Silicone intraocular lens resolution in air and in water

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ABSTRACT

The resolution efficiencies of 31 biconvex silicone intraocular lenses, ranging in power from 16.0 to 23.5 diopters, were tested in air and in water to see if a predictable relationship existed as previously reported with polymethylmethacrylate lenses. Resolution efficiency is defined as the percentage ratio of the actual resolving power of a lens to that of a perfect lens of the same focal length which is only limited in resolution by diffraction. The lenses ranged from 29% to 58% resolution efficiency in air. No lenses exhibiting multiple images were included. All 31 lenses achieved at least 73% resolution efficiency in water, and one lens achieved 82%. Based on these findings, a biconvex silicone lens that exceeds 30% resolution efficiency in air and does not produce multiple images can perform near its diffraction limit when implanted in the eye.

Key Words: biconvex silicone intraocular lens, diffraction limit, resolution efficiency

In a previous study,[1] we demonstrated a significant and predictable improvement in the resolution efficiency of polymethylmethacrylate (PMMA) lenses in water compared to measurements taken in air. We found that PMMA lenses that exceed 30% resolution efficiency in air will perform near their diffraction limit when implanted in the eye. We recommended that these values be adopted as a part of the new ANSI Standard, providing a more consistent standard, independent of dioptric power. These findings did not apply to lenses of other materials, such as silicone, since the indices of refraction and other optical characteristics may be different. The current study demonstrates the improvement in resolution efficiency for biconvex silicone intraocular lenses (IOLs) in air and in water.

MATERIALS AND METHODS

Thirty-one silicone IOLs with biconvex optics ranging in power from 16.0 diopters (D) to 23.5 D were tested. The 31 lenses were chosen from several hundred lenses to represent a wide range of resolution efficiencies in air. All lenses were from one manufacturer. An optical bench, as shown in Figure 1, was used to measure the resolving power of each lens in air and in water using the U.S. Air Force 1951 Resolution Target.* The measurements were made by one observer.

**Available from Melles-Griot, Irvine, California. Target consisted of bright lines on a dark background. The largest element corresponded to a resolution efficiency of 6.4% (using a 350-mm focal length collimator); the interval between elements is given by a ratio of 1:12.*

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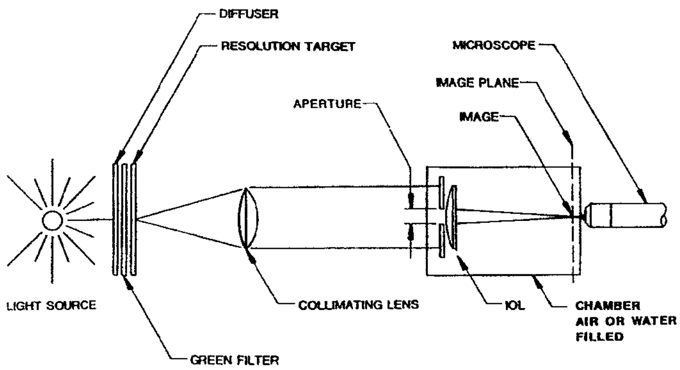

RESOLUTION TEST

Fig. 1. (Holladay) Optical bench apparatus as described in ANSI Standard Z80.7-1984 modified so resolution and dioptric power measurements could be made in air or water.

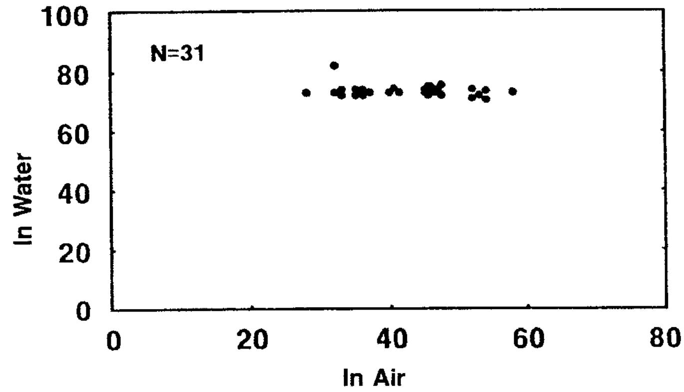

Fig. 2. (Holladay) The resolution efficiency for biconvex silicone IOLs in air and in water. The improvement factor in resolution efficiency from air to water ranged from 1.3 to 2.5. All lenses that equaled or exceeded 29% resolution efficiency in air exceeded 70% resolution efficiency in water. No lenses exhibiting multiple images were included.

The resolution efficiency was calculated for each lens in air and in water. Resolution efficiency is defined as the percentage ratio of the actual resolving power of a lens to that of a perfect lens of the same focal length which is only limited in resolution by diffraction.

The diffraction limit (Vo) was calculated using the small angle formula:

$$Vo = (n \times d) / (f \times L)$$

where Vo = diffraction limited resolving power (1p/mm), n = refractive index of the surrounding medium (air = 1.0003, water = 1.3333), d = diameter of the aperture for the optical system in millimeters (3 mm), f = actual focal length of the lens in millimeters in air or in water, and L = wavelength of illuminating light in millimeters (0.000555 mm).[2,3] For example, if a PMMA IOL (index of refraction n = 1.491) were +19.39 D in aqueous (index of refraction = 1.336), it would have a power of 61.66 D in air and a corresponding focal length in air of 16.22 mm. Using the formula, the diffraction limit (Vo) for this lens in air is 333 1p/mm. For instance, if the resolving power of the lens measured 199 1p/mm, its resolution efficiency would be 60% (199/333).

No lenses that exhibited multiple images in air or in water were included since we showed in the previous study that the change in performance of these lenses from air to water was unpredictable. The presence of multiple images was sufficient cause to fail a lens, particularly since the lens would result in symptoms of polyplopia for a patient in whom the lens was implanted.

RESULTS

The resolution efficiency in air and in water for all 31 silicone IOLs is shown in Figure 2. The resolution efficiency of these lenses in air ranged from 29% to 58%. All these lenses improved to 73% in water, except for one lens which achieved 82% resolution efficiency. The improvement from air to water ranged from a factor of 1.3 to 2.5.

DISCUSSION

The index of refraction of these silicone lenses was 1.408 compared with 1.491 for most PMMA lenses. Using these values, the expected decrease in dioptric power from air to water is approximately 5.25 for biconvex silicone lenses compared to 3.18 for plano-convex PMMA lenses. For example, a silicone lens with 52.5 D of power in air would be approximately 10.0 D in water. This greater change in dioptric power for silicone lenses, relative to PMMA lenses, would suggest a greater improvement factor in resolution efficiency, yet this was not the case.

The explanation lies in our inability to find lenses without multiple images that also had resolution efficiencies lower than 29% in air. If it were possible to find lenses with extremely low resolution efficiencies, without multiple images, larger improvement factors might have been found. The fact that we were unable to find any lenses that satisfied these requirements indicates that extremely low resolution lenses contain surface irregularities which often result in multiple images.

These findings underscore the need for a requirement to reject a lens of any material that exhibits multiple images in air or in water, even though it may pass standard resolution requirements. The elimination of multiple image lenses is particularly important clinically, since the only treatment is explantation and exchange.

Our study confirms that silicone IOLs can exceed 70% resolution in water, indicating that these lenses can perform near their diffraction limit when implanted in the eye. These findings agree with other investigators using this material.[4] The fact that all 31 lenses (no lenses with multiple images) achieved higher than 70% resolution efficiency in water and their resolution efficiency in air equaled or exceeded 29% is consistent with a lower limit of 30% in air for silicone lenses, as we proposed for PMMA lenses.

Although our theoretical calculations indicated that the limit in air for silicone lenses might be lower than 30% because of the lower index of refraction, our empirical data did not support a lower value. Therefore, we feel this limit in air has been substantiated and is conservative.

We still recommend that IOLs of any material or optical design be evaluated in water to assure they can exceed 70% resolution efficiency. Manufacturing and design differences, even using the same material, may alter the resolution efficiency relationship from air to water. Consequently, the 30% standard in air may not necessarily be generalized to other materials or other designs.

REFERENCES

1. Holladay JT, Ting AC, Koester CJ, Portney V, et al: Intraocular lens resolution in air and water. *J Cataract Refract Surg* 13:511-517, 1987
2. American National Standard for Ophthalmics - Intraocular Lenses - Optical and Physical Requirements, ANSI Z80.7-1984, American National Standards Institute, New York, 1984, pp 6-12
3. Dunn MJ: The resolving power of intraocular lens implants. *Am Intra-Ocular Lens Implant Soc J* 4:126-129, 1978
4. Kulnig W, Menapace R, Skorpik C, Juchem M: Optical resolution of silicone and polymethylmethacrylate intraocular lenses. *J Cataract Refract Surg* 13:635-639, 1987