A Comparison of Nd:YAG Laser Damage Thresholds For PMMA and Silicone Intraocular Lenses

Patricia E. Bath,* Andrew D. Romberger,f and Perry Brown‡

Power density producing damage at a probability of 0.5 (ie, damage threshold, DT-50) was determined for PMMA (with/without UV absorber) and Silicone intraocular lenses. Scattered light from a collinear diagnostic He:Ne beam was one of four damage monitors deployed to enhance the sensitivity of the system. In order of increasing laser resistance the following results were obtained: injection molded PMMA (1.9/GW/cm²) Silicone (2.63 GW/cm²) Lathe-cut PMMA (4.47 GW/cm²), Lathe-cut PMMA with UV absorber (8.32 GW/cm²), Cast-molded PMMA (12.30 GW/cm²). An analysis of variance revealed interclass differences significant at the .01 level. Cast-molded PMMA was the most laser-resistant IOL material. Invest Ophthalmol Vis Sci 27:795-798, 1986

Nd:YAG Laser IOL damage to the intraocular lens may occur during the procedure of photodisruption posterior capsulotomy. This damage is the result of optical breakdown occurring upon the surface or within the bulk of the intraocular lens. The phenomenon of optical breakdown occurs when the critical damage threshold for the material is reached or exceeded. This complication of intraocular lens YAG laser IOL damage could be minimized if the damage threshold for the intraocular lens is known and not exceeded during the photodissection surgery.

Damage threshold may be defined as that power density producing damage at a probability of 0.5., ie, damage threshold DT-50. The objective of our investigations was to determine the damage threshold for intraocular lenses. In this study we report the results of damage threshold investigation on PMMA and Silicone intraocular lenses.

Materials and Methods

Standard quality intraocular lenses were obtained from several of the major manufacturers of intraocular lenses in the U.S.A. Manufacturers participating in the study were as follows: Coburn, Clearwater, FL; Cilo, Pomona, CA; Intermedics, Pasadena, CA; Iolab, Claremont, CA; Surgidev, Goleta, CA; American Medical Optics, Irvine, CA; ORC, Azusa, CA, CooperVision, Bellevue, WA, and Staar Surgical. By prior agreement with the manufacturers, the results are reported generically. Five classes of IOL materials were tested as follows:

Class I: PMMA-IM PMMA, injection molded, Rohm and Haas, without UV-absorber.
Class II: PMMA-LC PMMA, latex cut, Perspex C.Q., without UV-absorber.
Class III: PMMA-LC/UV PMMA, Lathe cut, Perspex C.Q., with UV-absorber.
Class IV: PMMA-CM PMMA, cast molded, without UV-absorber.
Class V: SILICONE Silicone, without UV-absorber.

A minimum of four intraocular lenses were tested in each class for Nd:YAG damage threshold according to the following sequence of procedures: (1) Pre-irradiation inspection of IOL; (2) Controlled IOL irradiation with three in situ damage monitors; (3) Post-irradiation inspection of IOL.

Because Nd:YAG radiation damage may be manifest by pits and opaque inclusion defects, 100X transmission microscopy was conducted on each intraocular lens before any laser irradiation.

With 100X magnification, the sensitivity allowed detection of microstructural defects of approximately 2 μm. Some of the intraocular lenses prior to irradiation were noted to have particulate inclusions and other defects tabulated as follows in Table 1.

The laser and optical system used to perform the damage studies has been previously described. The laser is a Quanta Ray (Mountainview, CA) DCR-2A.
Table 1. Results of pre-irradiation inspection of IOls for particulate inclusions

<table>
<thead>
<tr>
<th>Number of particles</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class I (PMMA IM)</td>
<td>1/mm³</td>
</tr>
<tr>
<td>Class II (PMMA LC)</td>
<td>3/mm³</td>
</tr>
<tr>
<td>Class III (PMMA LC/UV)</td>
<td>1/mm³</td>
</tr>
<tr>
<td>Class IV (PMMA CM)</td>
<td>10/mm³</td>
</tr>
<tr>
<td>Class V (Silicone)</td>
<td>700/mm³</td>
</tr>
</tbody>
</table>

Q-switched Nd:YAG system with an unstable confocal resonator having a 1.06-μm wavelength output that is linearly polarized and produces $8 \pm 2$ nsec FWHM, 0–300 mJ pulses with a variable repetition rate of 1–10 pulses per second (pps).

The laser was pumped with a constant flashlamp energy and flashrate to foster thermal stability. The output could be continuously attenuated with thin-film polarizers placed in a rotatable mount. A bare silica wedge was used as a beam splitter with the 4% front surface reflection focused into the sample by a 24.7 cm focal length lens ($L_3$). The radiation transmitted by the wedge was collected by a Scientech Boulder, CO power meter (P.M.) for monitoring the laser power.

Since the HeNe laser had a different divergence, two lenses ($L_1$ and $L_2$) preconditioned the beam to focus at the same place in the sample as the Nd:YAG beam. $M_1$ and $M_2$ are folding mirrors. $S$ is the sample site. A dielectrically coated mirror ($M_3$) having a reflectivity of 70% at 632.8 nm and nearly 100% at 1.06 μm was used to separate the two beams and to allow observation of the diffraction pattern from damage on a screen (damage monitor #1). A 2 mw HeNe laser was used for alignment purposes and as a collinear source for the power meter (a Strehl detector). The Strehl detector was a beam diffraction analyzer and optically transmitted any light scattering centers onto the screen.

The reflected HeNe beam was then sent through the optics comprising the Strehl detector. The Strehl detector consisted of a 5-mm aperture (A) centered on the HeNe beam, a 2.5 cm focal length lens ($L_4$), a KG-3 crystal (F) used to block any stray 1.06-μm radiation, and an unbiased pin photodiode detector (P.D.). The photodiode output voltage was then displayed on a digital voltmeter (damage monitor #2) and recorded.

Fig. 1. Experimental set-up for intraocular lens damage test.
on a strip chart recorder. When damage occurs in the test sample, some red light is scattered resulting in a drop in photodiode voltage. The experimental set-up is diagramed in Figure 1.

The focused Nd:YAG beam was determined to have a 1/e² waist radius of 33 ± 1.7 μm, a Rayleigh range of 3.2 mm, and to be radially symmetric to 10% or better. The cone angle was 5 deg. The characterization was carried out using the knife-edge technique described by Mauck, and analyzed as described by O'Connell, et al. The same tests performed on the collinear HeNe beam yielded a waist size of 43 μm radius and a Rayleigh range of 9.2 mm. The HeNe and Nd:YAG beams almost completely overlapped.

Due to mode beating of the Nd:YAG laser, a widely varying and highly structured temporal shape was observed as previously reported by O'Connell. Because of this variance, the damage thresholds are reported in energy density, J/cm², as well as power density, W/cm². Damage was monitored by visual observation of the sample, looking for sparks (damage monitor #3) or bright scattering centers in the HeNe beam, observing changes in the transmitted HeNe beam displayed on the screen, and by the Strehl detector system. A change of .5% or more in the Strehl voltage was 98% reliable in detecting damage.

A post-irradiation examination of the sample was conducted using a 100X phase contrast microscope (damage monitor #4). The size of the damage site that could be reliably detected was approximately 2 μm in diameter. Damage was then defined for this experiment as those sites that exhibited 2 μm or larger changes (cracks, pits, etc) that could be observed with the microscope.

In order to determine energy producing damage, 50% of the time at a statistically significant level, each IOL was irradiated at approximately 69–86 sites per IOL.

The DT-50 damage data is reported for IOLs representing the five classes of IOL materials in the results section.

### Results

The results of the damage investigations for the five classes of IOL materials are tabulated in Table 2.

Because the data are not normally distributed, assumptions for the use of the standard parametric tests (ie, Student’s T-test, analysis of variance) could not be satisfied. Therefore, the data was transformed into a form which would make it more “normal.” The logs, mean logs, and geometric means of the power densities were calculated as tabulated in Table 3.

The significance of the differences between the classes of IOL materials was tested using one-way analysis of variance (Anova). Analysis of variance was performed based on the geometric means listed in Table 3. An F value of 28.5 was obtained from these calculations with 5 and 18 deg of freedom. [An F value of 4.96 is needed for statistical significance at the .05 level.]

Based on the above, the level of significance of interclass damage threshold differences is given in Table 4.
This analysis revealed that all interclass differences were significant at the .01 or .001 level except the difference between Class I and Class V. A comparison of damage thresholds for the 5 classes of IOL materials is illustrated in Figure 2.

**Discussion**

The results of our study indicate substantial differences among the classes of IOL materials tested. The most vulnerable IOL material was the injection-molded PMMA, which had a damage threshold of 1.91 GW/cm². The most laser-resistant IOL material was the cast molded, which had a damage threshold of 12.30 GW/cm². The damage threshold of lathe-cut PMMA was 4.47 GW/cm², representing over twice the damage threshold of injection-molded PMMA. Interestingly, the presence of a UV absorber in lathe-cut PMMA did not lower the damage threshold. Lathe-cut PMMA with an ultraviolet absorber had a damage threshold of 8.32 GW/cm². The damage threshold for silicone was 2.63 GW/cm². This value was not significantly different in comparison to injection-molded PMMA. In contrast, the interclass damage thresholds were significantly different at the .01 level for all other classes of IOL materials tested.

In summary, intraocular lenses fabricated of PMMA and Silicone were tested for damage threshold. Cast molded PMMA proved to be the most laser-resistant IOL material. The damage threshold of cast-molded PMMA had a laser resistance of over six times that of injection-molded PMMA. Injection-molded PMMA was the least laser-resistant. No significant difference was found between lenses fabricated from injection molded PMMA or Silicone.

The presence of a UV absorber in lathe-cut PMMA did not result in increased YAG laser vulnerability. In summary, a comparison of Nd:YAG laser damage thresholds revealed significant differences among the five classes of IOL materials tested.

**Key words:** Nd:YAG laser, damage threshold, intraocular lenses, polymethymethacrylate, silicone

**Acknowledgments**

The authors wish to express appreciation for the support of the Frank J. Seiler Research Laboratory of the USAF Academy and, in particular, the assistance of Lt. Col. Kenneth Siegenthaler, Capt. Billy Mullins, and Mr. Lee Burton.

**References**