Electro-Optical Synergy (ELOS™) Technology for Aesthetic Medicine Light Triggering Effect on RF Selectivity

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Introduction

Selective photothermolysis of skin targets is the theory behind several very popular procedures in cosmetic medicine [1]. These include laser assisted hair removal and treatment of vascular and pigmented lesions, which have been widely used in the past few years. The basic principle of these treatments is selective heating of the target without damage to surrounding tissue.

Attached to this basic principle lies the major challenge: to be able to reach the target, which in some cases lies deep in the dermis, without damaging the epidermis. A common approach to overcoming this problem uses wavelengths that have maximal difference in the absorption by the target compared with the surrounding tissue.

Currently, there are two main technologies used for such treatments:

1. Lasers - Monochromatic laser radiation is used in order to treat skin disorders. Laser-based procedures have become one of the most popular methods for skin treatment in the past decade [2].
2. IPL (Intense Pulsed Light) - takes advantage of the broad light spectrum. In this technology, output wavelengths can be tuned to achieve better results by filtering out certain parts of the spectrum generated by the light source, in accordance with skin pigmentation level [3].

In both technologies, the treatment is based on applying optical energy to the skin surface. The light should penetrate the skin to a depth of a few millimeters, where the energy is selectively absorbed by the target. One of the main limitations facing these technologies is the fact that the light has to penetrate through the epidermis before it can reach the depth necessary to cause the desired damage to the treated target. The epidermis, being rich in melanin, creates a major barrier for penetration of light. Additionally in some cases, such as hair removal, melanin is also the chromophor in the target. 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 to a temperature high enough to cause adverse effects, such as burns and pigmentation change. The problem and the risk become much worse in cases of dark skin as their melanin-rich epidermis is more likely to heat to a dangerous level before the target reaches the required temperature. The most sophisticated laser and IPL systems include a cooling system that decreases epidermal risk by lowering the initial epidermal temperature prior to heating.

To achieve selective photothermolysis of the target, the following fundamental principles should be implemented [1]:

- Light penetration depth should be enough to reach the hair bulge and bulb, or any other target to be treated.
- Light absorption in the target should be higher than absorption in the surrounding tissue.
- Pulse duration should be less than thermal relaxation time of the target.

Thousands of systems based on the principle of selective photothermolysis are in use today for hair removal, treatment of vascular and pigmented lesions and tattoo removal. The huge variations in skin and lesion parameters significantly affect treatment results. For example, in the case of vascular lesion treatment, the following main parameters must be taken into the account:

- Vessel size
- Vessel depth
- Location
- Skin pigmentation

It is clear that, with so many variables, choosing the optimal parameters for successful treatment requires a high degree of user skill and experience. In some cases, however, even the most skilled and experienced physician, with the best light/laser-based machine currently available on the market, may have difficulties in more complicated cases, such as hair removal treatment of a patient with light hair and dark skin. The inherent technological boundaries of light/laser-based systems therefore limit treatment of a wide variety of skin types and targets.

Thus, the current simple technology for treatment of skin targets using high heating selectivity between the target and the surrounding tissue has reached the theoretical limit.

In this paper, we suggest a novel method to overcome the inherent limitations of light/laser-based selective photothermolysis: combining an optical energy with RF energy. This method is called ELOS™ Electro-Optical Synergy.

Selective thermolysis using RF energy

The method described below for selective treatment of biological targets is based on the fact that higher temperature tissue better conducts an electrical current in the radio-frequency (RF) range, and as a result is heated more than tissue at a lower temperature.

Complete mathematical analysis of RF interaction with biological tissue is presented in *Appendix A*. The basic physical considerations that allow selective thermolysis with RF energy are presented below.

Conductivity of the tissue is linearly dependent on its temperature: tissue at higher temperatures has lower impedance for RF current.

Heat generation by RF current can be presented by is dependent on the square of the electrical field. Translating the heat into temperature changes involves solving a differential equation for heat conductivity, (see *Appendix A*).

By mathematical development we can arrive at the following connection:

$$\Delta T = \Delta T_0 e^{At}$$

DT₀ is the initial temperature changes between the surrounding tissue and the target; ***A*** is a parameter determined by the thermal conductivity of the tissue and the RF electric field; ***t*** is the RF pulse duration.

This equation shows that as the RF current is applied, the heating selectivity of the target increases exponentially. Therefore, by creating a relatively small initial temperature gradient ***DT₀ > 0***, and applying RF energy, a larger temperature gradient is obtained. This allows heating of the target to a sufficiently high temperature to destroy the target without heating the surrounding skin tissue to damaging levels.

In other words, selective thermolysis using RF energy can be obtained by creating initial temperature differences between the target and the surrounding tissue.

Light triggering effect

One of the methods for creating initial temperature distribution where the temperature of the target is higher than the temperature of the surrounding tissue is by applying an optical energy. The optical energy should be in the wavelength range that is selectively absorbed by the target. For example, when the goal is to treat superficial vascular lesions, the wavelength range of 570-590nm is optimal for creating initial selective preheating. For the deeper blood vessels, longer wavelengths can be used. For preheating pigmented lesions, wavelengths in the range of 550nm to 1000nm are appropriate. Aside from the wavelength choice, the optical pulse duration must be matched to the target thermal relaxation time.

We would like to note here that the optical energy is used in order to create small temperature changes between the target and the surrounding tissue. The temperature changes will be used to selectively treat the target with the RF energy. Therefore, the level of optical energies to be used should be much lower than what is currently used for aesthetic medicine. This allows for much safer and more efficient treatments.

Skin cooling

Temperature differentials between the target and surrounding tissue can be enhanced by pre-cooling of skin. External cooling reduces the skin temperature, while the temperature of the targets deep inside the tissue, such as blood vessels or hair follicles, stays at the same level [4]. Reducing the skin temperature leads to a decrease in skin conductivity. Therefore, application of an RF energy pulse will be less effective at heating the skin than the target; enabling the temperature level on the skin to remain low in contrast to the temperature of the treated target.

Thus, this combination of pre-cooling and selective heating using optical energy creates the optimal temperature distribution: surrounding tissue that is much cooler than the target. Application of an RF energy pulse selectively amplifies the heating of the treated target.

ELOS ä technology combining conducted RF, optical energy and external cooling

Conductive RF can be used for selective treatment of various skin targets. As outlined above, the RF current selectively heats the pre-heated target as opposed to the pre-cooled skin. Low optical energy safe for all skin types can be used for selectively heating the treatment target while external cooling can be applied to cool down the superficial dermis and epidermis. The described treatment is safer for the epidermis since the use of optical energy is at lower levels compared with complete photothermolysis treatment by optical pulses. The RF energy is not sensitive to skin pigmentation, and therefore can be applied on any skin color without any risk of complications, such as burns or hypo/hyper-pigmentation.

The optimal treatment method:

1. Pre-cool the epidermis
2. Apply light pulse to selectively heat the target. The applied energy should be at the level at which epidermis temperature does not exceed the target temperature.
3. Apply RF pulse to bring the target to coagulation temperature.

To understand the advantages of this new method we can consider a typical case in which heating of the epidermis by light is twice as high as of the target, (for example, dark skin). Heating of the dermis can be assumed to be negligible. After pre-cooling, the initial temperature of the epidermis is 10^{o}C, and the temperature of the target is 30^{o}C.

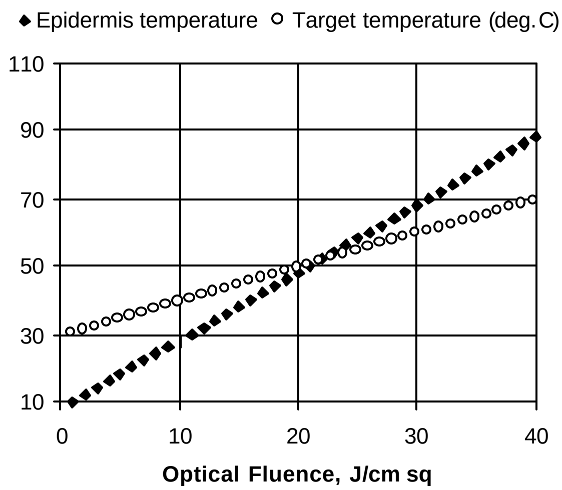

Figure 1. ***Epidermis and target temperature as a function of applied optical fluence calculated for dark skin.***

Figure 1. shows the temperature of the epidermis and target as a function of applied optical fluence, with no other energy applied. The epidermis temperature rises faster than the target temperature and, in spite of pre-cooling, reaches coagulation level (70^{o}C) first.

The advantages of ELOS technology can be clearly seen if we apply very low optical energy of 10J/cm^2 and then conducted RF is applied. Epidermis and target temperature as a function of applied RF fluence is shown in figure 2., below.

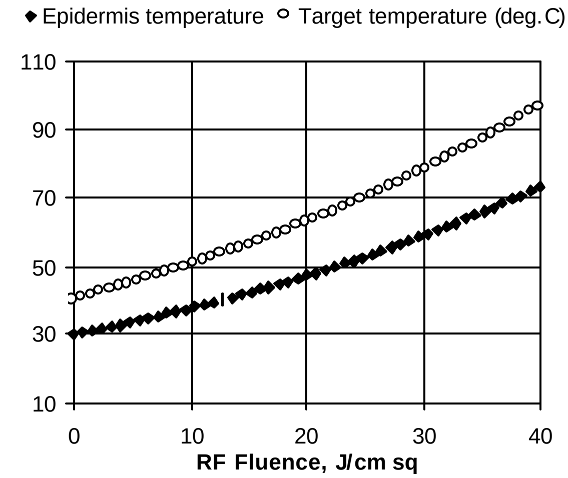

Figure 2. ***Epidermis and target temperature as a function of applied RF fluence calculated for dark skin.***

At the end of the optical pulse, the temperature of the epidermis and dermis is 30^{o}C, while the temperature of the target is 40^{o}C. As one can see, in contrast with the previous case where the temperature difference between the epidermis and the target decreases with the continued application of optical energy, conducted RF heats the target more than the epidermis, thus increasing the difference in their temperatures. This significantly improves treatment safety and efficacy because, when the temperature of the target reaches coagulation level, the epidermis is still at a safe level.

Conclusion

Selective thermolyisis of skin targets that relies on the use of optical energy alone is a far less than ideal methodology for treatment of skin disorders. Optical energy-based systems are limited in their ability to effectively heat targets to coagulation level without also damaging the surrounding tissue.

The combination of optical energy with conducted RF, as implemented in ELOS technology, prevents overheating of surrounding tissue. When the skin is pre-cooled and the target is selectively preheated by application of a low-fluence optical pulse, the RF energy increases the difference in temperature between the epidermis and the target. Thus, the combination of optical and RF energies enables the target to be heated to coagulation level with lower risk of side effects. The result is a more effective, safer methodology for cosmetic medical procedures.

Appendix A

Conductivity of the tissue is linearly dependent on its temperature [5].

$$\boldsymbol{s} = \boldsymbol{s}_o(1+\boldsymbol{a}(T-T_o)) \qquad (1)$$

where $\boldsymbol{s}_o$ is the conductivity at the normal temperature; $\boldsymbol{T_0}$ and $\boldsymbol{a}$ is each a constant known as the temperature coefficient.

Heat generation by RF current can be estimated by

$$H = sE^2 \qquad (2)$$

and the change in temperature in the tissue is obtained using the heat conductivity equation:

$$cr\frac{\partial T}{\partial t} = H \qquad (3)$$

where $\boldsymbol{c}$ is the heat capacity of the tissue, $\boldsymbol{r}$ is the mass density, and $\boldsymbol{E}$ is the intensity of the electric field.

Inserting Equations 1 and 2 into (3),

$$cr\frac{\partial T}{\partial T} = s_o(1+a(T-T_o))E^2 \qquad (4)$$

Setting $A = \dfrac{\boldsymbol{as}_o E^2}{c\boldsymbol{r}}$ (5)

and integrating Equation 4, the result is

$$T' = T_0 + \frac{e^{At}-1}{\boldsymbol{a}} + (T_i - T_o)e^{At} \qquad (6)$$

where $\boldsymbol{T_i}$ is the initial temperature of the tissue before the application of RF energy, $\boldsymbol{t}$ is the duration of the application of RF energy, and $\boldsymbol{T¢}$ is the final temperature of the tissue at the end of the application of RF energy.

Using Equation (6) we can calculate temperature of skin and target at the end of RF pulse. If the initial difference between the temperatures of the target and surrounding skin was ΔT_0, then after applying the RF current the difference is described as

$$\Delta T = \Delta T_0 e^{At} \qquad (7)$$

Equation (7) shows that as the RF current is applied, the selective heating increases exponentially. Therefore, by creating an initial relatively small temperature gradient $\boldsymbol{Tt_i \quad Ts_i > 0}$, and applying RF energy, a larger temperature gradient is obtained. This allows heating of the target to a sufficiently high temperature to destroy the target without heating the surrounding skin tissues to damaging levels.

Assuming a typical RF fluence (F) in the skin of 20J/cm^2, α = 0.03 (°C)$^{-1}$ and a heat capacitance $c\boldsymbol{r}$ = 3.6J/cm^{3}K, the factor e^{At} in Equation (7) is

$$e^{At} = e^{\frac{as_oE^2}{cr}} = e^{\frac{aHt}{cr}} = e^{0.83} = 2.3$$

Thus, the selectivity is increased by a factor of about 2.3 during the application of the RF energy.

Therefore, if the initial temperature of the target is higher than temperature of the surrounding tissue, then RF current increases target heating exponentially.

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