Laser Photocoagulation Spot-size Errors Stemming from the Refractive State of the Surgeon's Eye

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Purpose: Meaningful errors in photocoagulation spot size may result from several factors. In this article we discuss one major factor, namely, fluctuations in the surgeon's accommodative state, coupled with an inaccurate setting of the slit-lamp oculars.

Design: Experimental study.

Methods: We analyzed and tested the optics of slit-lamp mounted lasers. Varying the ocular setting is correlated with measurements of the actual spot size obtained with each system.

Main Outcome Measure: The spot size obtained.

Results: Three distinct, but related, phenomena that may lead to spot size errors are defined: (1) focusing the laser spot as opposed to focusing the retinal image; (2) instrument misalignment; (3) inadvertent accommodation.

Conclusion: The ocular setting must be meticulously calibrated to produce a true spot-sized burn. At the 50 μm setting, each diopter of induced accommodation, or erroneous ocular setting, almost doubles the actual spot size obtained. With large (500 μm) spot size settings, the defocused delivery system is more prone to spot-size errors in contrast with parfocal lasers. *Ophthalmology 2000;107:329–333 © 2000 by the American Academy of Ophthalmology.*

Several factors influence the actual spot size obtained during laser photocoagulation beside the spot size setting itself. Among these factors are the particular contact-type fundus lens used to view the retina (each fundus lens has a unique "laser spot magnification factor"), the patient's refractive error, and any beam or instrument misalignment. In this article, we wish to highlight the importance of the surgeon's refractive and accommodative state, coupled with the ocular setting, as clinically significant factors in determining the accuracy of the spot size obtained. Simple measures may rectify such errors. While discussing trabeculoplasty spot size errors, Wise[1,2] in 1984 has shown that most of the laser instruments tested by him were not calibrated correctly, whereas others simply could not deliver a true 50 μm spot, even after careful calibration. Furthermore, he demonstrated that in 85% of the instruments, an ocular setting different from the surgeon's distance refraction was able to decrease the spot size obtained, thereby reducing the magnitude of the error.

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The Laser Beam

As opposed to the parallel beam emitted from laser pointing devices (such as those used for lecturing), the beam of slit-lamp mounted photocoagulation lasers is a focused beam in the shape of a converging cone of light that comes to an aerial focal point at a preset plane in front of the slit lamp. Past this focal plane, the laser beam assumes the shape of a diverging cone. Consequently, small anteroposterior movements of the slit-lamp joystick will result in meaningful errors in the spot-size obtained (Fig. 1).

The Delivery System: Defocused Versus Parfocal

In the defocused system (Fig. 2, right), the laser beam maintains its three-dimensional shape. Changes in the spot-size setting are achieved through "defocusing" anteroposterior movements of the entire beam, so that the retina is no longer positioned at the beam's waist (narrowest cross-section). Although this system is easier to construct in terms of optical engineering, it has some drawbacks: larger spots appear out of focus (i.e., have fuzzy borders), the energy delivered throughout the spot is less homogeneous, and

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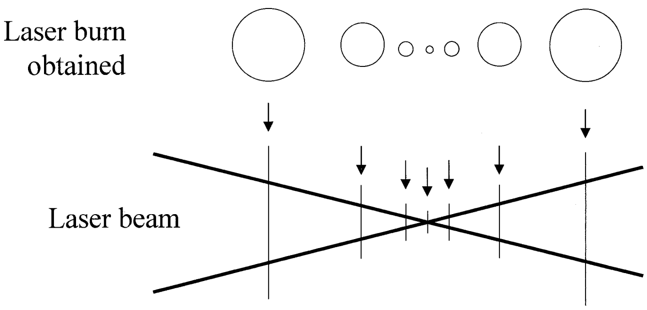

Figure 1. A ray-tracing diagram showing the effect of anteroposterior displacement of the laser beam on the spot size obtained.

spot-size errors may readily occur. On the other hand, defocused systems have the potential advantage of delivering less dense energy at the corneal plane.

The parfocal delivery system (Fig. 2, left) relies on a complex arrangement of lenses in its delivery system. Consequently, different spot sizes are obtained at the beam's waist, even with larger spot sizes. This is achieved through changes in the relative distance between the individual lenses of the delivery system. As a result, the spot appears focused even at larger spot sizes. This system has the potential of delivering a more homogenous spread of energy throughout the laser mark.

Spot-size Errors

Positioning the patient's treated retina in an anteroposterior plane different from the intended plane can result from several factors that will be discussed later. It is crucial to stress that such anteroposterior movements are corrective movements brought about to "regain focus" and not as a result of poor focusing ability or lack of dexterity on the part of the surgeon. For the surgeon, these erroneous focusing movements sharpen the view of the aiming beam spot or the treated retina. This, erroneously, leads the surgeon to assume that the laser treatment is in fact correctly delivered. We identified three such factors that may lead to spot-size errors.

Instrument Calibration Errors

Besides simply failing to notice the setting on the ocular eyepieces, two calibration-related errors may occur with slit-lamp mounted lasers.

An Inaccurate Ocular Diopter Scale.[3,4] The eyepiece settings on the slit lamp are often blithely rotated to a zero setting before the slit lamp is used to examine or treat a patient with the assumption that at that setting the optical system is indeed "emmetropic." That may not be true. The eyepiece markings are actually only a scale and do not necessarily correspond to true dioptric quantities. To make

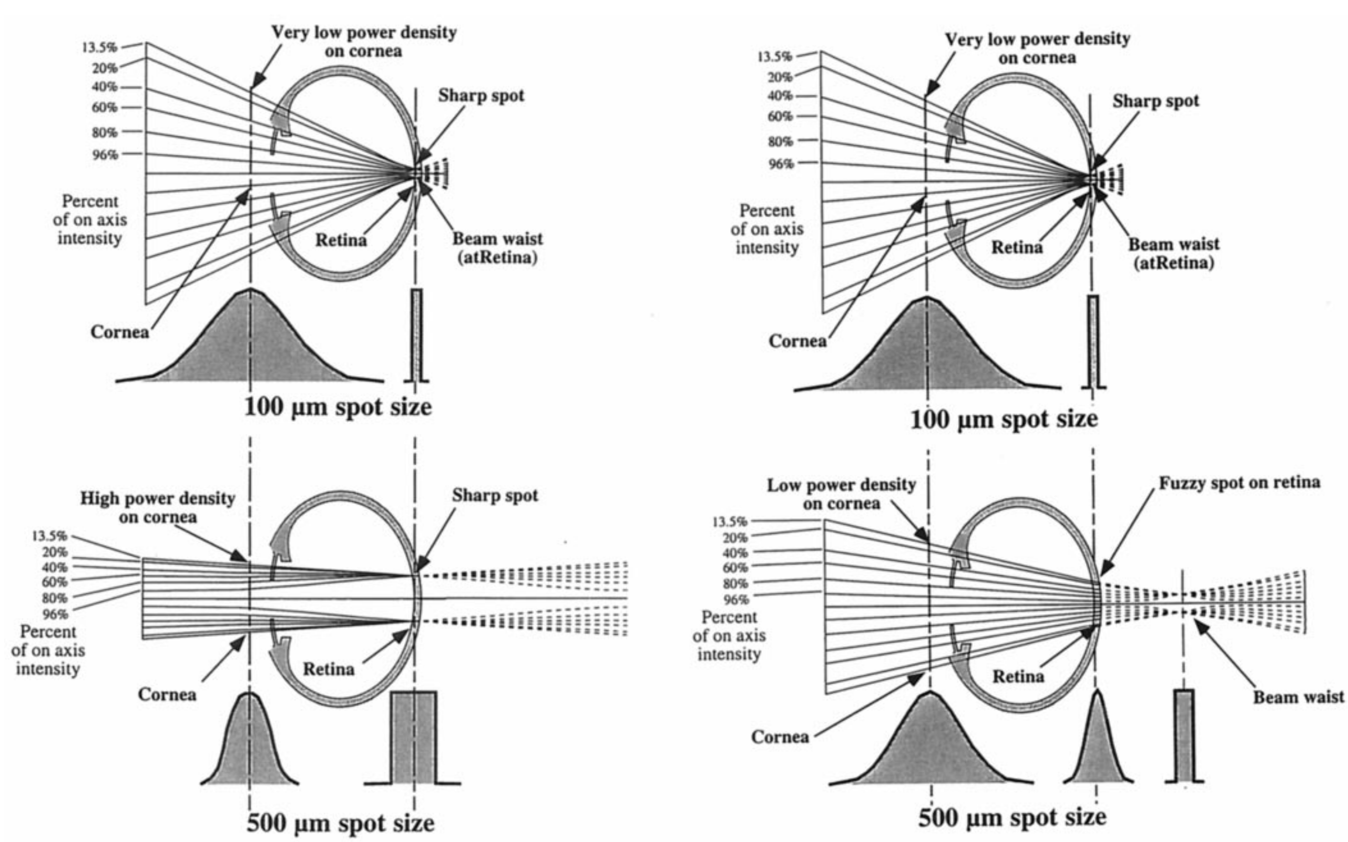

Figure 2. A diagram comparing defocused (right) and parfocal (left) delivery systems at small, 50-μm (top), and large, 500-μm (bottom), settings. (Diagram courtesy of Coherent Medical, Palo Alto, CA.)

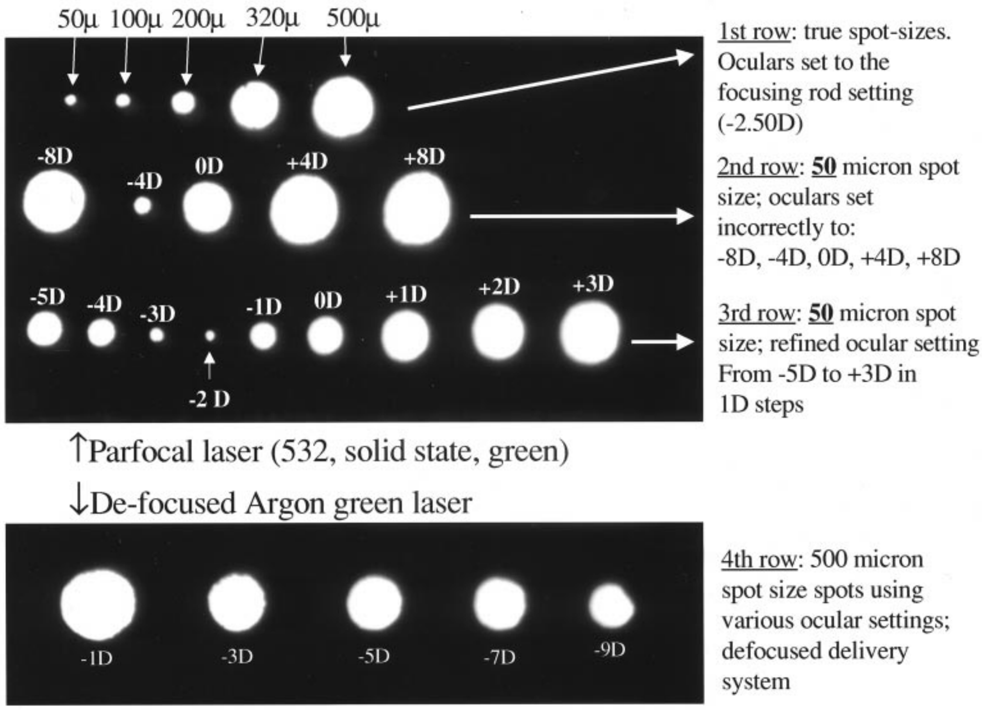

Figure 3. Laser burns applied to paper demonstrating the effect of varying the ocular setting on spot size. The duration and energy settings were fixed within each row. Upper three rows, a parfocal 532-nm solid-state green laser was used. Bottom row, a defocused argon green laser was used. From left to right: Top (first) row, 50, 100, 200, 320, and 500-μm spot-size laser settings, using the correct ocular setting as determined by the focusing rod (found to be −2.5 D). Second row, These spots were all produced while maintaining the laser spot size setting at 50 μm. These wide differences are attributed only to variations in the ocular setting: −8 D, −4 D, 0 D, +4 D, +8 D. Third row, In an attempt to so-called refract the examiner on this laser instrument, the ocular setting was advanced in 1-D increments, maintaining the laser spot size setting at 50 μm. The ocular settings were −5 D, −4 D, −3 D, −2 D, −1 D, 0 D, +1 D, +2 D, and +3 D. These spots suggest a refraction of around −2 D on this specific instrument, for this particular examiner, at this particular time. Notice that the −2 D (smallest) spot is slightly smaller than the −2.5 D spot obtained using the focusing-rod setting (top row, leftmost burn). Lower row, Using a defocused laser and a 500-μm laser setting, the ocular setting was −1 D, −3 D, −5 D, −7 D, and −9 D. Although the true 500-μm size is probably in between the leftmost (−1 D) and adjacent (−3 D) burns, a more myopic setting produces smaller and smaller spots.

sure the setting is appropriately established and set properly for each observer, the eyepieces must be individually focused subjectively to determine the true "zero setting," which may, for example, be −2.5 diopters (D) or even on the hyperopic side.

Laser Beam Focal Plane (Waist) Not Coincident with the Focusing Rod Plane. Wise[1] has shown that for a 50-μm spot-size setting, only 14% of the argon laser instruments tested were in fact properly aligned, when judged as a spot size of 70 μm (double the area of a 50-μm spot) or less. For a nonaccommodating emmetrope, using a zero ocular setting, most (70%) instruments tested produced spots of more than 75 μm, whereas 30% produced spot sizes of more than 100 μm. Even when the optimal ocular setting was determined using the focusing rod, as many as 37% of the laser instruments tested produced a minimum spot size of more than 75 μm.

Focusing the Laser Spot as Opposed to Focusing the Retinal Image

When using a defocused delivery system–type laser, only the small spot sizes appear sharply focused. Larger spots have fuzzy borders, and hence can be sharpened and made smaller by pulling on the joystick at the expense of losing focus of the retina. If one were to "focus" such an aiming beam spot, a smaller, erroneous burn would result, as shown in Figure 3, bottom row. It is the image (either the retina or trabecular meshwork) rather than the aiming beam spot that should be focused, especially when using defocused lasers. This not only helps to overcome some of the pitfalls but also makes the treatment session less stressful for the surgeon because he or she can comfortably view in sharp focus both the retina and the laser marks as they are applied. The slit-lamp oculars should be properly set, otherwise there is no way of getting the retina in focus and still obtain an accurate spot size. In the case of the parfocal laser and with small (50–100 μm) spot sizes on the defocused lasers, the aiming beam spot should appear in focus. Therefore, in such instances when an attempt to focus the laser spot is made, at the expense of losing clear view of the retina (or trabecular meshwork), the treatment session should be paused to allow for readjustment of the ocular rings (by testing the current setting with a focusing rod). If this does not rectify the discrepancy, technical support should be sought to verify whether the beam's waist is coinciding with the focusing rod plane.

Inadvertent Accommodation

Laser photocoagulation is undoubtedly a stressful procedure for the younger, pre-presbiopic surgeon, especially during macular work. Therefore, additional accommodation may be triggered during such slit-lamp work. This induced accommodation is the final common pathway of several related reflexes and responses, including book-induced myopia, tubular myopia, instrument myopia, and, most important, knowing that the target is, in fact, at an arms-length distance away. We examined eight emmetropic young residents and found that, after a day's work, the focusing-rod determined settings ranged anywhere from +0.50 D to −4.50 D, with 72% in the −1.00 D to −3.00 D range.[4,5] When such significant inadvertent accommodation is not compensated for by resetting the ocular rings, the far point of the eye is no longer at infinity but becomes much closer (induced myopia), necessitating a corrective joystick movement to refocus the retina. Such movement will lead to spot-size errors. Figure 3, third row, shows how a 50-μm spot varies in size when an ocular setting is gradually changed in 1-D increments.

A Spot Larger Than Intended

A larger spot than intended will occur when, in the course of using a parfocal laser or with small spot sizes of the defocused laser, the surgeon focuses on a plane other than the preset focusing rod plane. This can stem from any combination of factors previously discussed. The recently introduced procedure for shunting retinal to choroidal vessels of patients with central retinal vein occlusion[6] is another laser procedure in which meticulous spot size may be crucial for success.

A Spot Smaller Than Intended

A smaller spot size than intended will usually occur with defocused-type lasers set to a large spot size when the surgeon attempts to sharpen the aiming beam spot (by "pulling back" on the joystick).

A Suggested Calibration Technique

A simple technique is described to verify whether the ocular setting and alignment of a laser are properly coupled to ones habitual accommodative/refractive state. Because this procedure tests the interaction between the laser and the user, different results can (and most probably will) be obtained for the same laser checked against different individuals.

1. Large black text printed by a laser printer on regular paper makes a simple, yet dependable, target (as opposed to the orange target used by Wise[1]). Secure the paper (using adhesive tape) onto the chin rest, perpendicular to the laser beam.
2. Verify your ocular setting using a focusing rod.[3,4] This step must not be skipped.
3. Set the laser to a 100 to 200-μm spot size and duration of about 0.3 to 0.5 seconds. Gradually increase the energy until distinct, well-demarcated holes are made in the paper. Apply burns only to printed (black) areas of the paper because nonpigmented paper will not "scar."
4. Important: when applying laser marks, focus the printed matter, ignoring the laser spot. You should not establish focus on the basis of the appearance of the laser aiming-beam spot either in this exercise or when treating patients.
5. Reduce the spot size to 50 μm and apply several practice marks until uniform marks are made.
6. Perform a series of marks with the ocular setting bracketed 3 to 4 D in each direction. For example, if the focusing rod setting was found to be −2 D, burn consecutive marks using the following settings: −5, −4, −3, −2, −1, 0, +1 D. Verify which of the marks is the smallest.

The smallest mark signifies the setting that should be used for laser work on this particular instrument for that particular individual. Figure 3, third row, presents the results of such an exercise. Notice that the smallest spot obtained using this bracketing technique (third row fourth from the left) is indeed smaller than the 50-μm spot obtained using the focusing rod setting (top row leftmost mark).

If a different setting was found using this exercise compared with the setting initially indicated by the focusing rod, one should use the former. Two factors may explain such discrepancy: inadvertent accommodation or instrument misalignment. Regarding the actual size obtained using the "50-μm" setting, it may still not be a true 50-μm spot,[1] but it is probably the smallest spot you will be able to obtain. Because accommodation fluctuates from minute to minute, and most probably even from second to second, additional accommodation may be induced during the laser procedure itself.

The true spot size obtained at the level of the retina is typically different from the spot size preset on the instrument. One obvious reason is that the spot size magnification factor is individual to each lens. Interestingly, experienced laser surgeons may "calibrate" the effective spot size against fundus structures such as retinal vessels or the optic disc. This is probably the most accurate approach and should be referred to as the "gold standard," in a clinic setting, for determining the true "burn-size", at the retina level.

Conclusions

Setting the laser to any particular spot size does not necessarily mean that this spot size will be obtained at the retina or trabeculum. Besides magnification factors related to the fundus contact lens and to the patient's own refractive error, one needs to be aware of errors that stem from the surgeon's state of accommodation, and any uncompensated refractive errors derived from the optical system. Such errors are of meaningful clinical magnitude.

Because the energy delivered by the laser to the retina is concentrated in the laser spot, when the spot is larger, the energy density is decreased inversely proportional to the spot diameter. Thus, if the "blurred" spot is twice the size of what is desired, the energy being delivered over the surface is only a quarter of what one might expect. The converse could result in overtreatment.

Correct application of the laser involves focusing the fundus image as opposed to relying on the size and sharpness of the aiming-beam spot to fine tune the focus. If, in the context of a wrong ocular setting and a parfocal laser, or alternatively, a defocused laser and small spot size, the examiner prefers to focus the laser aiming beam rather than the image, it is still possible to produce a correct spot size but at the expense of losing focus of the treated area. In fact, whenever the surgeon is under the impression that the laser aiming-beam spot needs additional focusing in addition to the need to focus the treated area, it is almost certain that the ocular setting is imprecise.

When using larger spot sizes with the defocused laser system, it is important that a careful calibration of the oculars precede the laser session. In addition, the retina, not the laser spot, should be focused during photocoagulation, otherwise the obtained spot size will not be the one set up by the surgeon.

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