A New Contact Lens For Posterior Vitreous Photodisruption

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Effective and safe photodisruption requires that the laser pulse be brought to a fine focus. Contact lenses are generally required to compensate for the optical aberrations of the eye which degrade the laser focus. The theoretical analysis of these aberrations has led to the construction of a contact lens which minimizes aberrations in the posterior vitreous. Clinical applications confirm the increased efficacy and safety of posterior vitreous photodisruption using this contact lens. Invest Ophthalmol Vis Sci 27:946-950, 1986

A new contact lens for use when irradiating the posterior vitreous cavity is described. This lens produces high optical performance in the preretinal space, encompassing a zone 12 mm anterior to it and extending to the midperiphery of the retina. Within this space, the lens produces only a small amount of image degradation, even with oblique ray incidence.

In 1967, Fankhauser and Lotmar12 introduced the contact lens as a coupling element when photocoagulating the retina with radiation emitted by the xenon arc lamp and low power lasers. The use of a contact lens under such conditions is now universally accepted. The more recent clinical use of high power pulsed lasers for photodisruption in the human eye places even greater demands upon the optical performance of contact lenses as auxiliary coupling elements.3-7

One important property of all contact lenses for use with high power lasers is that they should create a large cone angle of the observation beam, as well as of the laser aiming and therapy beams. Enlarging the cone angle results in a linear reduction of the diameter of the focal spot, which increases the focal power and energy density. This focal concentration of energy and power is accompanied by a decrease in energy in the prefocal and postfocal laser field. The power and energy density are related quadratically to the change in the size of the cone angle, which therefore critically influences both efficiency in the focal area and the safety in the pre- and postfocal radiation field. An increase in the cone angle of the observation beam increases magnification, optical resolution, and, hence, focusing accuracy. Similarly, the depth of field of the aiming focus is lessened, which increases focusing accuracy.

The disturbing effect of spherical aberration must also be considered. Increasing the cone angle of a beam traversing a spherical refractive surface (RS), could increase the spherical aberration, which would reduce the beneficial effect of the cone-angle increase. This problem may be circumvented by taking advantage of image points which are not disturbed by spherical aberration. One such aberration free point coincides with the center of curvature (R) of the RS. Advantage of this is taken in the design of Roussel and Fankhauser's chamber angle contact lens CGA.9 Other aberration-free aplanatic points exist,13 and are known as the points of Young-Weierstrass. Aplanatism has been taken into consideration when designing contact lenses used in laser treatment of the iris, pupillary, and retro-pupillary spaces.10

Materials and Methods

Theoretical Basis of a Posterior Vitreous Contact Lens For Photodisruption

The principle of aplanatic points is shown in figure 1 and is defined by the equations below (1).

\[ d = R \times \frac{n + n'}{n} \quad \text{and} \quad d' = R \times \frac{n + n'}{n'} \quad (1) \]

In the combined optical system [eye + contact lens],

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there are a number of optical surfaces and interfaces, each of which possesses two non-coincident aplanatic points $A$ and $A'$ (Fig. 1). An ideal correction is thus not possible and, at best, the aberrations of only one interface may be corrected. Of all interfaces under consideration, the refractive index difference between air and the contact lens is the largest ($0.5$). Since spherical aberration increases with the optical refractive index difference, correcting the spherical aberration of the air-contact lens interface will minimize the aberrations of the combined lens and eye, and is an effective means for reducing system aberrations.

The increase in beam cone angle produced by the anterior face of a contact lens, when the condition of aplanatism is satisfied, is given by $d/d' = n'/n$, then the diameter of the focal spot is reduced according to $n'^2/n^2$. Substituting the values $n = 1$ (air) and $n' = 1.5$ (glass), the focal spot size is reduced by a factor of 2.25, and cone angle is increased by a factor of 1.5. From this it follows that an aplanatic surface, when compared to the flat surface of the Goldmann contact lens, produces a decrease in focal spot size and an increase in cone angle by a factor of 2.25.

Since not every structure to be irradiated in the vitreous cavity will coincide with the aplanatic point $A'$, the optical consequences of shifting the focal spot beyond this point must be considered. The rate of the image degrading effect is very much slower when moving the focal spot in the anterior direction. Since the center of curvature ($C$) of a spherical RS is also an aberration-free point, the interval $A'-C$ (including these points) will have little or no spherical aberration. Obviously, then, $A'$ should be made to coincide with the retina.

For oblique ray incidence, the condition of aplanatism may be generalized as follows: when rotating the laser beam around $C$ of RS, two surfaces, $S'$ (ie, the image of $S$) will be generated. For every point $A'$ (ie, the image of $A$) lying on the surface $S'$, the condition of aplanatism is satisfied, ie, such points may be considered to be aberration-free (Fig. 2).

If, in addition, $C$ of RS is made to coincide with the center of curvature of the retina ($r$), the region between the retina and its center of curvature will have its aberrations minimized. For computation of the beam diameter the following factors should be taken into consideration: a laser beam cone angle of $16^\circ$ in air (typical for a number of photodisruptive apparatus), a contact lens satisfying the condition of aplanatism (adapted to our requirements $A'$ coinciding with $S'$) and the distance of focus from the retina. For minimal focal size on the retina, a laser beam diameter of $8.5$ mm at the pupil is calculated, whereas a laser focal point $5$ mm from the retina would require a pupillary beam diameter of $6.5$ mm.

At this juncture, the optical constants of a contact lens required for irradiation of the posterior vitreous may be computed.

**Results**

**Contact Lens Design For Posterior Vitreous Photodisruption**

Taking equations (1) and (2) into account, a simplified model for a contact lens may be formulated. Symbols and abbreviations are given at the end of the text.

$$e + 1 = R \times \frac{n' + 1}{n'} = d'$$

$$e + 1 - r = R$$

Equations (2) can subsequently be solved for $R$ and $e$ (equations 3).

$$R = n' \times r$$

$$e = (n' + 1.) \times r - 1$$

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**Fig. 1.** Definition of the aplanatic points $A$ and $A'$. $V =$ vertex of a refractive surface (RS), $C =$ center of RS, having a radius of $R$. $A =$ focal spot in air, having a diameter of $2 \ Y$. $A' =$ focal spot in a medium with refractive index $n'$, having a diameter of $2 \ Y'$. $d =$ distance of point $A$ from $V$. $d' =$ distance of point $A'$ from $V$.

**Fig. 2.** Definition of aplanatic surfaces. They are realized by rotation of converging beam around $C$. There are two surfaces, $S$ and $S'$, $S'$ being the image of $S$. $A$ and $A'$ correspond to $A$ and $A'$ in Figure 1. All points of $S'$ are aplanatic.
Fig. 3. Application of the condition of aplanatism to contact lens CGV 1.4 (LASAG AG, Thun, Switzerland). The center of curvature of RS coincides with the center of curvature of the retina. R = radius of curvature of RS. r = radius of curvature of retina.

An axial length of the eye of 24.2 mm (l), a radius of retinal curvature (r) of 12.3 mm, and n' = 1.5 (the refractive index of the contact lens) are assumed and substituted in equations (3). This results in a contact lens whose RS has a radius of curvature, R, of about 18.5 mm and a thickness of about 6.5 mm (Fig. 3).

Additional corrections which are not described here must be made, which account for the various refractive indices of the eye (cornea, aqueous humor, lens, vitreous).

Allowance has to be made for deviations of axial length. Shorter axial lengths do not create any problems. Deviations towards longer axial lengths may do so as the diameter of the laser beam may become too large at the level of the pupil. Since more than 85% of all myopic eyes possess dioptic deviations of less than −6.0 D (corresponding to an increase in standard axial length of about 1 mm), a correction within these limits appears appropriate. In the foregoing we have derived a magnification factor of 2.25 for this new lens.

If this correction for myopia is included, this is reduced slightly to 2.08.

Applying these corrections results in a contact lens having an anterior radial surface of 18.7 mm, and a thickness of 5.8 mm. The lens is made of laser resistant glass (Schott BK 7, Mainz, Germany). The radius of its posterior surface is 7.4 mm, compensating for the residual refractive power of the eye and resulting in an afocal system. The maximal useful diameter of this lens is 19 mm. This allows full advantage to be taken of the condition of aplanatism, and permits acceptance of a broad slit lamp illumination beam. The front surface is provided with a coating antireflective to both Nd:YAG and visible light emitted by the auxiliary illumination source (Fig. 4).

Discussion

The irradiation and sectioning of structures in the vitreous cavity with high powered Q-switched or mode-locked laser systems pose a number of optical problems which may be solved using contact lenses. These difficulties may be overcome for the anterior vitreous by using contact lens CGP. The center of the vitreous cavity may be irradiated effectively without use of a contact lens for average corneas that have little astigmatism.

In the posterior vitreous, image degradation due to aberrations introduced at the various refractive surfaces of the contact lens and intraocular structures represents a major problem. One previous attempt was directed towards correcting the astigmatism of oblique ray incidence (a major contributor to the overall aberrations), which occurs when treating the far peripheral retina, by using two mirror contact lenses with prismatic anterior surfaces.6

An attempt has been made in this paper to design a contact lens without reflecting mirror surfaces which minimizes the spherical aberration arising from its anterior surface. The image degrading effect of the residual spherical aberration, as well as other aberrations such as astigmatism in oblique incidence, does, however, remain. In our practical clinical experience, these aberrations create serious problems only when ray incidence is very oblique. In such cases, the pupil is imaged as an extended ellipse, which then vignettes the large cone angle of the new contact lens (24°). In this case, we must resort to using one of the mirrored contact lenses described above or a Goldmann mirror lens (Haag-Streit, Bern, Switzerland). For all other applications in the vitreous, we have found the new contact lens easier and more practical to use than a mirrored lens.

The compression of the focal spot diameter and enlargement of the laser beam cone angle produced by the contact lens described here has been found to be
Fig. 5. Vitreous band in posterior vitreous seen through new contact lens CGV 1.4. A. (top, left) Before partial photodisruption. B. (top, right) After partial photodisruption. Fig. 6. Same vitreous band as displayed in Figure 5, seen through Goldmann contact lens. A. (bottom, left) Before partial photodisruption. B. (bottom, right) After partial photodisruption.
very effective in clinical use. Based on 15 trials, in which we compared the pulse energy needed for the same clinical task, we found an increase in efficiency that amounted to approximately 1.6 with the new contact lens, as compared with using a Goldmann lens. That is, for a given clinical problem, 1.6 times less energy is required using this new lens than when using a Goldmann lens. One limiting factor may be the large beam diameter created within the pupillary area. However, when working at a distance of 5 mm from the retina, the beam diameter in the pupillary region falls to 6.5 mm, which appears to be acceptable. Interaction of the laser beam edge with the iris has been found to be innocuous. The explanation for this is that the energy and power density in the peripheral parts of the laser beam are low, due to its Gaussian profile. For the same reason, even laser beam diameters of 8.5 mm in the pupillary region appear to be safe, although the situation when the laser beam is focused at the retina is highly exceptional for photodisruptive tasks.

This new contact lens appears as a complement to the Goldmann lens. It provides a magnification 2.08 times greater, thus facilitating observation of structural details and superior aiming accuracy. Were the magnification achieved using increased slit lamp magnification alone, the cone angle of Nd:YAG laser beam would remain unaltered. Use of the new contact lens increases both the viewing magnification and provides an enlarged laser beam cone angle at the same time. Since the cone angle of the new lens is greater, it is far safer and more effective than the Goldmann lens for photodisruptive tasks in the posterior vitreous (Fig. 5). However, the Goldmann lens, having a field of view which is 2.08 times greater than the new contact lens, allows a superior overall survey (Fig. 6). Since a compression of the focal spot is not useful for photocoagulation on the retina, aberrations enlarging the focal spot area are of no particular significance. Therefore, the Goldmann lens retains its traditional value as a useful tool for observation tasks and for retinal and choroidal photocoagulation.

Key words: vitreous, contact lens, laser surgery, photodisruption, Nd:YAG

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Symbols and Abbreviations

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<tr>
<th>Symbol</th>
<th>Description</th>
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<tr>
<td>n</td>
<td>refractive index anterior to surface RS</td>
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<tr>
<td>n'</td>
<td>refractive index posterior to surface RS</td>
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<tr>
<td>V</td>
<td>vertex of spherical surface</td>
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<tr>
<td>A</td>
<td>virtual object point</td>
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<tr>
<td>A'</td>
<td>real image point</td>
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<tr>
<td>2Y</td>
<td>diameter of virtual object</td>
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<tr>
<td>2Y'</td>
<td>diameter of real image</td>
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<tr>
<td>d</td>
<td>distance of virtual object point</td>
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<tr>
<td>d'</td>
<td>distance of real image point</td>
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<tr>
<td>S</td>
<td>surface of aplanatic points, intersecting optical axis at A</td>
</tr>
<tr>
<td>S'</td>
<td>surface of aplanatic points, intersecting optical axis at A'</td>
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<tr>
<td>e</td>
<td>thickness of contact glass</td>
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<tr>
<td>r</td>
<td>radius of retina</td>
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<td>l</td>
<td>axial length of human</td>
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References