The homogeneity of the retinal illumination is restricted by some erg lenses

Kooijman, AC

Published in:
Investigative ophthalmology & visual science

Publication date:
1986

The Homogeneity of the Retinal Illumination is Restricted by Some ERG Lenses

Aart C. Kooijman

Are all types of available electroretinographic contact lenses suited for Ganzfeld stimulation? To answer this question, calculations have been made of the retinal light distribution with several types of ERG lenses placed on a theoretical eye. The results make possible a division of the ERG lenses into three categories. Category 1: Lenses with which the homogeneity of the retinal illumination is nearly perfect and independent of pupil size. These lenses are especially well designed for Ganzfeld electroretinography. Category 2: Lenses which illuminate a large retinal area but with which the light distribution depends on the size of the pupil. The suitability of these lenses is questionable, because Ganzfeld electroretinography is used in order to obtain a homogeneous retinal light distribution under most conditions. Category 3: Lenses with which the size of the illuminated retinal area changes strongly with the size of the pupil. These lenses are unsuitable for Ganzfeld electroretinography. Invest Ophthalmol Vis Sci 27: 372–377, 1986

For clinical electroretinography (ERG) a Ganzfeld light source for stimulation and adaptation is advised in order to obtain responses from an evenly illuminated retina.[1-3] This minimizes the influences of pupil size and differences in light scattering in the optical media of the eye on the retinal light distribution. The ideal light source would be a Ganzfeld illumination globe positioned around the corneal rim so that the whole field of view of the eye optics has an even luminance. Less suitable, theoretically, is a globe placed around the head of the subject, because part of the visual field will be obscured by nose and brows. This shading by the facial structures will not seriously influence the peripheral light perception, however, if it is supposed that the ora serrata coincides with the border of the shaded area. An ERG lens may introduce further limitations on the field of view by its optical or geometrical properties.

In this study I have calculated how the light is distributed over the retina when several types of ERG contact lenses[4-10] are used (Table 1). ERG electrode types without a contact lens have been left out of consideration, because they alter neither the optics nor the visual field of the eye,[11-14] or because they are not used in combination with Ganzfeld stimulation.[15]

Materials and Methods

Calculations have been done on a theoretical eye fitted with different types of ERG lenses (Fig. 1), which will be referred to as B to G (Table 1: B–G). I have used a wide angle theoretical eye with spherical refracting surfaces (Table 2: A).[16] The calculation procedures were the same as those used in my earlier study on a theoretical eye without a contact lens.[17] Some of the ERG lenses considered have a clear corneal lens (C, E, F, G); others a diffuse one (B, D). The dimension of the contact lenses were obtained from literature[5,7-9] or were measured for this study[4,6,10] (Table 2: B–G). With some of the contact lenses (C, E, F) the object space is in air, with other lenses (B, D, G), object space resides within either translucent or transparent plastic (refractive index 1.49). While dealing with an eye with an ERG lens having a light diffusing surface, I have assumed that the configuration is identical with that of a bare eye with a limited corneal diaphragm surrounded by a Ganzfeld. In those cases, the calculations have been done on the theoretical eye without contact lens, the corneal diameter being limited to the diameter of the light diffusing contact lens (Table 2, B and D).

A ray tracing program in BASIC on a Commodore 3032 microcomputer (CBM; Santa Clara, CA) calculates the light rays in the meridional plane of the eye. The steps of the calculations are as follows: (1) The apparent pupil diameter PD(φ) in the meridional plane is calculated as seen from oblique directions. The apparent pupil is the image of the physical pupil focused in the object space by the optics of the cornea and the contact lens. (2) The retinal area per steradian visual field RS(φ) is calculated as a function of φ. (3) The retinal illumination RI(φ) with a Ganzfeld luminance A in the object space is calculated as a function of φ.

$$\mathrm{RI}(\varphi) = \frac{\mathrm{PA}(\varphi)}{\mathrm{RS}(\varphi)} \cdot \mathrm{A}$$

in which RI(φ) is the retinal illumination, PA(φ) is the

From the Kliniek voor Oogheelkunde, Rijks–Universiteit Groningen, Oostersingel 59, 9713 EZ Groningen, the Netherlands.

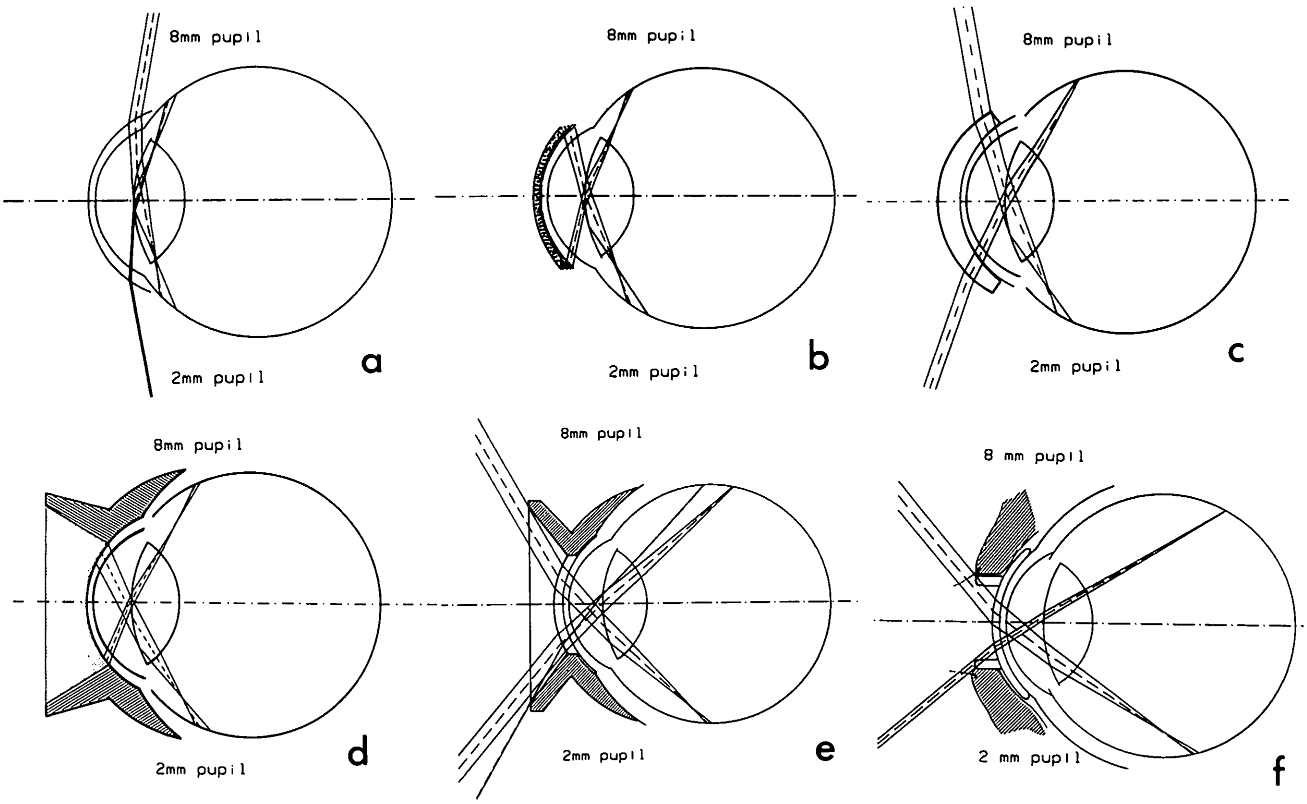
Submitted for publication: July 10, 1984.

Reprint requests: Aart C. Kooijman, Kliniek voor Oogheelkunde, Rijks–Universiteit Groningen, Postbus 30.001, 9700 RB Groningen, the Netherlands.

Table 1. ERG contact lenses

	Lens design	*Unobstructed corneal contact lens diameter*	*Lens texture*	*Light source*	*Visual field limiting structure*	*Ganzfeld "quality" category*
B	{ Siegel	12 mm	diffuse	not critical	retinal border	1
	{ Kooijman–Damhof	12 mm	diffuse	multiple LED's	retinal border	1
C	Burian–Allen	13 mm	clear	integrating sphere	facial structures/ retinal border	1
D	Missotten–Stanescu	10 mm	diffuse	not critical	corneal lens/pupil	2
E	Henkes–van Balen	9 mm	clear	integrating sphere	corneal lens/ speculum/pupil	2
F	Grounauer	horiz. 11.5; vert. 8 mm	clear	integrating sphere	horizontal: facial structures/retinal border; vertical: eye lids	2
G	Krakau	not critical	clear	single LED	pupil	3

apparent pupil area, RS(φ) is the retinal area per solid angle of visual field, A is the Ganzfeld luminance and φ is the direction in the visual field. For electroretinography the interest lies especially in the light distribution over the retinal surface. Therefore I have transformed RI(φ) into RI(*ra*): the "retinal illumina-



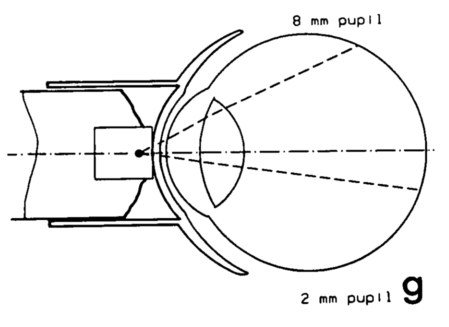


Fig. 1. Geometry of different types of ERG lenses with the most peripheral pencils of light rays which reach the retina. Calculated light rays with a 2-mm and an 8-mm pupil are drawn respectively in the lower and the upper half of the visual field. **a**, no contact lens; **b**, diffuse 12 mm diameter corneal lens as designed by Siegel or Kooijman–Damhof; **c**, Burian–Allen lens; **d**, Missotten–Stanescu lens; **e**, Henkes–van Balen lens; **f**, Grounauer lens; **g**, Krakau lens.

Table 2. Optical data of the theoretical eye and the ERG lenses

Surface i	*Optical parameter**	*A Theoretical eye*	*B‡ Siegel Kooijman-Damhof*	*C Burian-Allen*	*D‡ Missotten-Stanescu*	*E Henkes-van Balen*	*F Grounnauer*	*G Krakau*
	n_{-3}	—	—	—	—	1	1	—
−3	$r_{-3}\ x_{-3}\ d_{-3}$	—	—	—	—	∞; −2.8; 17ξ	∞; −2; 7.5ξ	—
	n_{-2}	—	—	1	—	1	1	1.49
−2	$r_{-2}\ x_{-2}\ d_{-2}$	—	—	8.48;−1.85; nl†	—	8.1;−0.8; 9	8.2;−0.6; 7.5	∞;−2; 0.2
	n_{-1}	—	—(1.49)	1.49	—(1.49)	1.49	1.49	1.49
−1	$r_{-1}\ x_{-1}\ d_{-1}$	—	—(8; 0; 12)	8.1; 0; 13	—(8; 0; 10)	8; 0; 9	7.9; 0; nl†	8; 0; nl†
	n_0	1	1 (1.333)	1.333	1 (1.333)	1.333	1.333	1.333
0 cornea (ant)	$r_0\ x_0\ d_0$	7.8; 0; nl†	7.8; 0; 12	7.8; 0; nl†	7.8; 0; 10	7.8; 0; nl†	7.8; 0; nl†	7.8; 0; nl†
	n_1				1.3371			
1 cornea (post)	$r_1\ x_1\ d_1$				6.5; 0.55; nl†			
	n_2				1.3374			
2 lens (ant)	$r_2\ x_2\ d_2$				10.2; 3.6; 10			
	n_3				1.42			
3 lens (post)	$r_x\ x_3\ d_3$				−6; 7.6; 10			
	n_4				1.336			
4 retina	$r_4\ x_4\ d_4$				−10.8; 24.2; nl†			

* n_i: refractive index; r_i: radius of curvature (mm); x_i: distance to corneal vertex (mm); d_i: diameter of optical element (mm),† nl: diameter is *not limited* to a value which influences the entrance of the light rays.

‡ With lenses B and D the real optical parameters are placed in parentheses, but the calculations are made with the simpler model (see Materials and Methods). ξ Surfaces (−3) of lenses E and F are diaphragms in air.

tion" as function of the "distance to the optic axis along the retinal arc." The place of incidence on the retina of the peripheral ray of a direction φ in the visual field is used to calculate *ra:* the distance from the place of incidence to the optic axis measured along the retinal arc. The influence of the pupil size in these calculations is tested by the use of pupil diameters of 2 and 8 mm.

In reality the differences in the retinal light distributions will be smaller than calculated. First of all because light rays, which are scattered or reflected by the media of the eye or the contact lens, will diminish the differences in illumination of the retinal surface. Moreover, it is assumed that parallel incident light rays will focus perfectly on the retina at the point of incidence of the principal ray. Light spreading by spherical and comatic aberration, however, will smooth in some degree variations in retinal illumination.

A special case is lens G, in which the light source in the object space is situated within the plastics of the ERG lens. Parallel rays that emerge from the light source are not focused on the retina, because the optical power of the eye with the contact lens is too low to do so. The same calculation procedure can be used, however, since a parallel ray pencil from the LED light source (ϕ0.2 mm) in front of the cornea has a small width and hardly diverges in traversing the eye (ϕ0.208 mm at the retina). In these calculations on lens G the apparent pupil area is replaced by apparent area of the flat light source, and retinal area per solid angle of visual field is replaced by retinal area per solid angle of light beam of the LED.

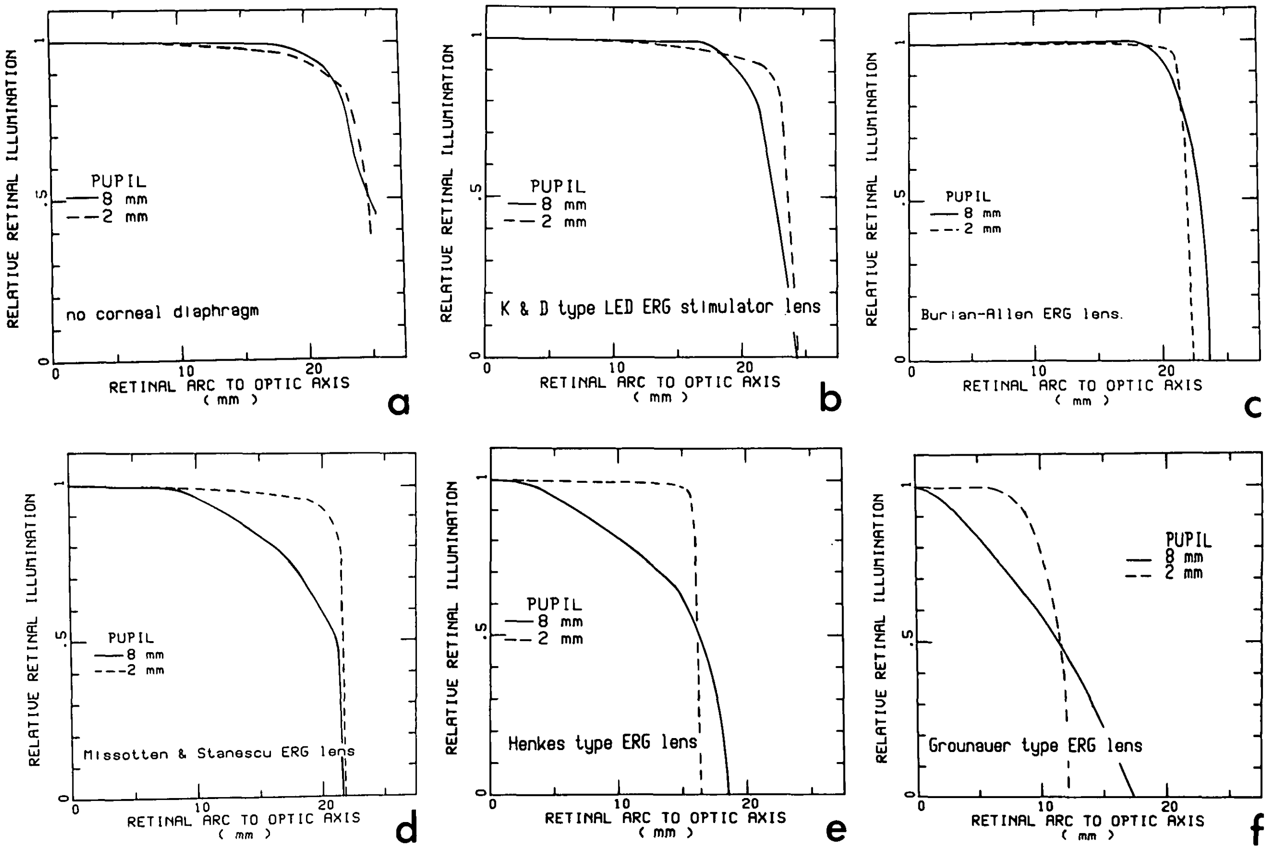
I have plotted the calculated retinal illumination on retinal area charts. A retinal area chart is a non-linear projection of the curved retinal surface on a flat plane on which the area of the retina is correctly represented.[17,18] The absolute border of the retinal area (the ora serrata) is determined by the calculation of the distance to the optic axis along the retinal arc which corresponds with the border of the absolute visual field.[19] This transformation is calculated for the theoretical eye with a 2-mm pupil diameter and is used in all cases.

Results

The relative retinal illumination is calculated for two values of the pupil diameter (2 and 8 mm) as function of the length of the retinal arc.

With a Ganzfeld light source the illumination on the inner wall of the eye is nearly homogeneous in a theoretical eye without a contact lens[6,20] (Fig. 2a). The ERG lenses B and C with large corneal diameters[6–8] affect the homogeneity but minimally, and only in the far peripheray does the pupil size have a small influence on the retinal light distribution. ERG lenses D, E and F, with smaller corneal lenses,[4,5,10] also allow the illumination of a large retinal area. The pupil size has considerable influence on the distribution of the light, however. With a large pupil size, a gradual decrease of the retinal illumination is caused by vignetting (Fig. 1d–f). With a small pupil the vignetting occurs only in a small area at the far periphery of the illuminated field. ERG lens G with a pointlike light source near a clear corneal lens[9] illuminates an area the size of which strongly depends on the pupil diameter. The illumination on that limited area is nearly homogeneous and is independent of the pupil size.

The retinal illumination is supposed to be radially symmetric around the optic axis, except with lens F[19]



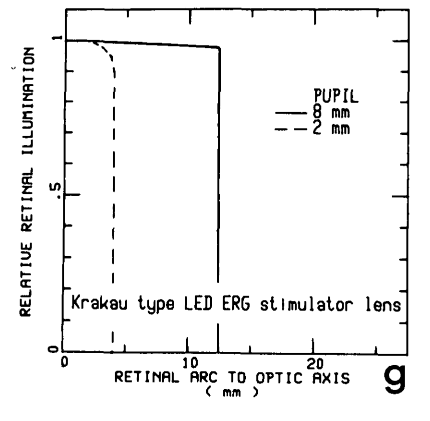


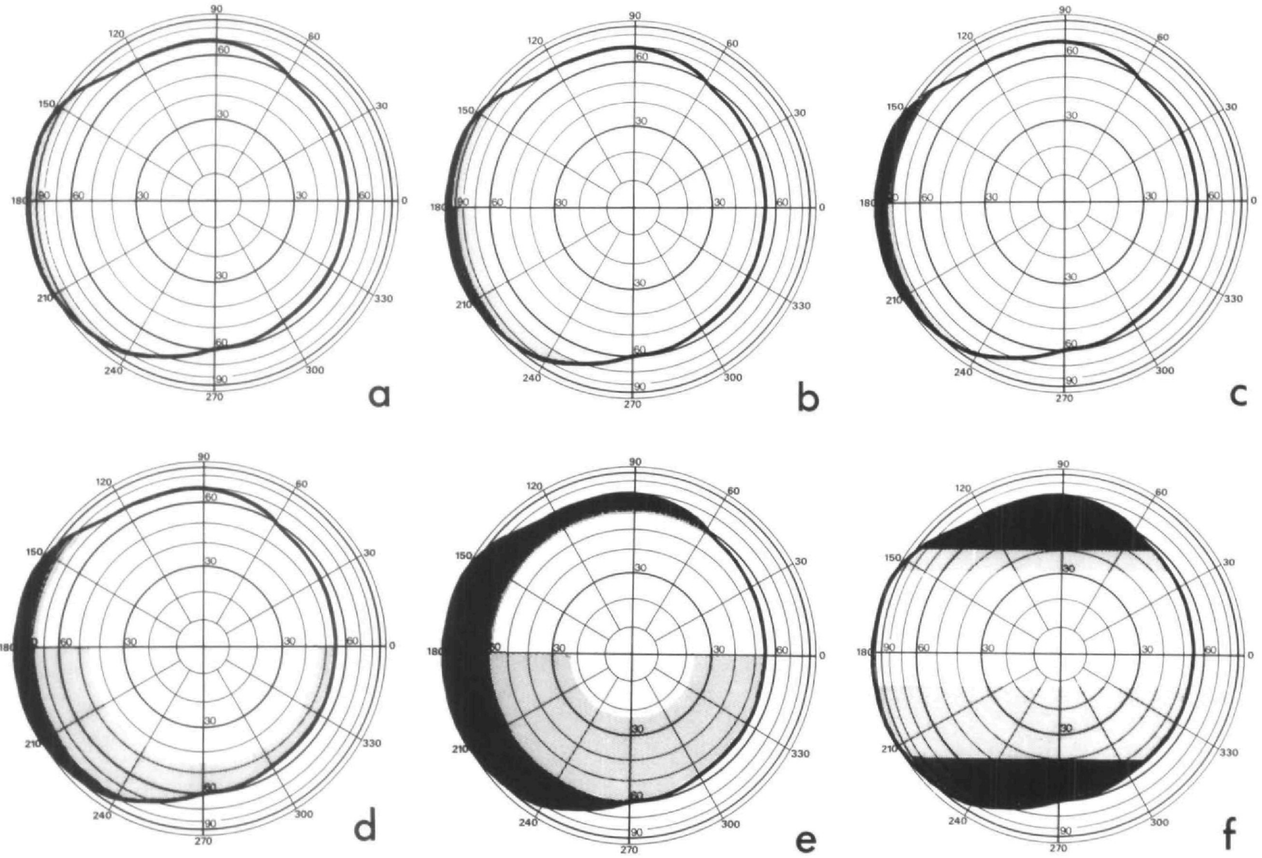
Fig. 2. Relative retinal illumination as function of the place on the retinal surface (**a–g** as in Fig. 1). In **a**, **b** and **c** there is little dependency on pupil size, **d**, **e**, and **f** show a less homogeneous illumination with a large pupil size, and in **g** the illuminated retinal area strongly depends on pupil size. The curves in Fig. 2f are valid along the vertical meridian. The other curves are valid along meridians in all directions.

where the eyelids cause a constriction of the field. In that case it is assumed that the use of the ERG lens limits the illuminated area in the vertical direction only.

The sensory retina, however, does not cover the entire inner wall of the posterior eye chamber. The effective stimulus area is the conjugate part of the illuminated inner wall of the eye and the sensory retina. From the retinal area charts (Fig. 3) it appears that different ERG lenses restrict the effective stimulus area to various degrees. How seriously do such restrictions influence the results in ERG measurements? For an estimate one has to know how much each part of the retina contributes to the ERG response. Some data concerning such area–response relations are available,[21–23,25] but the visual fields in these studies are limited to rather small angles. They cannot be used to evaluate the results of the calculations in this study in relation to the ERG responses. A study[26] with a modified Henkes-van Balen ERG lens (type E) revealed that it was not possible to obtain identical scotopic response amplitudes with a small and a large pupil though the differences in aperture were compensated by the luminance of the stimulus.

Discussion

Stimulation and adaptation with a Ganzfeld light source intends to illuminate the retina homogeneously.



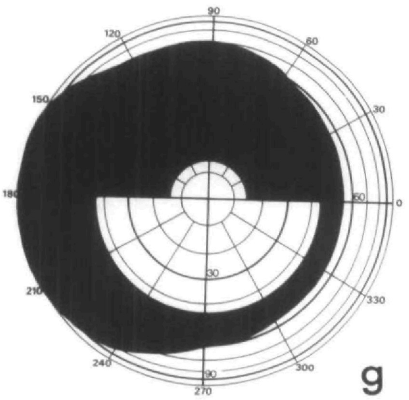


Fig. 3. The effective stimulus area of the inner wall of the eye projected on a chart in which the area of the retinal surface is correctly represented (**a–g** as in Fig. 1). The heavy line is the ora serrata. The upper and lower half of the figures outline the light distribution with an 8-mm and a 2-mm pupil diameter respectively. Relative Retinal Illumination: white > 90%; 90% > light shaded > 50%; 50% > heavy shaded > 0%; black: no illumination.

In a former study[17] I have shown that this objective is well achieved in a theoretical eye and, moreover, the alterations in the optics of the eye or in the size of the pupil hardly influence the retinal light distribution. In this study it has been calculated to what extent the light distribution is disturbed by the use of a specific ERG lens.

The results of the calculations show that the ERG lenses can be divided into three categories. The first category includes those lenses with which the retinal light distribution is nearly homogeneous and is minimally influenced by the size of the pupil (B, C). The design criteria promise that the retinal light distribution is nearly independent of pupil size and light scattering in the eye. Lens C, designed by Burian–Allen,[7] interferes less with the light rays in the visual field than the facial structures. Siegel[8] has modified the Burian–Allen lens by the use of a light diffusing contact lens. This modification annihilates the influence of all external limitations of the stimulus field. The same result is obtained by Kooijman–Damhof[6] with an ERG-lens with a built-in light source and a light diffusing contact lens.

Category 2 contains the ERG lenses D, E, and F. These lenses produce different retinal light distributions when the pupil size varies or with light diffusing eye media. Due to the smaller diameters of these lenses the homogeneity of the retinal illumination degrades by vignetting if the pupil diameter is large. With a small pupil or with much light scattering in the eye a more homogeneous retinal illumination will result. Missotten and Stanescu[5] have made an ERG-lens with a diffuse contact lens (ϕ10 mm) which limits the stimulus field slightly. The Henkes–van Balen[4] lens suffers from its relatively small central diameter (ϕ9 mm) in combination with the rim that acts as speculum. These last two lens types would perform better if the diameters of the light transmitting corneal lens were larger. Grounauer[10] has designed a lens with eye lid retracting posts with a spacing of only 8 mm. In the vertical direction the visual field can be restricted by the eye lids resting on these posts. A wider spacing of the posts on a larger lens enlarges the visual field in the vertical direction. Lens G in the third category illuminates a retinal area the size of which depends primarily on the pupil diameter if the media of the eye are optically clear. It is not suited for Ganzfeld stimulation. On the other hand, a stimulator-containing contact lens, as designed by Krakau et al[9] is a simple means to present central retinal stimuli with an illumination value that does not depend on the pupil size; only the illuminated area changes with pupil size. The lens described by Krakau et al should not be used for Ganzfeld electroretinography unless the corneal lens is made of light diffusing material.

This theoretical study indicates that an ERG lens for Ganzfeld electroretinography has to be fitted with a corneal lens with a diameter of at least 12 mm, made either of light diffusing material or of optically clear material combined with eyelid retractors that do not interfere with the field of view.

Key words: electroretinography, Ganzfeld, retinal illumination, ray tracing, ERG contact lens

References

1. Francois J and De Rouck A: A comparative study of the ERG obtained by stimulation with diffuse light and with a small area stimulus. Acta Ophthalmol (Suppl) (Copenh) 70:70, 1962.
2. Van Lith GHM, Meininger J, and Van Marle GW: Electrophysiological equipment for total and local retinal stimulation. *In* Documenta Ophthalmologica Proceedings Series, Pearlman JT, editor. The Hague, Junk Publ, 2, 1973, pp. 207–212.
3. Berson EL, Gouras P, and Gunkel RD: Rod responses in retinitis pigmentosa, dominantly inherited. Arch Ophthalmol 80:58, 1968.
4. Henkes HE and Van Balen ATM: Techniques of recording of the hitherto unrecordable ERG in the human eye. Acta Symp *In* Acta Fac Med Univ Brun, Luracovice, 1959.
5. Missotten L and Stanescu B: A new electrode for "Ganzfeld" ERG. *In* Documenta Ophthalmologica Proceedings Series, Francois J and De Rouck A, editors. The Hague, Junk Publ, 15, 1979, pp. 337–338.
6. Kooijman AC and Damhof A: ERG lens with built-in Ganzfeld light source for stimulation and adaptation. Invest Ophthalmol Vis Sci 19:315, 1980.
7. Burian HM and Allen L: A speculum contact lens electrode for electroretinography. Electroencephalogr Clin Neurophysiol 6: 509, 1954.
8. Siegel IM: A Ganzfeld contact lens electrode. Am J Ophthalmol 80:296, 1975.
9. Krakau CET, Nordenfelt L, and Ohmen R: Routine ERG recording with LED light stimulus. Ophthalmologica 175:199, 1977.
10. Grounauer PA: The new single use ERG corneal contact lens electrode and its clinical application. *In* Documenta Ophthalmologica Proceedings Series, Niemeyer G and Huber CH, editors. The Hague, Junk Publ, 31, 1982, pp. 89–93.
11. Borda RP, Gilliam RM, and Coats AC: Gold-coated Mylar (GCM) electrode for electroretinography. *In* Doc Ophthalmol Proc Ser, Francois J and De Rouck A, editors. The Hague, Junk Publ, 15, 1978, pp. 339–343.
12. Arden GB, Carter RM, Hogg C, Siegel IM, and Margolis S: A gold foil electrode: extending the horizons for clinical electroretinography. Invest Ophthalmol Vis Sci 18:421, 1979.
13. Dawson WW, Trick GL, and Litzkow CA: Improved electrode for electroretinography. Invest Ophthalmol Vis Sci 18:988, 1979.
14. Harden A: Non-corneal electroretinogram. Br J Ophthalmol 58: 811, 1974.
15. Koblasz A: Cup electrode for human ERG. Invest Ophthalmol Vis Sci 17:575, 1978.
16. Le Grand Y: Optique Physiologique. I. La dioptrique de l'oeil et sa correction. Paris, Revue d'Optique, 1946, p. 74.
17. Kooijman AC: Light distribution on the retina of a wide-angle theoretical eye. J Opt Soc Am 73:1544, 1983.
18. Drasdo N and Fowler CW: Nonlinear projection of the retinal image in a wide-angle schematic eye. Br J Ophthalmol 58:709, 1974.
19. Harrington DA: The Visual Fields. St. Louis, CV Mosby, 1971, p. 103.
20. Bedell HE and Katz LM: On the necessity of correcting peripheral target luminance for pupillary area. Am J Optom Phyšiol Opt 59:767, 1982.
21. Marg E: The effect of stimulus size and retinal illuminance on the human electroretinogram. American Journal of Optometry and Archives of American Academy of Optometry. 30:417, 1953.
22. Wirth A and Zetterstrom B: Effect of area and intensity on the size and shape of the ERG. Br J Ophthalmol 38:257, 1954.
23. Crampton GH and Armington JC: Area-intensity relation and retinal location in the human electroretinogram. Am J Physiol 181:47, 1955.
24. Armington JC: The electroretinogram, the visual evoked potential, and the area-luminance relation. Vision Res 8:263, 1968.
25. Kooijman AC, Smeets JLRM, and Tegelberg UF: Large and small field dark adaptation measurements with ERG. *In* Documenta Ophthalmologica Proceedings Series, Auerbach E, editor. The Hague, Junk Publ, 11, 1977, pp. 157–164.
26. Hoffman ML, Zrenner E, and Langhof HJ: Die Wirkung der Pupille als Apertur- und Bildfeldblende auf die verschiedenen Komponenten des menschlichen Electroretinogramms. Graefes Arch Clin Exp Ophthalmol 206:237–245, 1978.