment:

- Reduce optical fluence to the level that is safe for all skin types.
- Compensate for the lack of optical energy by applying RF current that selectively affects the hair follicle without absorption by the epidermis.
- Allows the on-line monitoring of skin parameters during the treatment.

Summary

Currently available hair removal technologies (electrolysis, laser and IPL) face significant obstacles in terms of safety, efficacy and patient acceptance. Electro-Optical Synergy (ELOS) technology, which combines RF energy and light, offers many advantages for treatment of unwanted hair. It heats the epidermis less, and heats evenly throughout the hair and follicle.

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