Lasers in Medical Science
https://doi.org/10.1007/s10103-019-02915-0

LETTER TO THE EDITOR

Back-scattered light during laser-tattoo removal treatments is hugely significant

Michael J. Murphy[1]

Received: 6 June 2019 / Accepted: 6 November 2019

Laser energy can be dangerous to the retina, particularly invisible wavelengths which will not stimulate the 'blink response'. Healthy skin naturally reflects up to around 5–7% of any incident light energy—diffuse Fresnel reflections due to the change in refractive index between air and the skin [1]. However, a significant amount of additional light energy can come from back-scattered radiation which leaves the skin in all directions.

Wearing the appropriate laser safety glasses will protect users from any harmful exposure. But how much power would a laser operator's eyes be exposed to if they were not wearing the correct glasses, assuming no major absorbers in the skin?

There are two stages to this calculation—firstly, the reflected/back-scattered light power emanating from the treatment site; secondly, the amount of this power entering the eyes. This method will calculate the maximum possible exposure. In reality, targets within the skin, such as (oxy)haemoglobin, melanin, water or tattoo ink, will absorb some of the light energy before it can be back-scattered.

With a typical Q-switched laser using standard outputs to treat tattoos (energy of 1 J in a 5-mm spot diameter with a 10-ns pulsewidth), the power per pulse directed at the skin may be routinely up to 100 million W. This may be considerably higher with some current picosecond lasers. The reflected power, solely due to Fresnel reflections, is around 5 to 7 MW.

Assuming the operator's eyes are, on average, between 50 and 100 cm from the treatment site, then, the light emanating from the skin fills a hemisphere of surface area 2π*(distance) [2] which is 15,700–62,800 cm^2. Hence, the average power per unit area at this distance is simply the reflected power divided by the surface area of the hemisphere, in the range 80–318 W/cm^2 (in reality, this distribution will not be homogeneous across the surface, but this first approximation will do for this analysis). These values exceed the maximum permissible exposure (MPE) for the eyes for some wavelengths between 400 and 1400 nm (according to BS EN207 [2]). As a comparison, on a clear day, the amount of sunlight reaching the Earth's surface at noon can be around 1000 W/m^2 (0.1 W/cm^2).

If we take the human eye pupil diameter with a maximum of 7 mm, then, the aperture of an eye is approximately 0.385 cm^2. Consequently, the amount of laser power entering an eye, due to Fresnel reflections, is simply the reflected light power per unit area leaving the skin surface (in all 'upward' directions) times the aperture area of the pupil which equals around 31 to 123 W in each eye, per pulse. While this may not sound like much, the light entering the eye from a standard, domestic 100-W light bulb is around 1.2 mW, at a distance of 50 cm, and 0.3 mW at a distance of 100 cm.

However, this assumes that the only light energy leaving the skin are Fresnel reflections. This is not true since back-scattered light will also leave the skin surface, into a hemisphere. Most back-scattered light originates in the dermis where photons undergo many deflections as they interact with tissue and water molecules [3]. Some of these end up turning sufficiently to leave the skin. Recent Monte Carlo calculations, in an 8-layer skin model, by PA Torstensson (unpublished data) show that the amount of laser power back-scattering from the skin is significant—up to 59.4% at 755 nm, 55.5% at 1064 nm, and 29.1% at 532 nm (these percentages are of the remaining light power entering the skin after deducting the Fresnel reflections and assuming no major absorbers in the skin).

This reveals that back-scattering is a serious issue when considering eye protection.

The curves in Fig. 1 show the maximum amount of power which can enter the eye when the pupil diameter is 7 mm. This indicates that up to more than 1590 W of laser power may enter each eye from reflected and back-scattered light, at 755

✉ Michael J. Murphy
mike.murphy@virgin.net

1 Dermalase Research Unit, Glasgow, UK

Published online: 23 November 2019

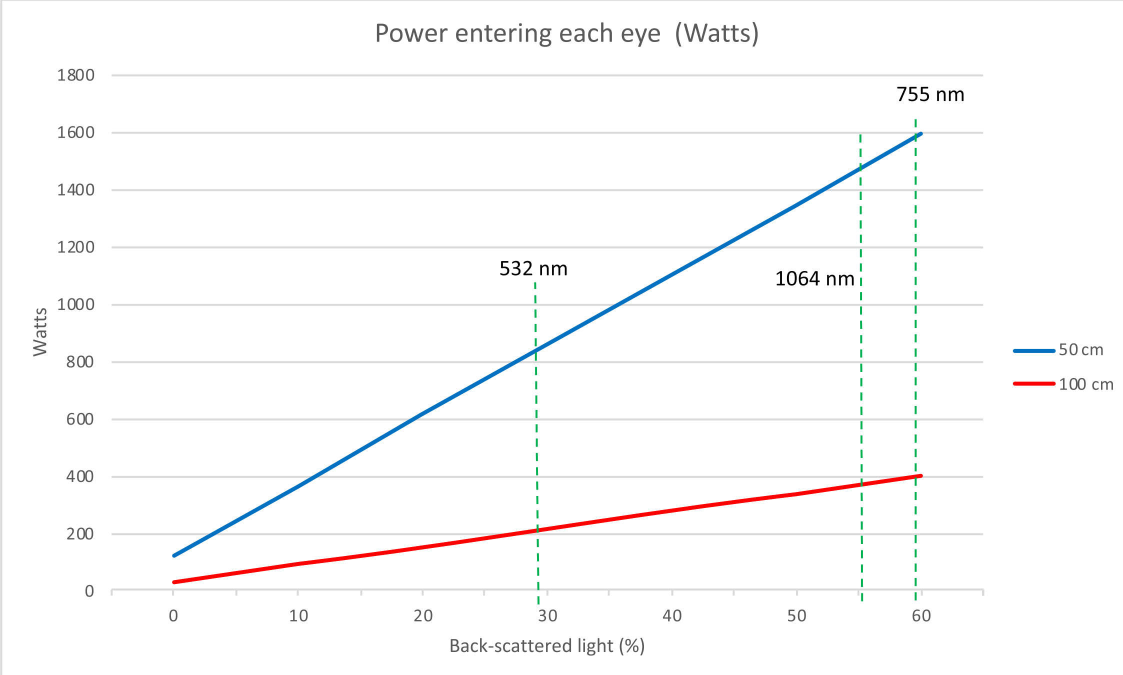

Fig. 1 The power entering an eye from Fresnel and back-scattered Q-switched laser light for two distances from the skin, 50 and 100 cm

nm. With visible wavelengths, this would be immediately obvious (see Fig. 2). However, with invisible Q-switched or picosecond laser light such as 755 nm (alexandrite), 1064 nm, and 1320 nm (Nd:YAG), this becomes a potentially serious issue, especially at close quarters.

It is known that exposure to high levels of visible and near-infrared (400–1400 nm) laser energy can lead to flash blindness or retinal burns [4] since most of the energy in this wavelength range is transmitted to the retina. The absorption of

Fig. 2 Reflected and back-scattered Q-switched laser energy at 532 nm during a treatment of a tattoo. The extreme intensity of this green light without the use of any safety filters is clearly obvious

such energy may result in a rise of anything from less than 1 °C to several hundred degrees Celsius, depending on the incident energy and pulsewidth of the light source.

Some laser users have reported having painful eyes or heads after a laser treatment session. This usually indicates an issue with their safety glasses. It has been my experience that such users are wearing the wrong glasses, or none at all.

There are at least three situations when exposure to these high power levels may be a problem—wearing glasses with the wrong safety specifications; wearing damaged safety glasses; or wearing no glasses. In each case, the eye will be liable to damage, especially as retinal cellular damage will accumulate over a sequence of laser pulses (in the wavelength range 400–1400 nm[4]). With some tattoos, thousands of shots may be fired in a single session. If the user is not properly protected, they will most likely experience accumulative and permanent ocular damage.

These calculations show that the amount of light energy which may interact with the operator's eyes or skin can be higher than previously thought, and hence, higher levels of protection may be necessary, especially with invisible outputs. They also indicate that the amount of energy retained by tissues, such as the skin, or its components, may be lower than previously calculated.

Acknowledgements The author would like to thank the contributions from Per-Arne Torstensson of Optopia, Sweden.

References

1. Lister T, Wright PA, Chappell PH (2012) Optical properties of human skin. J Biomed Opt. 17(9):0909011
2. BS EN 207:2017, Personal eye-protection equipment. Filters and eye-protectors against laser radiation (laser eye-protectors).
3. Jacques S. 1998 Skin optics. Steven L Jacques, Compiled by Göran Salerud;1(7).
4. MHRA 2015. Lasers, intense light source systems and LEDs– guidance for safe use in medical, surgical, dental and aesthetic practices. (September).