Coverage Rate: The Influence of Laser Parameters on Treatment Time

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BACKGROUND. Laser hair removal is becoming an increasingly popular alternative to traditional methods such as shaving, waxing, depilatory creams, or electrolysis. Numerous laser systems are currently available offering different maximum fluence levels, spot sizes, and pulse repetition frequencies, each of which influence the amount of time it takes to treat a given area.

OBJECTIVE. To analyze and discuss the influence of various laser parameters on coverage rate.

METHODS. The influence of various laser parameters, including spot size and shape, and repetition frequency, on coverage rate and their impact on available fluence and pulse duration were analyzed. Theoretical coverage rates for commercially available hair removal systems were calculated and compared.

CONCLUSION. For laser hair removal systems with square, rectangular, or hexagonal beam shapes, the coverage rate is equal to the area of the treatment spot times the pulse repetition frequency. Treatment with a circular beam requires a minimum of 17% overlap in order to cover the entire treatment area. In general, large spot sizes (i.e. >14 mm in diameter) enable more area to be treated with each laser pulse; however, at least 25–30 J/cm^2 at 755–800 nm (80–100 J/cm^2 at 1064 nm) must be available to effect clinically significant long-term hair reduction. Treatment with small spot sizes (i.e. <8 mm in diameter) may result in inadvertent "missed" areas as a result of the reduced penetration of the beam. Scanning systems without contact cooling are limited in the amount of fluence that can be used as a result of increased risk of epidermal injury. All Lumenis LightSheer Diode Laser Systems are effective at the appropriate treatment fluences. The LightSheer ET has a faster coverage rate (up to 1.5–2 times) than all major hair removal systems at fluences of 25 J/cm^2 and higher. The new Coherent LightSheer XC Diode Laser System with a 12×12-mm beam and repetition rates up to 2 Hz provides the fastest coverage rate of all commercially available hair removal systems.

LASER HAIR REMOVAL is becoming an increasingly popular alternative to traditional methods such as shaving, waxing, depilatory creams, or electrolysis. With a global device market estimated at approximately $200 million per year, laser hair removal is currently by far the largest opportunity in aesthetic lasers. Consequently, numerous manufacturers are now producing laser and non-laser based systems aimed specifically at serving this market.

In order to compare the relative merits of each of these systems, it is important to consider the underlying principles governing the treatment. This technical note, the third of a series discussing the important aspects of laser hair removal, focuses on the issue of coverage rate, i.e. how much area can be effectively treated in a given amount of time.

Photothermal Epilation

Hair removal using lasers is achieved by selectively depositing energy into the hair shaft and pigmented follicular epithelium, such that the rapid rise in temperature and subsequent heat transfer to adjacent tissue causes local thermal necrosis of the follicles' regenerative structures. For time periods characteristic of photothermal epilation, the threshold temperature for thermal necrosis is on the order of 70 °C [1]. The selective deposition of energy is accomplished by illuminating the treatment area with sufficient fluence (energy per unit area) at a wavelength that is preferentially absorbed by the endogenous melanin of the target hair shaft and pigmented follicular epithelium, but not by the surrounding tissue. In order to localize the thermal effects, the fluence is typically delivered within a time less than or comparable to the thermal relaxation time of the target structure. The process of

selective absorption leading to local thermal necrosis is known as selective photothermolysis [2].
As one might expect, the effectiveness of the treatment (i.e. the percentage of follicles permanently damaged) scales with the amount of fluence used. In a study of 92 patients (45 males and 47 females of varying hair color and skin type) treated with a Lumenis LightSheer™ Diode Laser System at the Massachusetts General Hospital in Boston and the Laser and Skin Surgery Center of New York in New York City, 32.5% hair reduction was observed at 12 months following a single treatment using a fluence of 40 J/cm^2 and a pulsewidth of 20 ms, while 25.9% was observed for settings of 20 J/cm^2 and 10 ms [3]. Interestingly, multiple pulses (3×) using the same fluence levels did not produce measurably better results.

The above results indicate that the higher the fluence, the more effective the treatment. In fact, in order for the treatment to result in any clinically obvious permanent hair reduction, the treatment area must be illuminated with an adequate amount of fluence. For individuals with fair skin and dark hair, the minimum fluence is estimated to be in excess of 25–30 J/cm^2 for 755–800 nm and approximately 80–100 J/cm^2 for 1064 nm (owing to a greatly reduced melanin absorption coefficient at 1064 nm). The results of the study also indicate that multiple exposures of the target tissue, either by repeated pulses or overlap of the treatment beam, during the same treatment session does not improve treatment efficacy [3]. Thus, multiple pulses and/or excessive beam overlap adversely affect treatment efficiency by reducing the effective treatment area per pulse.

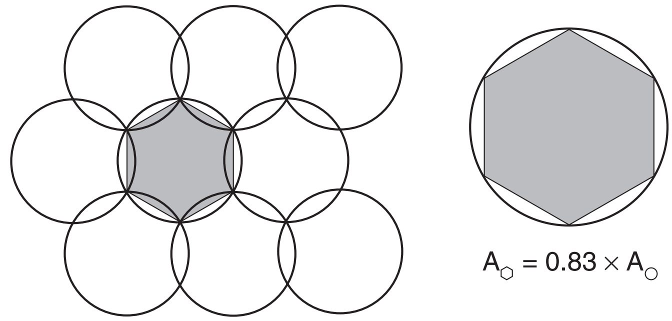

Figure 1. Treatment with a circular beam requires a minimum amount of beam overlap in order to completely cover the treatment area. As a result, the 17% overlap area that exceeds the inscribed hexagon is essentially wasted.

Coverage Rate

For many laser hair removal applications, the area to be treated (e.g. upper lip, chin, bikini line, axilla, etc.) is relatively small, and the time required for treatment is of little consequence compared to the time required for consultation and preparation. However, as more women and men recognize laser hair removal as a permanent alternative to the tedium of waxing or shaving unwanted hair, the treatment of relatively large areas such as backs or legs is becoming increasingly important. Because the treatment of large areas requires a significantly greater amount of time, such procedures can have a significant impact on the economics of the practice.

Although marketing claims for various laser hair removal systems tout “fastest” or “largest spot size,” the treatment time for a given body site is determined by the actual *coverage rate* of the laser system used. Square, rectangular, or hexagonal beams enable easy alignment of the treatment area such that little to no overlap is required in order to completely cover the entire treatment area. Thus, the theoretical coverage rate $CR_{\square}$ (cm^2/s) for laser systems with *square*, *rectangular*, or *hexagonal* beams is given by,

$$CR_{\square} = A \times f \ , \tag{1}$$

where A is the area (cm^2) of the laser spot, and f is the pulse repetition frequency (Hz).

However, as shown in Fig. 1, treatment with a circular beam always requires an amount of beam overlap in order to avoid missing portions of the treatment area. As a result, the minimum 17% overlap area, shown in Fig. 1, that exceeds the inscribed hexagon is essentially wasted. Thus, the theoretical coverage rate $CR_{\bigcirc}$ (cm^2/s) for laser systems with *circular* beams is actually given by,

$$CR_{\bigcirc} = 0.83(A \times f) \ , \tag{2}$$

Table 1: Comparison of theoretical coverage rates for commercially available laser hair removal systems.

Product	Specifications[a]			Coverage Rate (cm^2/s)
	Fluence (J/cm^2)	Pulse Rate (Hz)	Spot Size (mm)	
Lumenis LightSheer™ XC (5–30 ms, 100 ms)	**60**	**1**	**12×12**	**1.44**
	40	**1.5**	**12×12**	**2.16**
	25	**2**	**12×12**	**2.88**
	10	2	12×12	2.88
Lumenis LightSheer ET (5–30 ms)	**60**	**1**	**9×9**	**0.81**
	40	**1.5**	**9×9**	**1.22**
	25	**2**	**9×9**	**1.62**
	10	2	9×9	1.62
Lumenis LightSheer ST (5–30 ms)	**40**	**1**	**9×9**	**0.81**
	25	**1**	**9×9**	**0.81**
	10	1	9×9	0.81
Candela® GentleLASE® Plus (3 ms)	**100**[b]	**1**	**8**	**0.42**
	40	**1**	**12**	**0.93**
	30	**1**	**15**	**1.46**
	20	1	18	2.10
Candela GentleLASE (3 ms)	**100**[b]	**1**	**8**	**0.42**
	60	**1**	**10**	**0.65**
	40	**1**	**12**	**0.93**
	30	**1**	**15**	**1.46**
Cynosure® Apogee-40 (5–40 ms)	**50**	**1**	**7**	**0.32**
	35	**1**	**10**	**0.65**
	25	**1**	**12.5**	**1.01**
Altus CoolGlide™ (10–100 ms)	**100**	**1.2**	**10**	**0.78**
	75	**1.5**	**10**	**0.98**
	50	**2**	**10**	**1.30**

a. Specifications from data sheets or other sources as of September 2001.
b. Experimental only.

where A is the area (cm^2) of the circular laser spot, f is the pulse repetition frequency (Hz), and the factor of 0.83 accounts for the smaller area of the inscribed hexagon. It is important to note, however, that in practice, the overlap is somewhat greater, because it is especially difficult to align round beams with enough precision as to minimize the overlap.

Comparison of Commercially Available Hair Removal Systems

Table 1 compares the theoretical coverage rates, calculated using the above relations, of most commercially available hair removal systems, and Fig. 2 shows a graphical comparison of the theoretical coverage rates of the leading hair removal systems. It should be noted that some systems achieve high coverage rates,

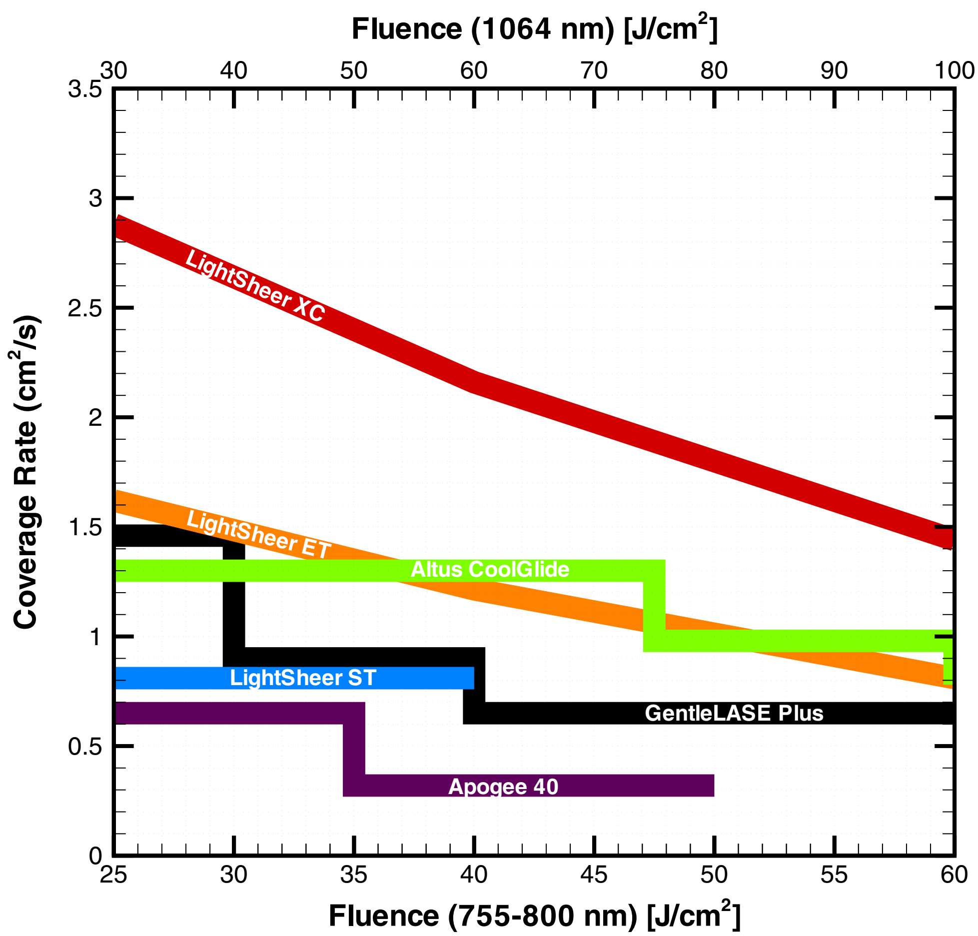

Figure 2. Graphical comparison of the theoretical coverage rates of the leading hair removal systems.

but only at reduced fluence. Such systems typically offer large spot sizes in order to increase the amount of area treated with each laser pulse. However, because the energy output of the laser is limited, the maximum fluence (energy per unit area) available falls precipitously with increasing spot size. As mentioned earlier, insufficient fluence will not result in clinically significant long-term hair reduction. On the other hand, if adequate incident fluence is obtained, but only with spot sizes less than approximately 8 mm in diameter, the actual fluence level at the 1–3 mm deep target structures will be significantly less as a result of rapid diffusion of the beam by scattering [4]. As a consequence, the actual area of follicular damage may be significantly less than the area illuminated on the surface resulting in inadvertent "missed" areas.

Although convenient, scanning systems that do not utilize contact cooling are limited in the maximum amount of fluence that can be safely used because of their increased likelihood of causing epidermal injury [5]. In addition, some systems achieve high coverage rates by increasing the repetition rate at the expense of pulse duration. Short pulsewidths (i.e. <5 ms) generally cause the hair shaft to fracture during treatment while effecting little or no damage to the outer root sheath of the follicle often resulting in only temporary hair loss [6]. Thus, systems with short pulsewidths are somewhat less desirable for high coverage rate permanent hair reduction.

The times required for the treatment of a typical male back or two typical female legs by Lumenis LightSheer Diode Laser Systems are summarized in

Table 2: Approximate time required for the treatment of a typical male back or two typical female legs by Lumenis LightSheer Diode Laser Systems.

Model	Coverage Rate @ 30 J/cm^2 (cm^2/s)	Treatment Time[a] (min)	
		Male Back (1775 cm^2)	Female Legs[b] (2075 cm^2)
LightSheer ST	0.81	37–49	43–57
LightSheer ET	1.49	20–27	24–31
LightSheer XC	2.64	12–15	13–18

a. Treatment time also depends on the amount of inadvertent overlap and/or pauses occurring during the treatment.
b. From the knee downward.

Table 2. As shown in Fig. 2, the Lumenis LightSheer ST Diode Laser Systems have about the same coverage rate as all of the major hair removal systems in the critical 25–40 J/cm^2 range. With a rate of 0.81cm^2/s, a typical male back, comprising an area of approximately 1775 cm^2, and two typical female legs (from the knee downward), totalling approximately 2075 cm^2, can be treated in approximately 37–49 and 43–57 minutes, respectively, depending on the amount of inadvertent overlap and/or pauses occurring during the treatment. It is important to note that sliding of the ChillTip™ handpiece using a thin layer of aqueous gel as lubrication (as opposed to the "pick-and-place" method) results in the fastest coverage, because the tip does not need to lifted as often for wiping.

The Lumenis LightSheer ET Diode Laser Systems offer 1.5–2 times the repetition frequency of the ST systems resulting in significantly faster coverage rates than all of the leading competitors. With a coverage rate of 1.49cm^2/s at a fluence of 30 J/cm^2, for example, the treatment times for a typical male back and two typical female legs reduce to approximately 20–27 and 24–31 minutes, respectively. The Lumenis LightSheer XC Diode Laser System with the same repetition frequency but larger 12×12-mm square beam provides coverage rates in excess of 2.88cm^2/s. With a coverage rate of 2.64 cm^2/s at a fluence of 30 J/cm^2, the same typical male back and two typical female legs can be treated in as little as 12–15 and 13–18 minutes, respectively. Thus, with the new Lumenis LightSheer XC, the throughput of a typical practice treating relatively large areas can increase almost two-fold.

Conclusions

For laser hair removal systems with square, rectangular, or hexagonal beam shapes, the coverage rate is equal to the area of the treatment spot times the pulse repetition frequency. Treatment with a circular beam requires a minimum of 17% overlap in order to cover the entire treatment area. In general, large spot sizes (i.e. >14 mm in diameter) enable more area to be treated with each laser pulse; however, at least 25–30 J/cm^2 at 755–800 nm (80–100 J/cm^2 at 1064 nm) must be available to effect clinically significant long-term hair reduction. Treatment with small spot sizes (i.e. <8 mm in diameter) may result in inadvertent "missed" areas as a result of the reduced penetration of the beam. Scanning systems without contact cooling are limited in the amount of fluence that can be used as a result of increased risk of epidermal injury.

All Lumenis LightSheer Diode Laser Systems are effective at the appropriate treatment fluences. The LightSheer ET has a faster coverage rate (up to 1.5–2 times) than all major hair removal systems at fluences of 25 J/cm^2 and higher. The Lumenis LightSheer XC Diode Laser System with a 12×12-mm beam and repetition rates up to 2 Hz provides the fastest coverage rate of all commercially available hair removal systems.

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NOTES

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