# Retinal light exposure from ophthalmoscopes, slit lamps, and overhead surgical lamps

## An analysis of potential hazards

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*The projected beam radiance of several common ophthalmologic instruments was measured, and potential hazard to the patient from light exposure was analyzed with reference to safety standards for coherent light. The indirect ophthalmoscopes tested appear to be "safe" under moderate voltage settings, provided exposure is reasonably brief. Slit-lamp biomicroscopy of the fundus, however, merits caution. It produces a three-times-higher retinal irradiance than the indirect ophthalmoscope. Overhead surgical lamps produce a retinal irradiance about one-third that of the indirect ophthalmoscope (for clear media and dilated pupil). This could be dangerous, since an operation may take long enough to exceed the maximal permissible exposure by several orders of magnitude. Major design changes are indicated for surgical illuminators to extend the "safe time" to the 40 to 60 min range.*

**Key words:** phototoxicity, light damage, laser safety, ophthalmoscopes, slit lamps, surgical illuminators, retinal burns, retinal irradiance, rhesus monkey, radiance

When the ophthalmoscope was first introduced over 130 years ago, some doctors thought it might be dangerous to admit "naked" light into diseased eyes.[1] Even today, this objection has not been settled. The purposes of this study are to quantitate retinal light exposure from several ophthalmologic instruments and to make estimates of their relative safety.

With the advent of the laser in the early 1960s, hundreds of researchers have tried to define retinal damage thresholds to laser light, using monkeys as the principal model. The American National Standards Institute (ANSI) guidelines for the safe use of lasers conveniently compiled much of this work.[2] Work is just beginning on white light (noncoherent) safety standards. The laser guidelines, however, correlate closely enough with white light studies of retinal damage thesholds so that first approximation comparisons seem justified.

We describe a method of measuring the beam radiance of ophthalmologic instruments and, from this, a method of calculating the retinal irradiance. Our results for the indirect ophthalmoscope agree quite closely with estimates made by an entirely different method.[3] We then make use of the ANSI laser guidelines to specify the time required to reach the presumed safety limit (the maximum permissible exposure, MPE). An example of noncoherent white light retinal changes is also shown to substantiate predicted hazards.

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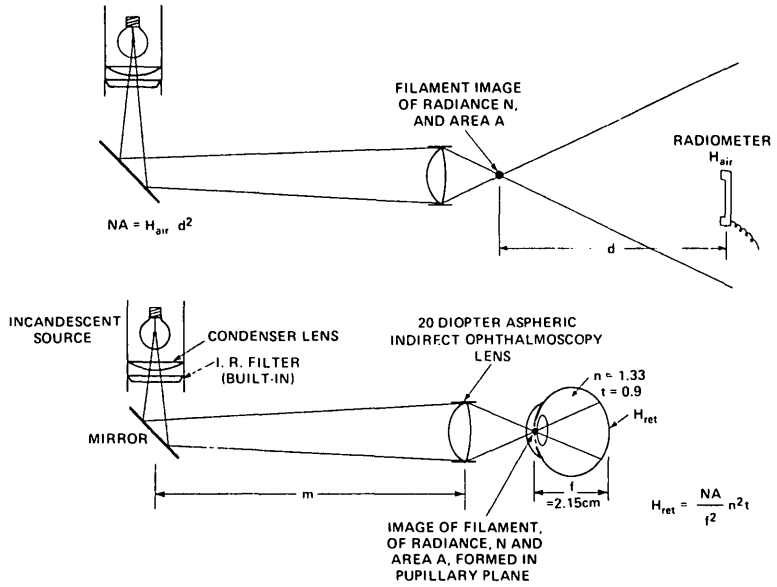


**Fig. 1.** Indirect ophthalmoscope radiometry and calculation of retinal irradiance. $H_{ret}$.

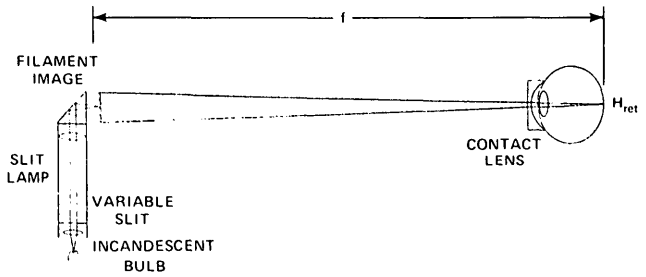


**Fig. 2.** Slit-lamp biomicroscopy of the macula through a plano contact lens.

## Materials and methods

Fifteen indirect ophthalmoscopes in daily use at the Wilmer Institute were measured as shown in Fig. 1. Ten of these were American Optical and five were Frigi-Xonix. A 20 D Nikon lens was placed 30 cm from each instrument to simulate actual clinical conditions. Fourteen and 27 D lenses were compared with the 20 D baseline. The ophthalmoscopes were tested as they were found in the clinics, without cleaning the optics.

All measurements were made with an EG&G Model 550 radiometer/photometer with a type A silicon multiprobe detector head, which passes approximately the same wavelengths as does the ocular media. Instrument lamp voltages were directly monitored and adjusted with a variable transformer to give the exact voltages shown.

As shown in Fig. 1, the radiometer was used to measure the quantity $NA$, where $N$ is the radiance of the filament image and $A$ is its projected area. The distance, $d$, was typically 90 cm. The quantity $NA$ was substituted into the equation shown to calculate expected retinal irradiance, $H_{ret}$, under typical clinical conditions. Assumptions are that the index of refraction, $n$, of the vitreous is 1.33, distance of the pupillary plane (and therefore the filament "hot spot") from the retina is 2.15 cm, and transmission, $t$, of clear ocular media is 90%.*

It is necessary to correct for index of refraction, n, because our radiometric measurements were made in air (index = 1.00); whereas the retina is "under water." The conservation of radiance theorem states that $N/n^2$ is constant along the ob-

*Even though the ocular media may transmit considerably less than 90% in aged or diseased eyes, certainly many healthy, young patients will exhibit 90% transmission. Also, many pupils will not be fully dilated. However, when discussing *safety*, "worst case" conditions are indicated.

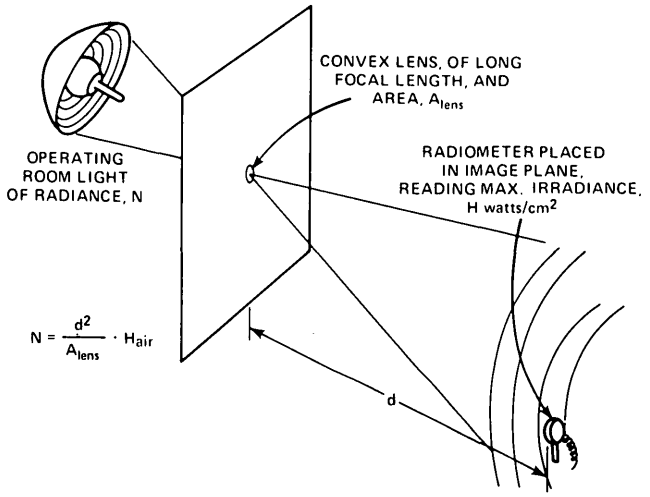


**Fig. 3.** Radiometric measurement of the source radiance, *N*, for an overhead surgical lamp.

servation path through a specular optical system. The ocular media is assumed to be specular prior to absorption of light at the retinal level. This, of course, would only be valid for clear media.

Four Haag-Streit slit lamps in the clinic were then measured, assuming the configuration shown in Fig. 2. It is assumed that a plano contact lens is placed on the cornea, as for biomicroscopy of a macular lesion. The distance, *f*, was computed for each individual instrument by locating the filament image. The distance from contact lens surface to retina was assumed to be 2.6 cm. Since the virtual image of the retina lies approximately 1/n of this distance from the contact surface, the distance measured from the sharply focused slit beam in air to the calculated position of the filament image was increased by 0.65 cm to arrive at a value for f. The formula for retinal irradiance ($H_{ret}$) is the same as for the indirect ophthalmoscope:

$$H_{ret} = \frac{NA}{f^2} \cdot n^2 t$$

and the quantity NA was measured by

$$NA = H_{air} \cdot d^2$$

where d is the distance from the filament image to the radiometer head during testing (typically 2 m) and $H_{air}$ is the radiometer reading in watts per square centimeter. The slit width adjustment was opened widely, since slit beam brightness is nearly independent of slit width.

Four Castle No. 24 minor surgical lamps (with ribbed reflectors 18 inches in diameter) and two Castle No. 800 ceiling-mounted lamps (with smooth reflectors 24 inches in diameter) were measured. A large baffle with a +0.75 D trial case lens placed in the center was used (Fig. 3). The baffle was positioned where the lamp "hot spot" seemed to focus, about 1 m from the reflector. The clear area of this lens, $A_{lens}$, was measured. In the case of the ribbed reflectors, a series of concentric circles were thus focused on the wall about 4.6 m away, giving a magnified view of the pattern which might appear on the patient's retina (Fig. 4). The radiometer head was then placed in the middle of one of the rings, to obtain $H_{air}$. From the formula shown in Fig. 3, *N* was then calculated. For the smooth reflector lamps, a large, nearly uniform pattern formed. The radiometer was placed near the center of this.

Since ANSI Z-136 laser safety guidelines are given in terms of radiance values, these were converted to $H_{ret}$ to provide a common denominator with which to compare our measurements. The data for extended sources in the 400 to 700 nm range from p. 34 of that publication[2] were used, with the following conversion formula:

$$H_{ret} = \frac{N_{max} A_{pupil}}{f^2} \cdot n^2 \cdot t = 0.133\ N_{max}$$

where $N_{max}$ is the MPE value given (if N is given in integrated radiance values such as joules per steradian per square centimeter, then $H_{ret}$ will be an integrated irradiance, i.e., $J/cm^2$.); $A_{pupil}$ is the area of the patient's 7 mm dilated pupil (since the guidelines were formulated with a 7 mm pupil assumed); and *f* is the distance from iris to retina, since the iris is the aperture stop in the system. The $N_{max}$ value listed for exposure times from 10 sec to a little less than 3 hr is 22 $J \cdot sr^{-1} \cdot cm^{-2}$. So the retina MPE would be $0.133 \times 22\ J \cdot sr^{-1} \cdot cm^{-2} = 2.92\ J/cm^2$.

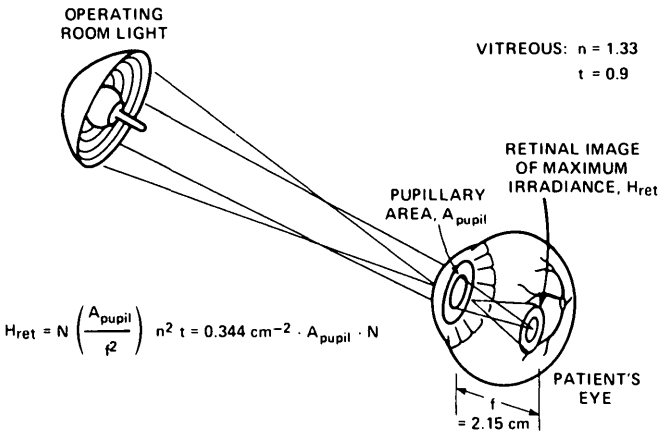


Fig. 4. Calculation of the retinal irradiance likely to be produced by an overhead surgical lamp aimed at the eye, once $N$ is known and several constants are assumed.

As a rough confirmation of our findings, a rhesus monkey's eye was exposed to a Zeiss photo-slit lamp through a plano contact lens for 20 and 40 min. $H_{ret}$ for the monkey was calculated at 296 mW/cm$^2$. The photoflash tube had been removed from the slit lamp. Follow-up fundus photos and fluorescein studies were done.[4]

## Results

The average $H_{ret}$ from the standard binocular indirect ophthalmoscopes tested is seen in Table I to be about 69 mW/cm$^2$ with the lamps operating at their design voltage (6.5 V) and 125 mW/cm$^2$ with the transformer turned up to its maximum setting.

Two direct ophthalmoscopes were tested (A-O Giantscope and Welch-Allyn with standard bulb) at design voltages. They yielded an $H_{ret}$ average of 29 mW/cm$^2$, or approximately half that for the indirect ophthalmoscopes (when a 20 D lens was used).

Twenty-seven and 14 D lenses were tried with a single, indirect ophthalmoscope operated at its design voltage. The 27 D lens yielded an $H_{ret}$ 47% lower than did a 20 D lens. The 14 D lens, on the other hand, gave an $H_{ret}$ 81% higher than the 20 D lens. Cleaning the dust off the optics changed the readings by only a few percent.

Slit lamps produced the average $H_{ret}$ values found in Table II for the three voltage settings indicated. Biomicroscopy of the fundus with a slit lamp, through a plano contact lens, with medium-intensity settings will produce an $H_{ret}$ of 217 mW/cm$^2$, or three times that produced by the indirect ophthalmoscope under medium-intensity settings with a 20 D lens.

Overhead surgical lamps produce the $H_{ret}$ values seen in Table III, typically 25 mW/cm$^2$ or less. This is almost as high as that from a direct ophthalmoscope.

A monkey exposed to a narrow slit beam for 40 min (710 J/cm$^2$) had a visible whitening 24 hr afterwards in the exact shape and location of the slit illumination.[4] This effect was not visible 1 hr after exposure but persisted for 1 week, although of diminished contrast with the surrounding retina. The adjacent slit exposure for 20 min (355 J/cm$^2$) never became visible on fundus photography. However, 1 year later, both exposures had a slight residual blocking pattern on the fluorescein angiogram. Exposures of 15 and 10 min produced no visible retinal change.

## Discussion

To put $H_{ret}$ values in perspective, one might use the ANSI Z-136 guidelines[2] for laser safety.* The power in watts per square

*The ANSI standard for the 400 to 700 nm range is based mostly on red laser light. Since ophthalmic instruments produce white light from an incandescent source, a correction factor would be desirable. Such a factor, though unavailable, is not essential for this first-order comparison because the infrared threshold limit value is five times higher than for red light whereas the 440 nm threshold limit value is 1000 times lower than for red.[5] The two effects tend to roughly balance each other, considering large infrared quantity in emission spectrum.

centimeter on the retina times the number of seconds of exposure gives the energy in J per square centimeter. And, in this domain, 2.92 J/cm$^2$ is identified as the MPE. For an $H_{ret}$ of 125 mW/cm$^2$, the time required to reach the MPE is

$$t_{MPE} = \frac{2.92 \text{ J/cm}^2}{0.125 \text{ watts/cm}^2} = 23.4 \text{ sec} = \text{"safe time"}$$

The MPE is intended to lie 2 orders of magnitude below the threshold for a 50% probability of producing an ophthalmoscopically visible retinal lesion in a series of monkeys.[6, 7]

For the results given in Tables I to III, the column or row labeled "Average safe time" is the time required to reach the MPE. For exposures longer than this, one presumably risks the occurrence of some retinal or RPE changes. Undoubtedly, many changes do occur which reverse completely in healthy individuals; otherwise we would all have been much more acutely aware of light-induced damage by now. However, the assumption that diseased or aged maculas will recover fully is much more tenuous.

One could argue that laser guidelines are inappropriate for noncoherent (white light) sources, and indeed they are. However, there is a mounting body of evidence that for the time domain of relevance here and in the visible spectrum, comparative threshold values seem in fairly close agreement (whether xenon lamp, carbon arc, He-Ne, ruby, or argon laser).[8–10]

In fact, there is good reason to suspect that light sources (coherent or noncoherent) which emit more heavily toward the blue may have a higher probability of producing subthreshold changes than even the laser safety standards would suggest. Sperling[11] produced extensive histologic damage to the retinal pigment epithelium in monkeys with a blue (463 nm) noncoherent light $H_{ret}$ of 0.01 to 0.1 mW/cm$^2$ for 60 min. The integrated $H_{ret}$ would thus be less than 0.36 J/cm$^2$ or around 1 order of magnitude less than the MPE level! Ham et al.[12] produced ophthalmoscopically visible retinal changes in a monkey with the 441.6 nm line from a He:Cd laser at 0.30 mW/cm$^2$ × 1000 sec = 30 J/cm$^2$, only 1 order of magnitude above the MPE.

These examples should be born in mind when attempting to discredit the use of laser safety guidelines in this context for being too conservative. Several additional citations validate the usefulness of the ANSI Z-136 guidelines in predicting approximate damage thresholds. They also form a basis of compari-

**Table I.** Indirect ophthalmoscope $H_{ret}$ (mW/cm$^2$)

| | *Lamp voltage* | |
|---|---|---|
| *Instrument* | *6.5 V (design voltage)* | *7.8 to 8.4 V (maximum transformer setting)* |
| American Optical: | | |
| 1. | 66.4 | 122 |
| 2. | 55.8 | 102 |
| 3. | 133 | 205 |
| 4. | 66.3 | 126 |
| 5. | 82.0 | 151 |
| 6. | 50.9 | 100 |
| 7. | 62.6 | 138 |
| 8. | 106 | 110 |
| 9. | 70.7 | 120 |
| 10. | 59.7 | 98.0 |
| Frigi-Xonix: | | |
| 11. | 75.1 | 150 |
| 12. | 45.0 | 96.0 |
| 13. | 81.0 | 161 |
| 14. | 53.4 | 114 |
| 15. | 40.3 | 85.0 |
| Average $H_{ret}$ | 68.6 | 125 |
| Average safe time* (MPE) | 42 sec | 23 sec |

*Safe time is defined as the time required to reach an integrated $H_{ret}$ of 2.92 J/cm$^2$.

**Table II.** Slit-lamp $H_{ret}$(mW/cm$^2$)

| | *Lamp voltage* | | |
|---|---|---|---|
| *Instrument* | *5.0 V* | *6.0 V (design voltage)* | *7.5 V* |
| Haag-Streit (Model 900): | | | |
| 1 | 157 | 243 | 381 |
| 2 | 173 | 269 | 468 |
| 3 | 116 | 177 | 293 |
| 4 | 115 | 179 | 289 |
| Average $H_{ret}$ | 140 | 217 | 358 |
| Average safe time | 21 sec | 13 sec | 8 sec* |

*Since "safe time" is less than 10 sec, the nonequilibrium equation is used: $t_{safe} = 1.68\ H_{ret}^{-3/2}$.

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**Table III.** Overhead surgical lamps

| *Instrument* | *d (cm)* | $H_{air}$ *(mW/cm²)* | $N = H \cdot \frac{d^2}{A}$ *(W/cm² · sr)* | $H_{ret} = 0.133\ N$ *(mW/cm²)* | *Safe time (MPE) (sec)* |
|---|---|---|---|---|---|
| Castle Model 800, ceiling mount with smooth reflector, 24-inch diameter: | | | | | |
| 1. | 346.7 | 6.5 | 0.18 | 24 | 122 |
| 2. | 337.8 | 7.0 | 0.18 | 24 | 122 |
| Castle minor surgical lamp with ribbed reflector, 18-inch diameter: | | | | | |
| 3. | 411.5 | 2.7 | 0.10 | 14 | 209 |
| 4. | 381.0 | 4.5 | 0.15 | 19 | 154 |
| 5. | 378.5 | 5.9 | 0.19 | 25 | 117 |
| 6. | 375.9 | 5.7 | 0.18 | 24 | 122 |

son with the white light levels available from ophthalmologic instruments.

Fuller et al.[13] demonstrated that a white-light fiber optic vitrectomy probe inside a monkey eye with a calculated $H_{ret}$ of 220 mW/cm² produced ophthalmoscopically visible retinal changes in 15 to 20 min. All the monkeys receiving the 20 min exposure had visible changes. This is 264 J/cm², or only about 1 order of magnitude above the MPE!

Ophthalmoscopically visible retinal lesions were produced by Cavonius et al.[14] in humans scheduled to undergo enucleation, using a xenon arc photocoagulator (2/3 disc diameter spot size) with 1 sec exposures. The threshold from their data for a 50% probability of producing a visible lesion (after adjusting the 57% ocular transmission, they assumed to the 90% we have assumed) was 86 J/cm² for blue-eyed patients and 34 J/cm² for brown eyes. Since the MPE for a 1 sec exposure would be 1.33 J/cm², these exposures were 1.8 log units above the MPE for blue eyes and 1.4 log units above the MPE for brown eyes. Remember that the 50% threshold for visible retinal changes in the monkeys selected to formulate the ANSI standards was 2 log units above the MPE. If anything, the ANSI model is not conservative enough by this comparison.

Monkey retinas were exposed to an indirect ophthalmoscope (20 D lens) for 15 min.[15] The following day, gross whitening was evident, and histologic changes were marked. According to our measurements and taking the "brightest" indirect ophthalmoscope in our series (140 mW/cm² at 7.0 V), retinal exposure would have been 228 J/cm² in the monkey (assuming an iris-to-retina distance of 1.60 cm in the monkey). Again, this is only 1.9 log units above the MPE.

An indirect ophthalmoscope (at 7.0 to 7.5 V), with a 20 D lens, was aimed at monkeys' eyes for 1 hr.[16, 17] Within 1 to 5 days, ophthalmoscopic and histologic changes were present in all eyes. Severely affected cases had pigment changes present even at 5 months, with evidence of photoreceptor regeneration.[17] We would guess from our averages and the shorter length of monkey eyes that the integrated $H_{ret}$ in these cases was from 482 to 911 J/cm², or from 2.2 to 2.5 log units above the MPE, a suprathreshold condition.

The indirect ophthalmoscopes are seen to be quite "safe" by the ANSI laser criteria when moderate voltage settings and appropriately short exposure times are used. Most fundus examinations take less than 10 sec for any given retinal position. Occasionally, however, as long as 40 to 60 sec are required to identify the pathology. The "safe time" would be exceeded in this case. On maximum intensity settings, not only does more of the blue end of the spectrum come through, but safe times drop to only 15 sec in one case (instrument 3) and 23 sec for an overall average. Of course, if a 27 D lens is being used, one could multiply the safe times shown by a factor of 2.

Slit-lamp biomicroscopy produces over three times greater $H_{ret}$ than the indirect

ophthalmoscope. This is cause for concern because one does not usually perform such an examination on a macula unless the macula is diseased. Yet a diseased macula is undoubtedly more susceptible to light damage than is a healthy one.

Overhead surgical lights probably present a greater hazard than ophthalmoscopes or slit lamps. Whereas the latter instruments are used for brief intervals for diagnostic purposes, the surgical lamps may expose the retina for prolonged periods of time. Exposure for various types of surgery could stretch from 5 to 45 min or more. Yet (for a dilated pupil) only about 2 min would be "safe." For a 3 mm pupil, one has about 11 min of "safe time." The large, smooth reflector lamps illuminate an area 5 disc diameters in size. Therefore some areas of retina may be continuously exposed even though the eye is constantly moving. Aphakia or other extreme refractive errors do not protect the patient (for smooth reflector lamps) because the source is so large. For ribbed reflectors, however, the concentric rings may be blurred enough to provide some protection.

One would not consider aiming a direct ophthalmoscope steadily at the macula for 15 min. Yet surgical lamps produce two thirds of the $H_{ret}$ of direct ophthalmoscopes (dilated pupils) and frequently for longer intervals than this. In another report,[18] various surgical microscopes were measured. Average $H_{ret}$ for myopes and emmetropes from popular models was 460 mW/cm$^2$. The nonfiber optic model produced 970 mW/cm$^2$, with a "safe time" of 1.8 sec! Surgical microscopes illuminate only a small spot on the retina, however, measuring about 1½ disc diameters which makes it difficult to compare them directly with overhead surgical lamps.

We urge manufacturers to design safe surgical illuminators, hopefully with a "safe time" of 45 to 60 min. Subtracting the especially hazardous portions of the blue spectrum and the unnecessary infrared spectrum will be a great help. Diagnostic instruments could hopefully be filtered as well. The primary impetus should come from the ophthalmologist in restricting nonessential light exposure, especially to the macula.

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