

# Comparative Monte Carlo Examination of Energy Penetration for Different Hair Removal Lasers

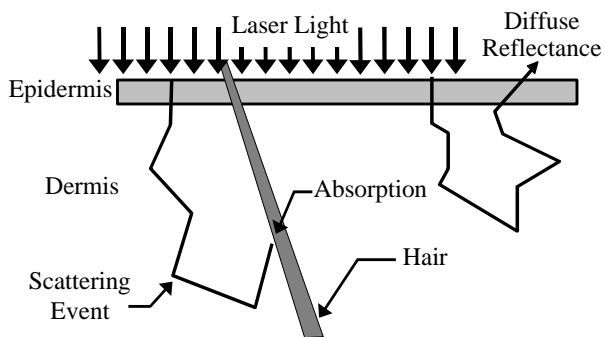
Karl Pope, Candela Corporation

**INTRODUCTION** The distribution of light within tissue during a laser pulse is important when determining which parameters have the greatest effect on the ultimate outcome of the procedure being undertaken. There have been many papers and talks on how different wavelengths penetrate to different depths and the effect of spot size on the depth of penetration.

This paper builds on that work by showing the distribution of light at 755nm, a near IR wavelength used for hair and leg vein removal. A practical application of this information is also presented and shows that less energy may be needed to achieve the same results by using a larger spot size .

## Monte Carlo Modeling

Monte Carlo Modeling is a computer simulation that is used to predict light distribution in tissue. The model simulates billions of individual photons interacting with the optical and thermal properties of the tissue, as illustrated in Figure 1. The optical and thermal properties of skin accurately represent the epidermis, the dermis and the hair follicle. Details of the model are provided at the end of this paper.<sup>1</sup>



**Figure 1:** Monte Carlo “Random Walk” simulation for light distribution in skin. This diagram shows the possible path a photon may travel as it is scattered within the skin before it is either absorbed by the hair or passes out of the skin as diffuse reflectance. Only one hair and two photons are illustrated for simplicity.

## Software and Initial Conditions

Three dimensional Monte Carlo simulations were performed for a laser pulse at 755nm being applied to a light skinned individual, Type II. Table 1 has the optical properties used for the different layers in the simulation.

The numbers in Table 1 for the epidermis and dermis were arrived at empirically in our labs. The values for stratum corneum and fat are extrapolated from other wavelengths. The central plane of the “tissue”, surface to bottom, centered below the laser was examined.

Tissue Name	Index of Refraction	$\mu_a$ (absorption) [1/cm]	$\mu_s$ (scattering) [1/cm]	g (anisotropy)	Depth [mm]
Air	1.00	0.00	0	0	$\pm \infty$
Stratum Corneum	1.50	0.30	250	0.900	0.01
Epidermis	1.37	0.40	100	0.873	0.07
Dermis	1.37	0.04	150	0.869	5.00
Fat	1.37	0.05	4.1	0.800	7.00

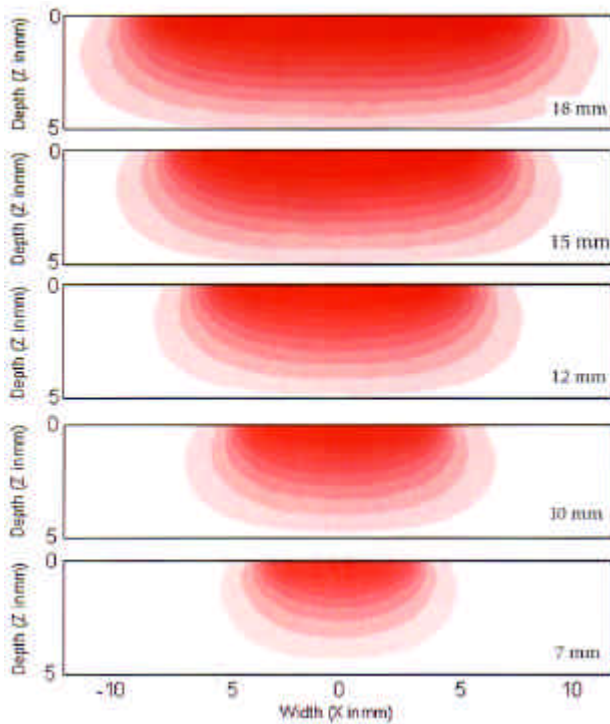
**Table 1:** Optical properties used in the Monte Carlo simulation. These optical properties attempt to represent fair skin, Fitzpatrick skin type II. Where  $\mu_a$  and  $\mu_s$  are the absorption and scattering coefficients and g is the anisotropy factor which determines the angle of scatter.

## Results

The energy distribution as a function of depth is shown in Graph 1 for five different spot sizes: 18, 15, 12, 10, and 7 mm. The red color contours increase in intensity from 0 to 100% saturation in steps of 10%. Only the epidermal and dermal layers are plotted due to the low scattering and absorption of the fat layer, very few photons are absorbed in that level.

In Table 2, the percentage of fluence delivered to the depth (0.1 to 4.5 mm) is shown given the same starting fluence.

These values have been normalized to the 18 mm spot size and were derived from the same Monte Carlo data used in Graph 1.



**Graph 1: Monte Carlo simulated energy distribution as a function of depth and width within tissue shown for different spot sizes 18, 15, 12, 10 and 7 mm from top to bottom, respectively.**

Depth	Laser Spot Size				
	18 mm	15 mm	12 mm	10 mm	7 mm
0.1 mm	100%	98%	95%	92%	84%
0.5 mm	100%	98%	94%	91%	81%
1.0 mm	100%	98%	93%	88%	74%
1.5 mm	100%	96%	91%	85%	69%
2.5 mm	100%	96%	88%	79%	59%
3.5 mm	100%	94%	83%	74%	52%
4.5 mm	100%	92%	78%	67%	46%

**Table 2: Spot size comparison for different depths showing the percent energy delivered to a given depth. The values were normalized to the 18 mm spot size.**

## Discussion

One of the obvious results from using a larger spot is that it covers more surface area. However, one of the concepts that is not fully appreciated is how acutely the beam diameter can effect the depth of penetration.

This is shown in a two dimensional fashion in Graph 1. What is not obvious from this graph is that the tissue under the laser beam, i.e., the treatment

volume ( $\pi \times (\text{radius})^2 \times \text{depth}$ ), increases faster than the area ( $\pi \times (\text{radius})^2$ ) because the penetration depth is increasing as well.

Of particular interest to clinicians is the outcome of using a larger spot size. This is demonstrated in Table 2 where the equal depth fluence factors are presented. No one has determined the exact mechanism or area for hair removal, the bulb and/or the bulge are thought to be important targets. The bulge is around 1.5 mm for a terminal hair and the bulb can be between 3 and 5 mm in depth. When examining studies that report needing a minimum fluence to remove hair, it is very important to know the spot size used in the study. If the study used a 7 mm spot size and reported needing a minimum of 30 J/cm<sup>2</sup>, then using an 18 mm spot only 15 to 20 J/cm<sup>2</sup> (1.5 to 4.5 mm depths) might produce equivalent results. One of the biggest advantages is that using lower fluence levels minimizes the risk of epidermal damage.

## Notes

Table 2 can be used to determine the equivalent fluence at several depths for different spot sizes. For example, if the area of interest is at 4.5 mm depth and an 18 mm was compared to a 10 mm spot size (almost the same area as a 9x9 mm spot size). Assume 20 J/cm<sup>2</sup> was used for both spot sizes, the surface fluence for both lasers. At 4.5 mm the 10 mm will only get 67% of what the 18 mm is delivering. To deliver the same fluence at 4.5 mm the 10 mm spot would have to be increased to 30 J/cm<sup>2</sup> ( $20 \text{ J/cm}^2 / 67\% = 29.9 \text{ J/cm}^2$ ).

The increase needed with a 15 mm spot size would only be 1.7 J/cm<sup>2</sup> when compared to an 18 mm spot at a depth of 4.5 mm ( $20 / 97\% = 21.7$ ). Obviously the amount of energy delivered at all depths would be higher using a 15 mm spot 30 J/cm<sup>2</sup>

Which is better? It always depends on what you are doing. If the consideration is treating large, deep hair and the skin is very light, Type I or II, then higher fluence levels might be used with a smaller spot. If the skin is dark, then a lower fluence may be required to minimize the risk of epidermal damage. For example, a Type I or II might tolerate 40 J/cm<sup>2</sup>. To achieve this fluence level with the GentleLASE® Plus, a 12 mm spot would need to be used. While the 12 mm spot only delivers 78% of the energy of the 18 mm spot at a depth of 4.5 mm, at 40 J/cm<sup>2</sup> with the 12 mm spot, the total energy delivered to the hair bulb is 50% more than 20 J/cm<sup>2</sup> delivered with the 18 mm spot. Since most Type IV and V can not tolerate 40 J/cm<sup>2</sup>, it is better to use an 18 mm spot size at 20 J/cm<sup>2</sup> to maximize the energy directed to the bulb.

At least in this empirical study, the 18 mm spot at 20 J/cm<sup>2</sup> should deliver sufficient energy at all depths to remove hair.

Finally, in Table 3 there is a comparison of spot areas to the percent of area covered. It can be seen that an 18 mm spot will cover 5 times the area of an 8 mm spot. The 9x9 mm spot is 1.6 times larger than the 8 mm spot. However, when compared to the 18 mm spot, the 9x9 mm spot will take three times longer to treat a particular area since it covers only 32% of the area.

Spot Diam. (mm)	Area (cm <sup>2</sup> )	%Area of 8 mm	%Area of 10 mm	%Area of 9x9 mm	%Area of 12 mm	%Area of 15 mm	%Area of 18 mm
8	0.503	<b>100%</b>	64%	62%	44%	28%	20%
10	0.785	156%	<b>100%</b>	97%	69%	44%	31%
9x9	0.810	161%	103%	<b>100%</b>	72%	46%	32%
12	1.131	225%	144%	140%	<b>100%</b>	64%	44%
15	1.767	352%	225%	218%	156%	<b>100%</b>	69%
18	2.545	506%	324%	314%	225%	144%	<b>100%</b>

**Table 3. Comparison of spot area and percentage of coverage.**

<sup>i</sup>The tissue is simulated by forming layers and structures that consist of 7 factors: thickness, position, shape, index of refraction ( $n$ ), anisotropy ( $g$ ), absorption ( $\mu_a$ ) and scattering ( $\mu_s$ ) coefficients. The index of refraction tell the program at what angle the photon will reflect or pass through any interface in the tissue. The anisotropy determines the average angle the photon will travel after it scatters. The scattering coefficient describes the average distance the photon will travel before it hits the next scattering event. And the absorption coefficient establishes the extent of absorption that would occur between two scattering events.

In the computer simulation the movement of the photon is performed through a “Random Walk”, (see Fig. 1). Every time the photon is moved to its next position, random numbers are generated that are then used with  $n$ ,  $g$ ,  $\mu_a$  and  $\mu_s$  to determine the direction,

distance and amount absorption that arise along the way. The movement of the photon is tracked at each step and after thousands or millions of photons are put through the model a matrix of data is established. This data describes the fluence and/or absorption of light in the tissue.

There are many other factors that can be added to the program. The input light can be from a laser (all one wavelength) or from a light source. The beam diameter angle and intensity distribution (flat top vs. Gaussian) can be changed. Modeling different skin types and blood also add factors that can be introduced. Each of these will effect the outcome of the model.

The output from a Monte Carlo is only as good as the optical properties and geometry that were used as input.



CANDELA CORPORATION  
530 Boston Post Road  
Wayland, Massachusetts 01778, USA  
Phone: 508-358-7637 Fax: 508-358-5569  
Printed in USA 1/00. 0920-15-0013 Rev 01

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