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Control system for laser therapy of teleangiectasies

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ABSTRACT.

Background. When working parameters are set incorrectly, laser therapy has many undesired side effects. European research project iLUMEN is trying to develop an intelligent laser control system capable of determining optimal parameters of laser therapy during treatment. The rise of the skin temperature should be as short as possible, yet still long enough to destroy the target - the vein.

Methods. We have developed a prototype of a control system to measure skin surface temperature, which is based on measuring the infrared (IR) radiation. Contactless measuring sensor was mounted on the handle of Nd:YAG laser system (λ = 1064nm) to measure the skin temperature difference in real-time during the laser treatment of varicose veins and venectasies. The treated region was simultaneously actively cooled with medical gel and air.

Results. Settable work parameters during therapy were laser beam diameter (2-3 mm), fluence (150-250 J/cm2), laser pulse duration (10-20 ms) and frequency (1-1.5 Hz). Good results were seen with teleangiectasies up to 2 mm in diameter and with previous sclerotherapy of larger feeding varices. At the beginning of each therapy cycle air cooling lowered the skin temperature to 20°C and the additional use of the medical gel lowered the temperature for further 10°C. During the laser treatment, skin temperature never exceeded an average temperature of 60°C. This kind of cooling significantly lowers the temperature of the skin surface and lessens the pain during laser therapy.

Conclusions. By using such control systems during laser therapy, we can quantify the interaction between the laser beam and the skin surface in real-time. The results that were monitored for six months show that this measuring method provides good control over the work parameters and consequently directly affects successful treatment. For future work we intend to upgrade the control system by implementing an automated warning algorithm for excessive tissue irradiation. Using the upgraded control system, we expect an improvement of various laser based therapeutic methods.

Key words: laser therapy, work parameters, intelligent laser sources.

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I. INTRODUCTION

Lasers are used in cosmetic procedures, skin rejuvenation, lipolysis and hair and tatoo removal. Besides all this, they can also be used in dermatology for treatment of varicose veins and teleangiectasies. The role of laser treatment is becoming more and more important in the field of phlebology. High-power, short-wave lasers were at first used for treatment of teleangiectasies. However, the development of long-wave lasers make percutaneous treatment of teleangiectasies, reticular varicoses and endovenous laser treatment of trunk varices[1, 2] possible.

Laser technology is used in the field of phlebology for treatment of:

- teleangiectasies that cannot be channeled,
- varices that are unresponsive to classic sclerotherapy,
- sensitive areas (ankles and feet) prone to complications(hyperpigmentations and ulcerations)
- small vessels, which appear after surgical treatment or sclerotherapy (teleangiectatic matting),
- non-surgical ablation of small and great saphenous vein [3].

Cutaneous vascular lesions are categorized according to pathology and age of onset to congenital and acquired [4]. Congenital lesions begin in infancy and include port-wine stains, hemangiomas, venous malformations, and lymphangiomas. Acquired lesions develop in persons of any age and include telangiectasias, cherry angiomas, pyogenic granulomas, venous lakes, poikiloderma, and Kaposi sarcoma. Acquired lesions may occur spontaneously, or they may be caused by trauma, ultraviolet exposure, hormonal changes or genetic reasons. Due to chronic venous disease, women with lower extremity telangiectasias and venectasias were included in our study.

The theory of selective photothermolysis from 1980 states that a specific wave length of light and pulse duration uses thermal energy to damage or destroy only certain body tissues [5,6]. The heat is released at absorption of light, which are produced by different lasers. Pulse duration must always be smaller or equal to the time needed for cooling of a target structure (i.e. thermal release time) and the density of energy must be high enough to reach a certain temperature in the tissue [7]. The basic properties of the lasers that are appropriate for use in phlebology are: better absorption of light in haemoglobin than in surrounding tissues, the depth of beam penetration covering the width of target organ and energy density high enough to harm vessels, but not skin or surrounding tissues [1]. The blue vessels contain more deoxyhaemoglobin, which has a different peak in absorption spectrum (800 to 1200 nm), whereas the red vessels contain more oxyhaemoglobin (absorption at 500 to 600 nm) [4,8].

The cooling system is an important part of the laser system because it reduces the risk of epidermal damage and enhances the effects of laser therapy. The parts of skin treated remains cool before, during and after the treatment. There are two types of cooling systems - the contact and the dynamic cooling system. Their properties lower the temperature of epidermis while increasing the temperature in the dermal vessels. The use of longer pulses at higher densities are recommended because this makes the treatment less painful, has less adverse effects and completes the therapy with less repetitions. [4,7].

Reversible side effects seen immediately after the laser treatment of teleangiectasies and smaller varices are swelling, redness, hives and purpura. Later laser treatment complications are hyperpigmentation, hypopigmentation, teleangiectatic matting, thrombosis or imperfect varices removal. African-Americans (Fitzpatrick type IV and more [1]) are prone to hyperpigmentation. Scarring can rarely be seen as a consequence of high energy used in laser treatment or as a consequence of a tendency to scarring. Relative contraindications for laser treatment in phlebology are tanned skin, pregnancy, the use of photosensitive medicine, anticoagulants or iron supplements, photosensitive skin diseases, tendency to hypertrofic scarring or keloids [1].

Before any laser treatment in phlebology, a detailed anamnesis must be performed. The age of the patient, hormonal treatment, occupation, pregnancy the presence of varicose veins in other family members has to be determined. Besides this, the patient needs to be thoroughly examined, for example assessing obesity and describing the type and extent of varices and any other skin abnormalities on legs [1]. Depending on history and the clinical picture we can also carry out additional tests, such as manual continuous wave (CW) Doppler or colour Doppler ultrasound.

There has been a lot of effort in developing methods that would automatically determine the most appropriate settings of the laser beam working parameters with respect to the type of treatment and tissue properties. Most non-contact methods are based on thermal imaging, where an infrared camera is used to monitor the effects of laser therapy [9]. Such control systems have not yet been integrated into the lasers and used in a clinical practice so far. The reasons for this are over-complicated and unreliable measuring methods. Another obstacle is the size of a measuring system; it is simply too large to be integrated into a laser system.

The purpose of iLUMEN research project is the improvement of effectiveness and reliability of laser treatment in the field of dermatology and cosmetic medicine by introducing effective control systems. With this in mind we have studied different aspects of the impact of laser light on body tissues, especially in treatment of varicose veins and venectasies. In addition to measuring the skin temperature, we have also observed the change of colour and optodynamic phenomena, which appear at intense reaction of laser light and tissue. Based on the acquired data we have analyzed which quantity (or the combination of quantities) is the most appropriate for observing and controlling an optimal laser treatment. Our motivation is to develop a protocol for automated warning method for excessive or insufficient tissue irradiation that will be based on the described quantities and the previous reference measurements. For that purpose we developed a prototype control system that is integrated into the laser system. It is based on real-time skin temperature measurement. The presented system enables us to perform the treatment under optimal conditions.

II. METHODS

Figure 1(a,b) shows the experimental setup during laser therapy. Infrared temperature sensor (1) is mounted on the laser handle. Its measuring region (diameter is 8 mm) covers the region of interaction between the laser beam and the skin surface. The infrared camera (2) is used to simultaneously monitor the temperature of the skin and the site where the beam interacts with the surface. The signal output of both measuring systems is acquired, processed and saved by the laptop (3).

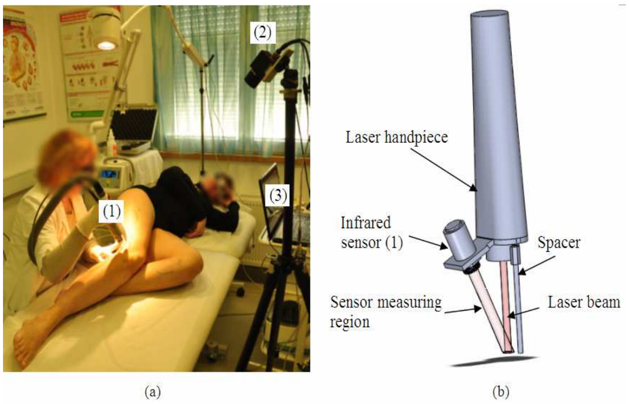

Figure 1 (a) Experimental setup during laser therapy; (1) – laser head with mounted infrared sensor, (2) – infrared camera, (3) – data acquisition and processing. (b) 3d model of laser handle with mounted infrared sensor.

Table 1 shows the main characteristics of the temperature sensor. Because the pulse duration is short, the most important parameter is the fast response time of the sensor (6 ms). Additional advantage of the sensor is its small size which eases its mounting and maintains simple handling during the therapy.

Table 1. Technical specifications of the infrared sensor.

MODEL	Optris CTFast LT25F
Housing dimensions	L = 28 mm, d = 14 mm
Spectral band	8-14 µm
Temperature range	-50℃ to 975℃
Accuracy at 23.5±5℃	±2℃
Repeatability at 23.5±5℃	±0.75℃
Response time	6 ms

Infrared camera was used as an additional control system to measure the entire course of the individual therapy, which consequently provided an additional method to verify the results of the measurements. The technical specifications of the camera are shown in table 2.

Table 2. Technical specifications of the infrared camera.

MODEL	Thermoteknix Miricle 307K
Spectral band	7-14 µm
Sensor array size	640x480 pix
NETD* at 30℃	≤ 80 mK
Response time	40 ms (USB 25 Hz)

The system was used to monitor the skin temperature during the laser treatment. We have also monitored the clinical results of treated teleangiectasias and venectasias monthly in six months period with photodocumentation of normal and dermatoscopic images, with magnification of 10 times (Heine delta 20).

Various working parameters for red veins can be set for the Nd:YAG laser system (Sp Dynamis, Fotona, λ = 1064 nm) such as laser energy density or fluence (60 to 600 J/cm2), laser pulse duration (2 to 50 ms) and frequency (0.5 to 9.0 Hz) and laser beam diameter (2 to 9 mm). These settings are adjusted according to tissue properties. It is common that lower beam energy is set at the beginning of the therapy. Working parameters are later on gradually increased until optimal treatment results are achieved. Such procedure is time consuming and the laser therapy is not optimal.

During the treatment, we have cooled the skin area with medical gel and air. A cooling system (CRYO Mini, Zimmer Medizine Systeme) is mounted on the fiber laser handle, which introduces cool air directly on the site where the laser beam interaction occurs. A layer of medical gel was applied to the same site prior to air cooling. After the treatment, all patients were advised to wear compression stockings, compression class 2, every day for at least a month after the last laser treatment.

III. RESULTS

Only partly, preliminary results are presented here, since the study is not yet concluded. The measurements were performed during the laser treatment of venectasias and teleangiectasias on lower extremities. Settable working parameters were laser beam width (2-3 mm), energy density (150-250 J/cm2), laser pulse duration (10-20 ms) and laser pulse frequency (1-1.5 Hz). Good results (clinical and dermatoscopic regression of teleangiectasies) were seen in teleangiectasies up to 2 mm in diameter and in previous sclerotherapy of larger varices (see Figure 2 and Figure 3).

a)

b)

Figure 2. Teleangiectasies before treatment (a) and six months after treatment (b).

Right leg was treated with Nd:YAG 1064 nm laser and left leg with liquid sclerotherapy.

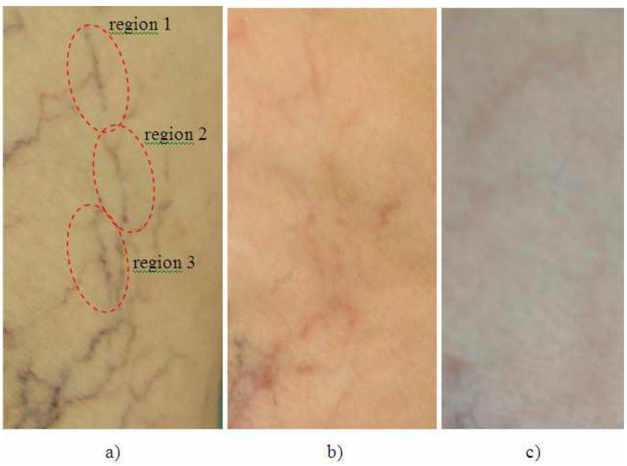

Figure 3. Dermatoscopic image (magnified 10x) of teleangiectasies before treatment with Nd:YAG 1064 nm laser (a), 7 weeks after it (b) and 11 weeks after treatment (c).

Figure 4 shows the measured temperature of the skin surface for a single laser beam pass over the threated region. First, the local minimums and maximums were detected. These points represent the start and the end of an individual laser pulse. Next, the average value of maximums and minimums for all passes over an individual therapy region were calculated and are shown in table 3, along with the main working parameters. The measurements were acquired on the regions shown on Figure 3.

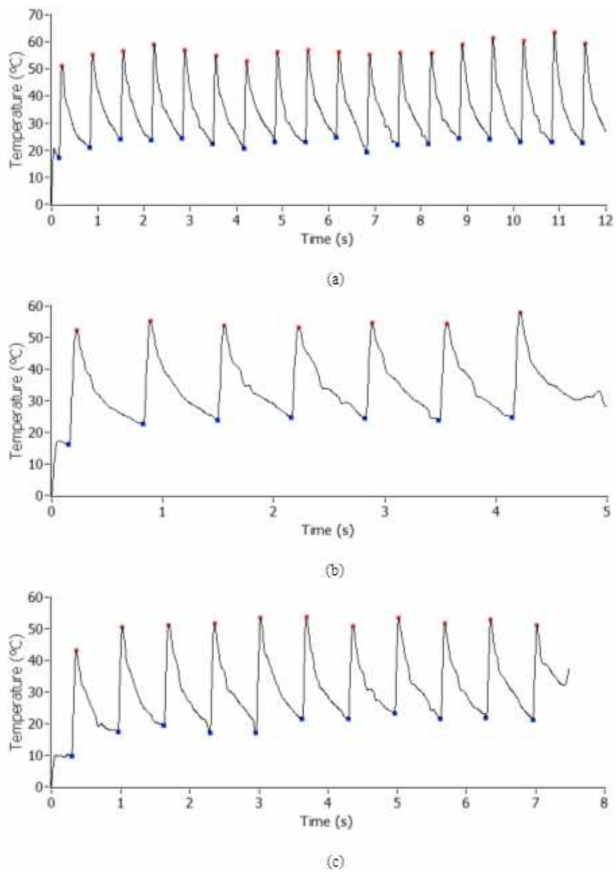

Figure 4. Example of measured temperature on the skin surface during the laser therapy for region 1 (a), region 2 (b) and region 3 (c).

Table 3. Main therapy parameters and measured temperatures for maximum and minimum values for three different regions; Φ – laser beam diameter, F – fluence, tp –pulse duration, f –pulse frequency.

	Working parameters				T average [℃]		Number of passes
Region	Φ [mm]	F [J/cm^2]	t_p [ms]	f [Hz]	max	min	

1	3	200	10	1.5	59.1	23.7	2
2	3	200	10	1.5	54.5	22.9	2
3	3	200	10	1.5	51.4	19.2	2

At the beginning of each individual laser treatment, the minimal average temperature on the skin surface was 20°C when cooled with air and 10°C when cooled with air and medical gel simultaneously. The maximal average skin temperature during the therapy was below 60°C, which is the recommended value in available scientific literature [10]. With the proceeding of each individual laser treatment, the minimal average temperature became higher, but did not exceed 25°C. In the cases where we used lower parameters and the same cooling procedures for laser treatment of teleangiectases, the peak skin temperatures and pain were lower but the final results were not satisfied.

IV. DISCUSSION

If we wanted to achieve the best results in therapy of teleangiectasia with laser, we had to choose the optimal laser parameters and effective cooling methods. Therefore we have to achieved temperature in the skin high enough to destroy the vessel and temperature in the epidermis low enough to prevent pain and its permanent damage. The combined cooling system of the skin using air and medical gel enables us to use higher parameters during the laser treatment of teleangiectasias with pain reduction. This method also lessens the degree of immediate tissue reactions such as oedema and erythema of skin. We also expect less frequency of late (pigmentation, scar) adverse effects.

The skin temperature control using non-contact infrared radiometry enables easier adaptation of the working parameters during the laser treatment. We intend to discover possible different outcomes of measuring the skin temperature during laser irradiation of red or blue vessels.

The results have shown that the implementation of the control system enables measuring of the skin temperature in real-time and consequently provides a higher degree of control during the therapy. The settable work parameters along with the real-time control offer an excellent starting point for determining the optimal laser therapy conditions. We propose visual control of treated vein and non-contact infrared radiometry of skin temperature as an early laser treatment control parameters and combination of visual and dermatoscopy observation of treated veins as late laser treatment control parameters.

V. CONCLUSIONS

A prototype control system mounted on the laser handle was developed. The system is capable of monitoring the skin temperature during varicose veins and venectasies therapy. The sensor is based on measuring the infrared radiation in the spectral band of 8 to 14 μm. The results during the six months treatment show that the temperature is an important parameter, which needs to be controlled throughout the therapy. Future work includes the upgrade of the control system by implementing a protocol using automated warning algorithm for excessive tissue irradiation. We expect that such control system will enable safer and less invasive treatment of varicose veins and venectasies with good clinical results and minimum side effects and complications.

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