Graefe's Arch Clin Exp Ophthalmol (1992) 230:24–28

Graefe's Archive
for Clinical and Experimental
Ophthalmology

Correction of optic disc measurements on fundus photographs*

Bo Bengtsson and CET Krakau

Department of Experimental Ophthalmology, University Eye Clinic, S-21401 Malmö, Sweden

Received January 22, 1991 / Accepted March 21, 1991

Abstract. If defined as *diameter of image/diameter of object*, the magnification M of the eye-camera system is kB, where k is a camera constant and B represents the vergence of the internal axis of the eye. The magnification may be assessed (1) from the length l of the eye, using the formula $1.336\ k/(l-0.0016)$; (2) from the glass refraction G, using the formula $k\bar{D}/(1-G/\bar{D})$, in which $\bar{D}$ is the "normal" refractive power of the eye; or (3) from the principal point refraction A and the deviation ΔD_1 from the "normal" refractive power of the cornea, using the formula $k\bar{D}\cdot(1+\Delta B/\bar{D})$, where $\Delta B = A + 0.84\ \Delta D_1$. If k is 0.042 m, as in the Zeiss camera, and $\bar{D}$ is about 60 dpt, the formulas may be written as (1) $M = 0.056/(l-0.0016)$; (2) $M = 2.5/(1-0.017\ G)$; and (3) $M = 2.5\cdot(1+0.017\Delta B)$.

Introduction

Blurred disc margins are common in small discs, and many large discs are pale or show high cup: disc ratios. Therefore, the question as to whether a certain optic nerve head is oedematous, atrophic, glaucomatous or normal often leads to the question as to whether the optic disc is small, large or medium-sized. The latter question, however, is nearly always left without an answer. A major reason for this seems to be that correction of optic disc measurements is considered to be necessary but intricate and cumbersome.

It is impossible to place a measuring rod directly on the fundus of the living eye. Information concerning the size of an optic nerve head must be obtained by measurements on an *image* of the optic disc rather than on the disc itself. The image is usually much larger than its object, and variations in the size of the image may be caused by variations in the degree of magnification as well as in the size of the object. Indeed, apparent interindividual variations in optic disc size were long supposed to be predominantly spurious rather than true. Uncorrected length measurements on disc photos are deeply mistrusted despite their being strongly correlated to their corrected counterparts [1, 3, 5].

A simple factor, $(1-0.017\ G)$, in which G represents the glass refraction, was used by Bengtsson [3] to correct optic disc measurements on fundus photos. A comprehensive derivation of this factor was provided 1977 by Bengtsson and Krakau [4] in a paper on some essential features of the Zeiss fundus camera, in which the authors stressed a remarkable fact, namely, that the magnification is entirely dependent on the vergence of the internal axis. The refraction and the corneal curvature are involved only as means of estimating this quantity when actual measurements of the axial length are not available.

In 1982 Littman [6] published a method for correction based on measurements of the principal point refraction and corneal curvature: by means of a system of curves, one obtains a correction factor q, which can in turn be corrected using similar curves based on measurements of the length of the optical axis of the eye. In a second paper, Littman [7] fitted quadratic equations to the curves.

In the present paper we describe simple equations by which the magnification of the eye-camera system can be estimated (1) directly from measurements of the internal axis of the eye, (2) from the glass refraction or (3) from the principal point refraction and the corneal curvature. The first two estimations seem to be suitable for practical purposes; the third enables us to compare the results of our approach with those obtained by Littman.

The magnification

In all discussions of the design and function of optical instruments, Gullstrand's exact schematic eye is always the starting point. Careful measurements on normal eyes

* This work was supported by the Herman Järnhardts Stiftelse, by the Swedish Medical Research Council (projects 5202 and 7527) and by the Kung Gustaf V:s och Drottning Victorias Stiftelse

Offprint requests to: B. Bengtsson

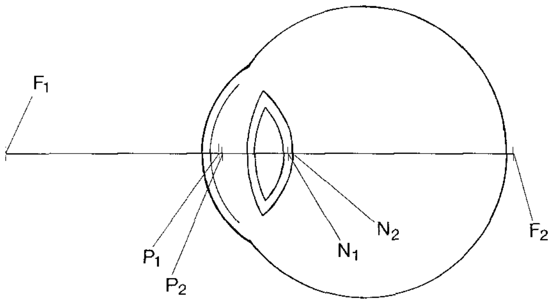

Fig. 1. Gullstrand's exact schematic eye

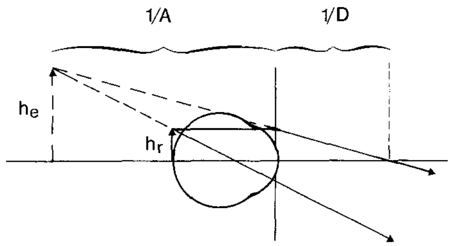

Fig. 2. Formation of an image of a retinal object: $M_{eye}=h_e/h_r=(1/A+1/D)/(1/D)=(D+A)/A=B/A$

of the curvature and position of surfaces separating structures with different refractive indices are summarized in a model to which the well-known formulas of Gaussian (ordinary geometric) optics can be applied. From Fig. 1 it can be seen that there are six cardinal points: two are focal (F_1 and F_2), two are principal (P_1 and P_2), and two are nodal (N_1 and N_2). Distances are counted to or from the nearest principal point and are reduced, i.e. divided by the refractive index of the pertinent medium. Formulas and calculations are further simplified if distances (expressed in metres) are substituted by vergences, i.e. by their inverted values (expressed in diopters). An example is provided by Gullstrand's formula $B=D+A$, in which A stands for the principal point refraction – i.e. the power of a hypothetical correction glass located in the anterior principal plane of the eye – D represents the refractive power of the eye, and B stands for the vergence of the internal axis – i.e. the reduced and inverted distance between the posterior principal point and the fovea. (If written $A=B-D$, this formula shows that the principal point refraction is equal to the difference between the vergence of the internal axis and the refractive power.)

Using this notation, the magnification of the eye is $M_{eye}=B/A$ (Fig. 2), that of the fundus camera is $M_{camera}=kA$ (Fig. 3) and that of the eye-camera system, therefore, is

$$M=kB \tag{1}$$

If the camera is correctly positioned in relation to the patient, k is a constant and the magnification is a linear function of B. A comprehensive derivation of Eq. (1) was provided in a previous paper [4].

Equation (1) may be written $k=M/B$ and be used to calculate k from measurements of the magnification on fundus photos of an artificial eye in which B is known. If, as in the Zeiss camera, 1 dm on a measuring-tape situated 0.5 m behind a +2-dpt lens yields an image measuring 8.4 mm, the "magnification" is 0.084, B is 2 dpt and k, accordingly, is $0.084/2=0.042$ m.

Estimate based on ultrasonography

In the human eye, B may be calculated from measurements of the axial length l with the aid of the formula $B=n/(l-p)$, in which n is the refractive index and p is the distance from the apex of the cornea to the posterior principal point. Using Eq. (1), we obtain $M=nk/(l-p)$ or, if we disregard small variations in p and insert $n=1.336$ and $p=0.0016$,

$$M_{e\,1}=1.336\,k/(l-0.0016) \tag{2}$$

If, for instance, $k=0.042$ and $l=0.024$, we obtain $M=2.5$ and may conclude that an image with a diameter of 4 mm is derived from an object with a diameter of $4/2.5=1.6$ mm.

Estimate based on glass refraction

If measurements of the internal axis are not available, B may be estimated using Gullstrand's formula $B=D+A$, inserting an observed value for A and accepting a "normal" value $\bar{D}$ for D. Thus, the estimated magnifica-

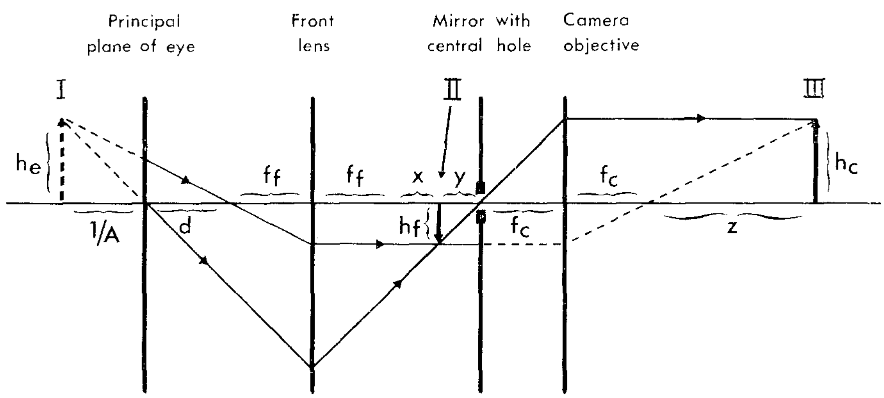

Fig. 3. The imaging system of the Zeiss fundus camera: $M_{camera}=h_c/h_e=[f_f/(1/A+d)]\cdot[f_c d(1+dA)]/f_f^2=(f_c d/f_f)A=kA$. Reproduced with permission from *Acta Opthalmologica*

tion is $M_{e2}=k(\bar{D}+A)$, which may be written as $M_{e2}=k\bar{D}(1+A/\bar{D})$ or, since $(1+A/\bar{D})=1/(1-G/\bar{D})$ if the distance from the test glass to the anterior principal plane of the eye is $1/\bar{D}$, as recommended by Gullstrand,

$$M_{e2}=k\bar{D}/(1-G/\bar{D}). \tag{3}$$

If $k=0.042$ and $\bar{D}$ is about 60 dpt, we obtain

$$M_{e2}=2.5/(1-0.017\ G). \tag{4}$$

Estimate based on refraction and keratometry

The total refractive power D of the eye is composed of the refractive powers D_1 and D_2 of the cornea and lens, respectively. Only the corneal power is easily measured. D_1 and D_2 are not simply additive (since $D=D_1+D_2-\delta D_1 D_2$, where δ is the effective depth of the anterior chamber) and are probably not uncorrelated. The change in D associated with a deviation ΔD_1 from the "normal" refractive power $\bar{D}_1$ of the cornea, therefore, is $\beta\Delta D_1$ where β is the coefficient of regression of D on D_1. Thus, the estimate of B is $(\bar{D}+A+\beta\Delta D_1)$ and that of the magnification is

$$M_{e3}=k(\bar{D}+A+\beta\Delta D_1). \tag{5}$$

Since $\beta=r\cdot\sigma y/\sigma x$, the figures given by Stenström [12] can be used to calculate an approximate value $\beta=r_{D_1 D}\cdot\sigma D/\sigma D_1=0.66\cdot 1.78/1.40=0.84$. The insertion of $\beta=0.84$, $k=0.042$ and $\bar{D}=58.64$ (as in Gullstrand's exact schematic eye) in Eq. (5) yields

$$M_{e3}=0.042(58.64+A+0.84\ \Delta D_1), \tag{6}$$

which, if $(A+0.84\Delta D_1)$ is replaced by ΔB, may be written as

$$M_{e3}=2.46(1+0.017\ \Delta B). \tag{7}$$

Comparison with Littman's approach

Deduction of q

Littman [6, 7] describes the diameter t of a retinal object as being a product of the observed diameter s of the image, the camera constant 1.37, and a factor q:

$$t=s\cdot 1.37\cdot q.$$

Since $t/s=1/M$, $q=0.73/M$.

The introduction of Eq. 7 for M yields

$$q=0.73/[2.46(1+0.017\ \Delta B)]=0.297\cdot 1/(1+x),$$

where $x=0.017\ \Delta B$. However,

$$1/(1+x)=1-x+x^2-x^3+x^4\ldots$$

This series is convergent if the absolute value of x is <1. In the relevant range, $0.017\ \Delta B$ is so small that three terms are sufficient to give a good approximation of q. Hence,

$$100\ q=29.7-0.5\ \Delta B+0.009\ (\Delta B)^2+R,$$

which is similar to the quadratic equations provided by Littman [7].

	r (mm)	$\beta\Delta D_1$ (dpt)	Range of A (dpt)
□	6.0	10.4	-30.0 to +5.0
+	7.7	0.0	-25.0 to +10.0
○	10.0	-8.4	-20.0 to +15.0

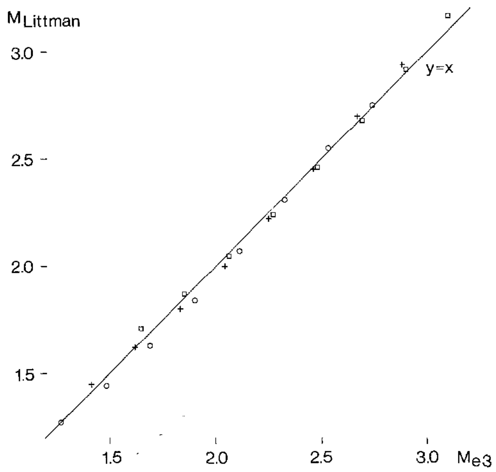

Fig. 4. Comparison of the numerical values of $0.73/q(=M_{Littman})$ and $0.042(58.64+A+0.84\ \Delta D_1)\ (=M_{e3})$ for different combinations of refraction and corneal curvature

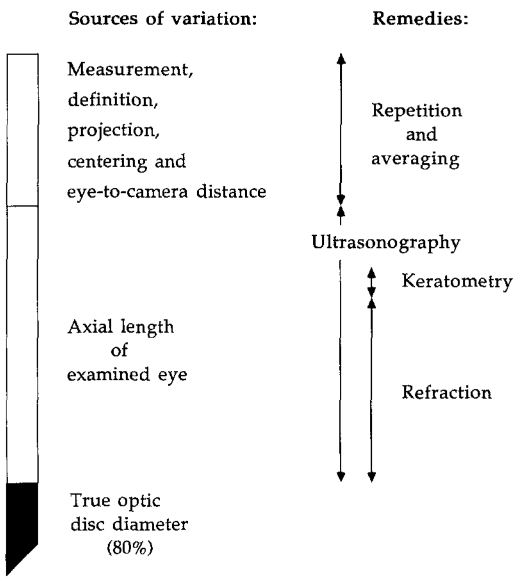

Fig. 5. Schematic representation of relative sizes of different components of the interindividual variance in optic disc-diameter measurements

Transformation of Littman's curves

Conversely, the equation $q=0.73/M$ may be written as $M=0.73/q$ and be used, together with the formula for the refractive power of the cornea $(D_1=0.336/r)$, to transform Littman's curves into almost straight lines

Table 1. Symbol, value, derivation and denomination of constants and variables

A	$G/(1-G/\bar{D})$ dpt	Principal point refraction of the eye
B	$n/(l-p)$ dpt	Vergence of the internal axis of the eye
ΔB	$(A+\beta\Delta D_1)$ dpt	Estimated deviation of B from $\bar{D}$
β	0.84 (Stenström)	Coefficient of regression of D on D_1
D	$(B-A)$ dpt	Total refractive power of the eye
$\bar{D}$	58.64 dpt (Gullstrand)	"Normal" refractive power of the eye
D_1	$0.336/r$ dpt	Refractive power of the cornea
$\bar{D}_1$	$0.336/\bar{r}$ dpt	"Normal" refractive power of the cornea
ΔD_1	$(D_1-\bar{D}_1)$ dpt	Deviation of D_1 from $\bar{D}_1$
D_2	$(D-D_1)/(1-\delta D_1)$ dpt	Refractive power of the crystalline lens
δ	0.0043 m (Gullstrand)	Effective depth of the anterior chamber[a]
G	measured (dpt)	Glass refraction
k	measured (m)	Camera constant[c]
l	measured (m)	Distance from the apex of the cornea to the retina
M	kB	Magnification of the eye-camera system
M_{e1}	$nk/(l-p)$	First estimate of M
M_{e2}	$k\bar{D}/(1-G/\bar{D})$	Second estimate of M
M_{e3}	$k\bar{D}\cdot(1+\Delta B/\bar{D})$	Third estimate of M
n	1.336 (Gullstrand)	Refractive index of the eye
p	0.0016 m (Gullstrand)	Distance from the apex of the cornea to the posterior principal point
q	$0.01\,(aA^2-bA+c)$ mm/°	Correction factor of Littman[b]
r	measured (m)	Corneal radius
$\bar{r}$	0.0077 m (Gullstrand)	"Normal" corneal radius
s	measured (mm)	Diameter of the image of the eye-camera system
t	(s/M) mm or $(s\cdot u\cdot q)$ mm	Diameter of the retinal object
u	$(0.0573/k)$ °/mm	Camera constant of Littman[c]

[a] Reduced distance between the principal planes of the cornea and the crystalline lens
[b] a, b and c vary with r
[c] In the Zeiss camera $k=0.042$ and, thus, $u=1.37$

that may be approximated by the following expression:

$$M=2.45\,(1+0.018\,\Delta B),$$

which is similar to (7).

Graphic comparison

The values of $0.73/q$ ($=M_{\mathrm{Littman}}$) and $0.042(58.64+A+0.84\,\Delta D_1)$ ($=M_{e3}$) for different combinations of refraction and corneal curvature are compared in Fig. 4, which shows an excellent agreement between the two.

Discussion

Littman's graphs are the result of trigonometric calculations that are not further specified and, therefore, not easy to check. They have been suspected by Quigley et al. [11] of underestimating the disc diameter. However, it is reassuring that Littman's results agree with ours. It is indeed possible that Gullstrand's value for $\bar{D}$ (58.64 dpt) is too low and that 60 dpt is a more realistic figure. This would make estimates of the disc diameter that are not based on actual measurements of the internal axis even lower.

Choices between different methods of correction should be based on accurate information about different sources of error. Figure 5 gives a schematic overview based on information provided by Stenström [12], Bengtsson [3], Balazsi et al. [1], Jonas et al. [5] and Mansour [9].

According to Stenström [12], variations in lens power are slightly more important ($r_{DD_2}=0.7$) than variations in corneal power ($r_{DD_1}=0.66$), even in persons aged <35 years. Age-related lens changes should be expected to increase this difference. Mansour's results [9] seem to indicate that variations in lens power are almost twice as important as variations in corneal power. Measurements of the corneal curvature are therefore hardly rewarding for the present purpose.

If correction for the influence of the glass refraction is considered to be unsatisfactory, correction based on measurements of the axial length seems to be the only alternative. However, if ultrasonography is to make sense, other errors must be rectified as well. The camera has to be correctly positioned in relation to the patient [8], and the optic disc must be centered in the photographic field [2, 10]. Photography, projection, tracing and planimetry should be repeated and the results, averaged [5]. Nevertheless, small but inevitable errors arising from many sources are added up; moreover, as there is no way to check the outcome, excessive expectations of exactness will remain unrewarded. Therefore, the use of a method that is comprehensible and easy to practise is the only reasonable approach.

References

1. Balazsi AG, Drance SM, Schulzer M, Douglas GR (1984) Neuroretinal rim area in suspected glaucoma and early chronic open-angle glaucoma. Arch Ophthalmol 102:1011–1014
2. Behrendt T, Doyle KE (1965) Reliability of image size measurements in the new Zeiss fundus camera. Am J Ophthalmol 59:896–899
3. Bengtsson B (1976) The variation and covariation of cup and disc diameters. Acta Ophthalmol (Copenh) 54:804–818
4. Bengtsson B, Krakau CET (1977) Some essential optical features of the Zeiss fundus camera. Acta Ophthalmol (Copenh) 55:123–131

5. Jonas JB, Gusek GC, Guggenmoos-Holzmann I, Naumann GOH (1988) Variability of the real dimensions of normal human optic discs. Graefe's Arch Clin Exp Ophthalmol 226:332–336
6. Littman H (1982) Zur Bestimmung der wahren Größe eines Objektes auf dem Hintergrund des lebenden Auges. Klin Monatsbl Augenheilkd 180:286–289
7. Littman H (1988) Zur Bestimmung der wahren Größe eines Objektes auf dem Hintergrund eines lebenden Auges. Klin Monatsbl Augenheilkd 192:66–67
8. Lotmar W (1984) Dependence of magnification upon the camera-to-eye distance in the Zeiss fundus camera. Acta Ophthalmol (Copenh) 62:131–134
9. Mansour AM (1990) Measuring fundus landmarks. Invest Ophthalmol Vis Sci 31:41–42
10. Pach J, Pennell D, Romano PE (1989) Optic disc photogrammetry: magnification factors for eye position, centration, and ametropias, refractive and axial; and their application in the diagnosis of optic nerve hypoplasia. Ann Ophthalmol 21:454–462
11. Quigley HA, Brown AE, Morrison JD, Drance SM (1990) The size and shape of the optic disc in normal human eyes. Arch Ophthalmol 108:51–57
12. Stenström S (1946) Untersuchungen über die Variation und Kovariation der optischen Elemente des menschlichen Auges. Acta Ophthalmol (Copenh) [Suppl XXVI] (104 pages)