Quantitative measurement of skin tissue response during laser irradiation in photorejuvenation

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Received September 8, 2008

Light dose plays an important role in the non-ablative photorejuvenation based on the theory of selective photothermolysis. However, present techniques for determining the light dose in clinical practice are still not accurate enough. We present a new system which monitors the skin tissue response during the laser irradiation in photorejuvenation by measuring the change of the total attenuation coefficient. We also investigate the relationship between the total attenuation coefficient and the energy density, pulse duration, and pulse repetition. In this procedure, the total attenuation coefficient decreases when the light dose increases and the reduction dependes on the light dose. These experimental results indicate that the new system would be a potential tool for accurate light dose determination.

OCIS codes: 170.1870, 170.1610, 160.4760.
doi: 10.3788/COL20090706.0512.

With low risk of complications and no downtime, non-ablative photorejuvanation has been one of the major approaches for the treatment of photodamaged skin. Based on the principle of selective photothermolysis[1,2], accurate light dose is important in non-ablative photorejuvenation. Traditional approach of determining light dose is to observe skin response after laser irradiation by the doctors. Due to the complexity of the skin tissue and the subjective experience of the doctors, the light dose determined by the traditional method is not adequate. Previous clinical results, where the improvement for fine wrinkle ranging from 46% to 88%[3], have verified the shortcoming of this method. Objective test techniques are therefore in urgent need for the clinical practice to improve the therapy effect. For the purpose of clinical application, noninvasion and high accuracy of the test technique is necessary. As a novel noninvasive imaging tool, optical coherence tomography (OCT) with micrometer resolution and millimeter penetration depth has critical advantages over other medical imaging systems[4−6]. Medical ultrasonography and magnetic resonance imaging (MRI) have poor resolution, while confocal microscopy lacks deep enough penetration in turbid tissue[7]. Therefore, OCT is the most suitable tool for applications in dermatology. Although many researches of monitoring the wound in photorejuvenation utilizing OCT have been done, most of the works concern the tissue morphology imaging[8−9].

The new system combining the OCT and the therapy laser system is applicable for the measurement of the tissue optical properties, such as the total attenuation coefficient (μ_t), during the laser irradiation in photorejuvenation. In this letter, the relationship between μ_t and light dose in photorejuvenation is presented and discussed.

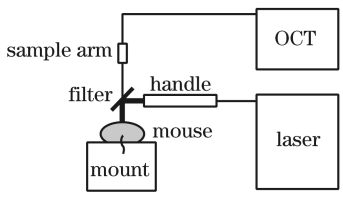

Fig. 1. Schematic of the experimental setup.

The experimental setup is shown in Fig. 1. It consists of a Nd:YAG laser (Gemini, Laserscope Inc., USA, λ =1064 nm) and an OCT system. The initial parameters of the Nd:YAG laser were set with the energy density of 50 J/cm^2, the beam diameter of 5 mm, the pulse duration of 30 ms, the pulse repetition, 3 Hz, and the number of pulses of 20. The axial resolution of the OCT system was 15 μm, and the lateral scanning range was 1.5 mm.

Before laser irradiation, the animal samples, KM mice, were treated with intraperitoneal injection with 2% pentobarbital sodium of 0.3 ml and the hair of the back was removed by using depilatory[10]. 65 mice were divided into three groups (30 mice for group 1, 20 mice for group 2, and 15 mice for group 3) and irradiated by different light doses, respectively, as shown in Table 1.

The flux of light propagating through a scattering and absorbing homogeneous medium exponentially decreases, as shown by

$$F(z) = F_0 \exp(-\mu_t z), \tag{1}$$

where F_0 is the flux of incident light, μ_t is a total attenuation coefficient. The μ_t is extracted by analyzing the slope of the OCT signal in logarithmic scale[11]. Due to the disturbance of the speckle noise to the signal, the signal-to-noise ratio is very low, as shown in Fig. 2(a). To reduce the speckle noise, the spatial and temporal averaging is employed. The method of spatial and temporal averaging is to average the axial scan signal over 40 seconds. The noise can be substantially suppressed by the spatial and temporal averaging, as shown in Figs. 2(b) and (c).

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Table 1. Laser Parameters Setup

Group	Mice Number (pcs)	Energy Density (J/cm^2)	Pulse Duration (ms)	Pulse Repetition (Hz)
1	5	20	30	3
	5	24	30	3
	5	27	30	3
	5	30	30	3
	5	40	30	3
	5	50	30	3
2	5	50	30	3
	5	50	50	3
	5	50	70	3
	5	50	90	3
3	5	50	30	1
	5	50	30	2
	5	50	30	3

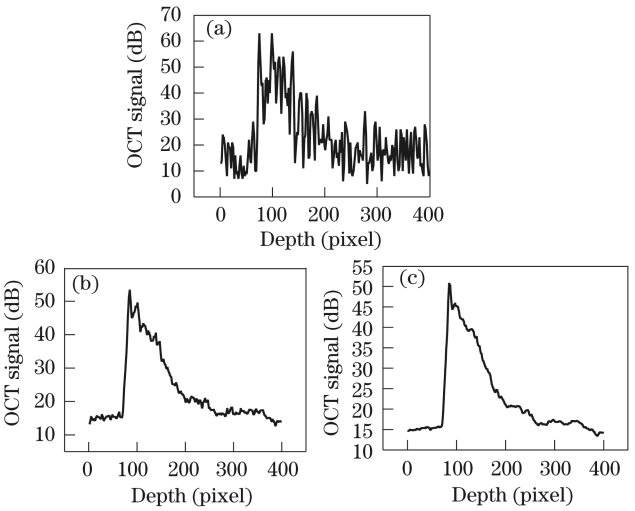

Fig. 2. OCT signals in depth for (a) single axial scanning, (b) after spatial averaging, and (c) after spatial and temporal averaging.

The μ_t reduces after laser irradiation, as shown in Fig. 3. These results are in agreement with the Mie scattering theory. Thermal denaturation of collagen, which is the major scatter in the dermal layer, reduces the characteristic length of scatter to much less than the wavelength of the probe light, leading to the reduced light scattering[12]. Figure 3 also presents the relationship between different light doses and the reduction of μ_t. Compared with pulse duration and repetition, energy density affects the reduction of μ_t most significantly, ranging from 0 to -1.21 mm^{-1}. The relationship between energy density and the reduction of μ_t indicats that the threshold is between 27 J/cm^2 ($p = 0.63 > 0.05$) and 30 J/cm^2 ($p = 0.0002 < 0.05$), as shown in Fig. 3(a). Threshold is very important in clinical practice. If the therapy light dose is lower than the threshold, no tissue will be damaged and no improvement will be achieved.

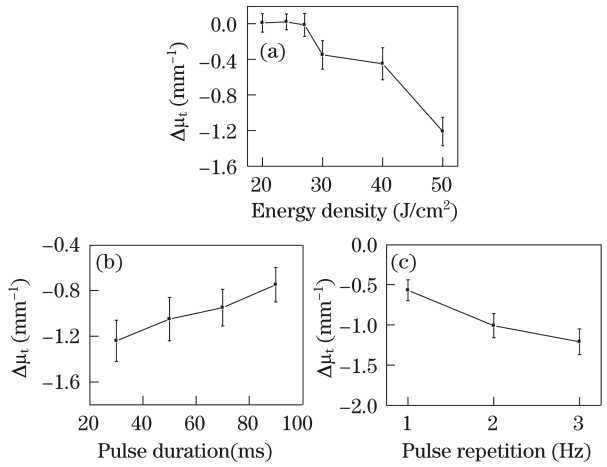

Fig. 3. Relationship between light dose and the change of μ_t ($\Delta\mu_t$, equals μ_t (after irradiation) minus μ_t (before irradiation)). (a)$\Delta\mu_t$ versus energy density with pulse duration of 30 ms and pulse repetition of 3 Hz; (b) $\Delta\mu_t$ versus pulse duration with energy density of 50 J/cm^2 and pulse repetition of 3 Hz; (c) $\Delta\mu_t$ versus pulse repetition with energy density of 50 J/cm^2 and pulse duration of 30 ms.

Figures 3(b) and (c) show that the reduction of μ_t depends not only on the energy density, but also on the pulse duration and repetition. The μ_t decreases steadily ($p < 0.05$) when the pulse duration decreases or the pulse repetition increases. When the energy irradiating on the skin remains the same, the increase of the pulse duration or decrease of the pulse repetition will enhance the heat diffusion to the surrounding tissue, resulting in lowering of the temperature of the irradiation area and the degree of the heat damage in the target tissue.

In conclusion, the reduction of μ_t reflects the degree of the heat damage. Measuring the reduction of μ_t in real time with the new system therefore can be used to evaluate the heat damage and determine whether the light dose is appropriate. Experimental results demonstrate that the new system would be a potential tool for the determination of accurate light dose.

This work was supported by the National Natural Science Foundation of China under Grant No. 60678054.

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