The Effect of Axial Length on Laser Spot Size and Laser Irradiance

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Objective: To determine the effect of the axial length of the eye on laser spot size and irradiance.

Design: Experimental study using a calibrated Gullstrand-type model eye.

Methods: The model eye, which was fitted with a scale of half circles in the center of the artificial fundus, was first examined using 2 different fundus imaging systems, then with a setup of a slitlamp, 2 indirect condensing laser lenses, and a laser unit with a spot size of up to 7 mm. The axial length of the model eye was set to different values ranging from 20 to 31 mm, and the magnifications of the fundus imaging systems and the laser lenses were calculated and compared for a treatment spot with a diameter of 4 mm. The laser irradiance for treating the spot at different axial lengths was also recorded.

Results: Whereas the magnification of a fundus imaging system is inversely related to the axial length, the laser spot size is directly related to axial length when using indirect condensing laser lenses. Therefore, the changes of magnification produced by axial ametropia are mostly compensated, so that the intended size of the treatment spot is obtained even in eyes with a high axial ametropia. The laser irradiance, on the other hand, has a significant variation for the observed range of the axial length.

Conclusion: Axial length has a significant effect on laser spot size and laser irradiance.

Clinical Relevance: The effect of axial length on laser spot size and laser irradiance may be ignored when administering photodynamic therapy with verteporfin but has to be considered for transpupillary thermal treatment of choroidal neovascular lesions.

MATERIALS AND METHODS

The objectives of our methods were as follows: (1) to calculate the correlation between image magnification and axial length when using 2 different fundus imaging devices, the fundus camera (CF-60 UV; Canon, Tokyo, Japan) and the scanning laser ophthalmoscope (SLO 101; Rodenstock Instruments, Düsseldorf, Germany); (2) to compare the results with the requirements of establishing the correct laser-spot size with when using the 2 Mainster lenses; and (3) to determine the variation of laser irradiance when using the 2 Mainster lenses with different axial lengths.

MAGNIFICATION OF THE FUNDUS IMAGING SYSTEMS

A Gullstrand-type model eye with a laser-etched scale of concentric half circles in the center of the artificial fundus (Figure 1) was filled with distilled water and placed in front of each of the 2 fundus imaging devices. The axial length was set at different values ranging from 20 to 31 mm, corresponding to a refractive range of −16.5 to +12.5 diopters (D). At each value, we obtained an image of the scale with the 40° image-field setting and measured the diameter of the smallest half circle, which has a true size of 4 mm. By dividing the measured length by 4, we obtained the actual magnification of the fundus image at the different axial lengths, and by dividing the measured lengths by the camera magnification factor, we calculated the laser-spot size according to the treatment protocol of the Treatment of Age-Related Macular Degeneration With Photodynamic Therapy (TAP) study group. Similar setups can be used to calculate the fundus camera correction factor  (degrees per millimeter) and thus to calculate the exact magnification using the Littmann or Bennett formulas. Since we only wanted to compare the magnification factors obtained within our setup, these last 2 calculations will be described in another report (Siamak Ansari-Shahrezaei, MD, unpublished data, December 1998).

MAGNIFICATION OF THE MAINSTER STANDARD AND WIDE FIELD LENSES

The model eye was placed in front of the laser (Opal PDT-Laser; Coherent, Palo Alto, Calif). A Mainster Wide Field lens and a Mainster Standard lens whose cups were filled with 2% methylcellulose (2% Methocel; Cibavision, Munich, Germany) were placed on the cornea, the aiming beam was carefully focused on the scale in the fundus of the model eye, and we tried to fit the spot of the aiming laser into the half circle with a diameter of 4 mm. After fitting the aiming-beam spot into the half-circle scale, we recorded the reading from the laser console, which provided the setting of the spot size required at each axial length and the laser power setting provided for this spot size. The actual spot-size magnification of the laser lens was calculated using the following formula:

\[ \text{Ma} = \text{Ms} \times \frac{S}{R}, \]

where \( \text{Ma} \) is the actual magnification; \( \text{Ms} \), the standard magnification provided by the manufacturer of the lens; \( S \), the actual diameter of the half circle; and \( R \), the spot-size reading obtained at each axial length from the laser console.

STATISTICS

For statistical calculations, we used commercially available software (Statview 5.01; SAS Institute, Cary, NC) for descriptive statistics and bivariate scatter charts.

Figure 1. Image of the scale of half circles as obtained using the 40° field of the fundus camera (CF-60 UV, Canon, Tokyo, Japan).
there is no immediate change in the ophthalmoscopic appearance of the lesion. In TTT, there should be no change or only a minimal whitening of the lesion at the end of the laser exposure. This raises the question whether it might be useful to know the exact amount of laser irradiance applied to the CNV, and to investigate whether the laser-spot size and the laser irradiance are affected by the axial length of the treated eye, especially when using indirect condensing laser lenses (eg, Mainster Standard and Wide Field or Volk Transequator). These lenses produce a real inverted image of the fundus and, therefore, have optical characteristics similar to those of a fundus camera. To answer these questions, we performed an experimental study using a calibrated model eye of the Gullstrand type and investigated the effect of axial length on the treatment variables currently recommended for verteporfin therapy.

### RESULTS

The results of our measurements are listed in the Table. Correlations between axial length and magnification of each device are presented in Figure 2 and Figure 3. The fundus camera is a nontelecentric device and uses compensation lenses for high ametropia, which results in a nonlinear relation of axial length and magnification and additional changes of magnification when the compensation lenses are used. The scanning laser ophthalmoscope and the Mainster lenses are also not pure telecentric imaging systems, but they show an almost linear relation between axial length and magnification for an axial length of 20 to 29 mm and can be considered telecentric within this range. Figure 4 provides the correlation between the measured spot sizes of both imaging devices and the required spot size for covering the 4-mm spot at each axial length with both laser lenses. Figure 5 and Figure 6 show the differences between required and calculated spot sizes in relation to axial length. When using the Mainster Standard lens, there is a maximum deviation of −440 µm at a refraction of +10 D with the fundus camera, whereas there is a maximum deviation of −300 µm at −10 D with the scanning laser ophthalmoscope. These deviations result in a calculated spot size smaller than that required. When using the same spot

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**Table**

Variation of Magnification, Spot Size, and Laser Irradiance for Different Values of Axial Length

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<th>Axial Length, mm</th>
<th>Refraction, D</th>
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</table>

*D indicates dioptr; magn, actual magnification factor for fundus image or laser spot; calc spot, spot size calculated with fixed magnification factor; required spot, spot size required to cover a spot 4 mm in diameter; laser power, setting at required spot size; plus, hyperopia compensation lens used; minus, myopia compensation lens used.

†CF-60 UV (Canon, Tokyo, Japan), 40° field.
‡SLO 101 (Rodenstock Instruments, Dusseldorf, Germany), 40° field.
§Mainster Standard lens (Ocular Instruments, Bellevue, Wash).
||Mainster Wide Field lens (Ocular Instruments).
size calculations and the Mainster Wide Field lens, the differences between calculated and required spot size will only produce larger spot sizes than those intended. The variation of laser irradiance when using a Mainster lens for treating a 4-mm spot at different axial lengths of the model eye is also shown in Figure 7 and listed in the Table. The laser power required for PDT to treat a spot of 4 mm with a laser irradiance of 600 mW/cm² is 75 mW. According to our measurements, the laser power used to treat a 4-mm spot at different axial lengths varies from 47 to 116 mW for the Mainster Standard lens and 39 to 92 mW for the Mainster Wide Field lens. This translates into a variation of laser irradiance between a minimum of 312 and a maximum of 928 mW/cm² or a laser fluence of approximately 25 to 75 mJ/cm² for axial lengths ranging from 20 to 31 mm.

**COMMENT**

It is well known that the calculation of the true size of an object in the ocular fundus depends on the knowledge of the refraction, corneal curvature, and axial length of the eye and the magnification of the fundus imaging system. Nevertheless, exact calculations of the size of fundus lesions have until now mainly been performed to calculate the true area of the neuroretinal rim of the optic disc or the size and volume of intraocular tumors. Although most laser surgeons have noticed, when using indirect condensing laser lenses, that laser spots are significantly larger in myopic eyes than in hypermetropic eyes, these findings were of little importance, since the actual size of a laser spot is also affected by the accommodative status of the laser surgeon, the optical quality of the refractive media of the treated eye, and the optical quality of the laser delivery system. Most experienced laser surgeons are aware of these factors and include them when changing the optimal setting for transpupillary laser photocoagulation of the retina.

In the phase 1/2 trial investigating the correct dose of verteporfin and laser fluence for the treatment of subfoveal CNV, and in the TAP and Verteporfin in Photo-
dynamic Therapy (VIP)\textsuperscript{10} trials, the transparent overlay sheet generated by the Wilmer Reading Center for the Macular Photocoagulation Study trials was used to measure the size of the lesion on the film negative. This sheet uses circles of different diameters to represent areas of different disc size and a smaller ruler with a total length of 2 cm and subunits of 0.1 mm. To calculate the largest linear dimension of the lesion, the measurement performed with this ruler was divided by 2.5, when the Zeiss 30° (FF 4 fundus camera; Carl Zeiss, Oberkochen, Germany), the Topcon 35° (TRC-50 series fundus cameras; Topcon, Tokyo), or the Canon 40° image fields had been used for obtaining the images, since the respective manufacturers indicated that their cameras all had a magnification factor of 2.5 at these field angles. The PDT protocol adds 1000 µm to the largest linear dimension to provide a treatment area that would include the whole lesion and a safety margin of 500 µm. On the other hand, the aiming beam of the treatment laser used a green or red laser and produced a bright spot exactly the size of the treatment area, which allowed easy identification of lesion details. Thus, it was quite easy for the investigator to verify that the treatment spot calculated according to the study protocol indeed covered the whole lesion. In the TAP trial,\textsuperscript{2} the inclusion criteria required the study eye to have an ametropia of less than 6 D, which prevented any significant deviation of the measured lesion size due to an abnormal axial length of the study eye. In the VIP trial,\textsuperscript{10} eyes that were seen with a subfoveal classic CNV due to pathologic myopia were also included. Many investigators in the VIP pathologic myopia trial noted that when examining angiograms obtained from myopic eyes, the magnification of the images was much different from those of eyes treated for subfoveal CNV in AMD. However, when using the Mainster Standard and Mainster Wide Field lenses, which were the lenses preferably used, the treatment-spot size always fitted the lesion in a similar way as in all nonmyopic eyes. This experience prompted us to investigate the exact relation of the lesion size measured using different fundus imaging systems with the actual treatment spot size obtained using the Mainster lenses and a laser commercially available for PDT.

The results of our study indicate that the current method of using a fixed magnification factor does not produce clinically significant errors. The observed maximum deviation of 4400 µm with the fundus camera and 300 µm with the scanning laser ophthalmoscope, when using the Mainster Standard lens, is still much less than the 1000-µm margin added to the largest linear dimension. Therefore, even in the extreme situation of a deviation of 4400 µm, there is still a safety margin of 500 µm, which should be sufficient for a complete treatment of the lesion. The Gullstrand-type model eye used for our study has a fixed corneal curvature and power of the intraocular lens, providing a model for ametropia only by varying the axial length of the model eye. Since the axial length is the most important factor for the change of the magnification due to ametropia,\textsuperscript{4} the deviations recorded in our setup are therefore most likely the maximum deviations to be expected in vivo, where a wide variation of corneal curvature, refractive power of the crystalline lens, and total axial length provide the refractive status of the patient’s eye. Our results stress the importance of a correct definition of all lesion components (eg, classic and occult CNV, pigment epithelial detachment, blocked elevated hypofluorescence, and blood) to achieve a treatment-spot size that covers the whole lesion. On the other hand, the use of a fixed magnification factor with a Goldmann-type fundus lens, which has a magnification independent of axial length,\textsuperscript{20} would produce a treatment spot too small to cover the whole lesion in myopic eyes and a treatment spot much larger than necessary in hyperopic eyes. Thus, indirect condensing laser lenses (Mainster Standard and Wide Field, Volk Transequator, and PDT lenses) should be preferred for PDT treatment to achieve a correct treatment spot size. Still, it might be useful to examine other fundus imaging systems and other laser lenses for their deviations of calculated and required laser spot size.

The laser irradiance observed in our experimental setup suggests that in myopic eyes with an axial length of 31 mm, the irradiance is more likely close to 300 mW/cm\textsuperscript{2}, which is only half the irradiance intended by the TAP protocol (600 mW/cm\textsuperscript{2}).\textsuperscript{2} On the other hand, the phase 1/2 trial demonstrated that there is indeed a strong treatment effect within a range of 300 to 1200 mW/cm\textsuperscript{2}, and the 600-mW/cm\textsuperscript{2} dose was chosen because there was a maximum of vision improvement at 4 and 12 weeks after treatment. The VIP study group has also reported the first results of the randomized treatment of subfoveal CNV in pathologic myopia. The percentage of eyes with less than 3 lines of visual loss was significantly higher in the treatment than in the placebo group (86% vs 66%), a difference of the same magnitude as in the 12-month results of the TAP study.\textsuperscript{10} This indicates not only that a slightly reduced laser irradiance in myopic eyes is sufficient for a treatment effect similar to the results of the TAP trial, but also suggests that there might be a different situation when activating the photosensitizer in myopic eyes, where the choroid is significantly thinner and the CNV is much smaller than in eyes with classic CNV due to AMD. Thus, the current protocol for verteporfin therapy seems to provide an optimized laser irradiance also for eyes with high axial myopia, although the influ-
ence of a reduced laser irradiance on the outcome of verteporfin therapy should be investigated further in future studies. On the other hand, we cannot comment on the effect of the variation of laser irradiance caused by variation of the axial length when using other photosensitizers for PDT for choroidal neovascular lesions.

The effect of the axial length on laser irradiance when using indirect condensing laser lenses might be much more important when considering TTT. At present, no standardized treatment protocol for TTT exists, and although the first reported study used a Goldmann lens for TTT, others might prefer to use wide-field indirect condensing laser lenses to cover the whole lesion with the maximum spot size of 3 mm currently available with the laser adapter for TTT. Since most eyes currently recruited for TTT are eyes with AMD, and since AMD is associated with hypermetropia, it is likely that in some hyperopic eyes with a short axial length the laser irradiance during TTT using an indirect condensing laser lens will be significantly higher than when using the same spot and the same laser power in an emmetropic eye. Therefore, we recommend the use of the Goldmann-type lens for every TTT application, but also would remind users that any lesion size calculated with a fixed magnification factor cannot be used for treatment with a Goldmann-type lens. This setup would require the knowledge of the size of the lesion using the formulas provided already by several authors.

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REFERENCES


