ASSESSMENT OF THE NORMAL DISC

BY *P.K. Teal*, MD (BY INVITATION),
J.D. Morin, MD (BY INVITATION),
AND *C. McCulloch*, MD

EVALUATION OF THE OPTIC DISC, THE RIM, AND THE CUP ARE OF PRIME importance in the study of glaucoma. In this report these elements are assessed in the normal eye. The disc area is the entire retinal aspect of the optic nerve. The cup area is the central depression in the disc, left when the nerve fibres, converging on the disc from the retina, turn outwards to form the nerve trunk. The rim area is delineated on the inside by the optic cup margin and on the outside by the scleral boundary of the disc; it represents the viable nerve fibres and their supporting elements in the nerve head.

Attempts have been made to correlate the appearance of the optic cup with the diagnosis of early open-angle glaucoma. It has long been generally felt that a large optic cup in adult life should be considered to be suspicious of glaucoma.

It is our impression, however, that the area of the optic cup is widely variable among normals and not the significant measurement needed in assessing the state of the nerve. We propose, instead, that it is the amount of nerve fibres going through the disc, i.e., the optic rim, which is the important parameter.

To investigate this proposal we have determined:

1 the distribution of the areas of the optic rim, cup, and disc of the normal population;
2 the relationship between the size of the optic cup and the size of its corresponding rim and disc; and
3 the relationship between the size of the optic cup and the size of the blind spot as plotted on tangent screen.

Finally it is known that the earliest field defect in glaucoma is often an upper nerve fibre bundle defect. In light of this we have measured the upper and lower temporal rim dimensions to determine if rim symmetry is present in normal eyes.

TR. AMER. OPHTHAL. SOC., VOL. LXX, 1972

SUBJECTS

The survey was conducted upon 64 "normal healthy adults"; one eye was chosen randomly from each subject for the purpose of this study. These subjects fulfilled the following requirements:

1 absence of significant general medical disease, including diabetes mellitus and any form of cardiovascular disease;
2 absence of any personal or family history of glaucoma;
3 absence of any history or evidence of past or present ocular disease;
4 visual acuity of 20/20 or better;
5 distance refraction not exceeding 1.50 dioptres;
6 normal visual field examination of each eye using the tangent screen at 1 m with a 3-mm test object;
7 keratometry reading between 42 and 44 dioptres; and
8 applanation pressures less than 16 mm of mercury.

METHOD

1. Ocular normalcy was established by:
(a) determination of best corrected visual acuity using the Snellen chart;
(b) ophthalmoscopic examination to exclude any obvious intraocular lesions;
(c) keratometry reading; and
(d) applanation tonometry.

2. The actual size of the blind spot was determined in the following fashion:

The patient was seated 1 m from a tangent screen with head supported in a head rest. The refractive error was fully corrected and the pupil was not dilated. The eye not under examination was occluded.

Using a 3-mm test object the blind spot was outlined by an eight-point configuration. The position of each of these eight points was determined in centimetres, using the point of fixation as the zero point; the 180° line as the x axis; and the 90° line as the y axis. The blind spot measurements were then plotted on graph paper (scale 2½ mm = 1 cm), the eight points joined, and the enclosed area measured by planimetry.

3. Fundus photographs of the eye were taken using a Zeiss Fundus camera loaded with Kodachrome II film. These coloured slides were projected to constant size (× 27 magnification), and the boundaries of

the optic disc and optic cup were traced onto plain paper. Assessment of the optic disc and cup boundaries was made primarily on the basis of colour change – the disc projecting pink, the cup white. Pigment boundaries, when present, were used as an aid in identifying disc margin. Any crescents observed were not included in the disc measurement.

Blood vessels were excluded from cup measurements when possible. These measurements were made by three independent observers with different backgrounds – an experienced ophthalmologist, a first-year ophthalmology resident, and a general practitioner with no additional ophthalmological training. This was done in an attempt to verify the accuracy of our tracings.

These traced areas were then measured by planimetry from records. Figure 1 shows a typical record with the tracing of the disc and cup × 27 magnification, and the plotted blind spot of Eye 36.

4. Rim symmetry measurements were made by obtaining the width, in centimetres, of the upper and lower temporal rim. These measurements were made at the eight and ten o'clock positions – again at a constant magnification of × 27.

All data were transferred to cards and analysis of variance and relationships was done with the aid of a computer.

RESULTS

A. ANALYSIS OF VARIANCE AMONG OBSERVERS

The F-ratio between observer differences is a remarkable 0.39 compared with a 95 per cent critical value of 3.07.

B. OPTIC RIM, DISC, AND CUP AREA DISTRIBUTION

These areas as noted in Table 1 are measured from the projected slide. Note that the S.D. as a percentage of the mean of disc and rim is distinctly different from that of the cup. The disc area as seen in Figure 2 is regularly distributed in distinction to the cup area, which is randomly scattered as in Figure 3. The rim area, Figure 4, is clustered about a mean of 99.9 sq. cm. The correlations of cup, rim, and disc areas is seen in Table 2. Note the differences in the sample correlation coefficient – r between rim-cup and disc-cup.

C. SIZE OF BLIND SPOT

The size of the blind spot on the graph paper had a mean value of 8.5 sq. cm, S.D. 2.7 sq. cm, and S.D. as a percentage of the mean is 32. In

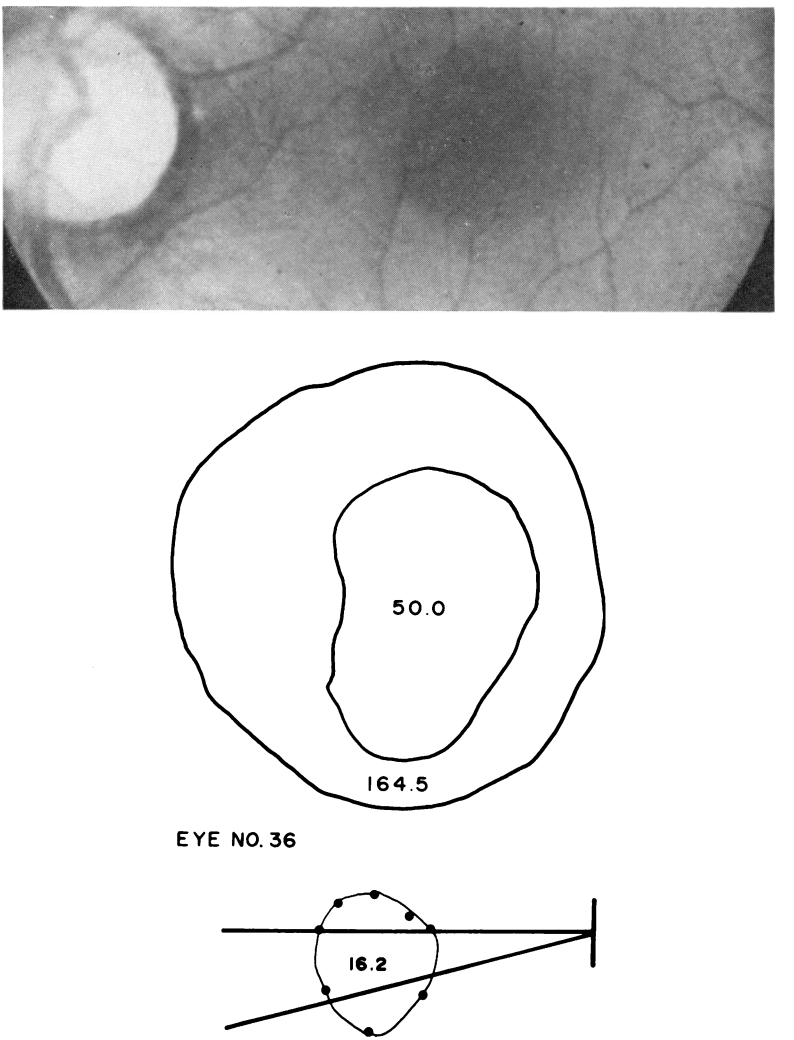

FIGURE 1

Top: Typical photograph of optic disc with large cup. *Middle:* Tracing of this disc and cup (× 27) with areas noted in sq cm. *Bottom:* Blind spot of this eye plotted on tangent screen with area in sq cm.

Table 3 the correlations of the blind spot with both cup and disc are noted to be quite good. In Figures 5 and 6 these correlations can be seen, so that a larger blind spot is associated with a larger disc and cup area.

D. RIM SYMMETRY

Rim symmetry measurements and correlations are seen in Table 4. The line graph Figure 7 illustrates how highly correlated these dimensions are.

TABLE 1. DISC RIM AND CUP AREA IN SQ. CM AS MEASURED FROM PROJECTED SLIDE (× 27)

	Mean	S.D.*	S.D. as % of mean
Disc	118.0	19.3	16
Rim	99.9	13.9	14
Cup	18.1	11.5	66⅔

*Sq. cm.

TABLE 2. CUP CORRELATIONS WITH RIM AND DISC

P–M correlation	*r* value	Critical *r* value
Rim: cup	+0.15	+0.25
Disc: cup	+0.74	+0.25

Cup area correlates well with disc area and not rim

TABLE 3. BLIND SPOT CORRELATIONS WITH CUP AND DISC

P–M correlation	*r* value	Critical *r* value
Cup: blind spot	+0.76	+0.25
Disc: blindspot	+0.70	+0.25

Blind spot area graphically recorded from tangent screen correlates well with disc and cup area

TABLE 4. RIM SYMMETRY (RIM DIMENSION MEASURED 45° ABOVE AND BELOW A HORIZONTAL THROUGH CENTRE OF DISC)

	Mean*	S.D.*	S.D. as % of mean
↓Temp.	4.2	1.2	30
↑Temp.	4.1	1.7	40

P–M correlation	*r* value	Critical *r* value
↑Temp.: ↓Temp.	+0.81	+0.25

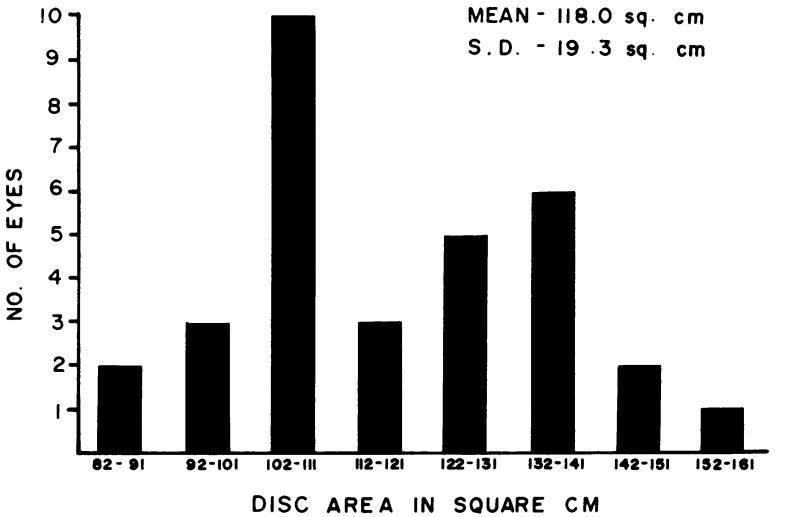

FIGURE 2
Disc area distribution.

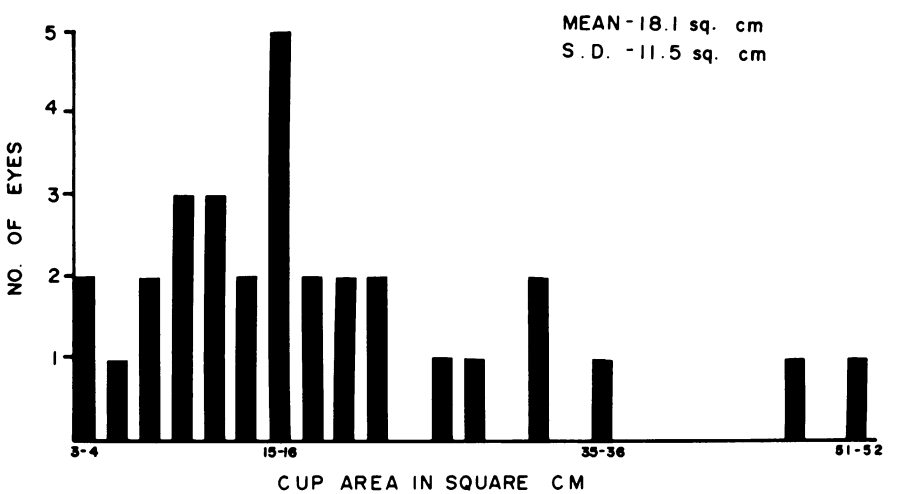

FIGURE 3
Cup area distribution.

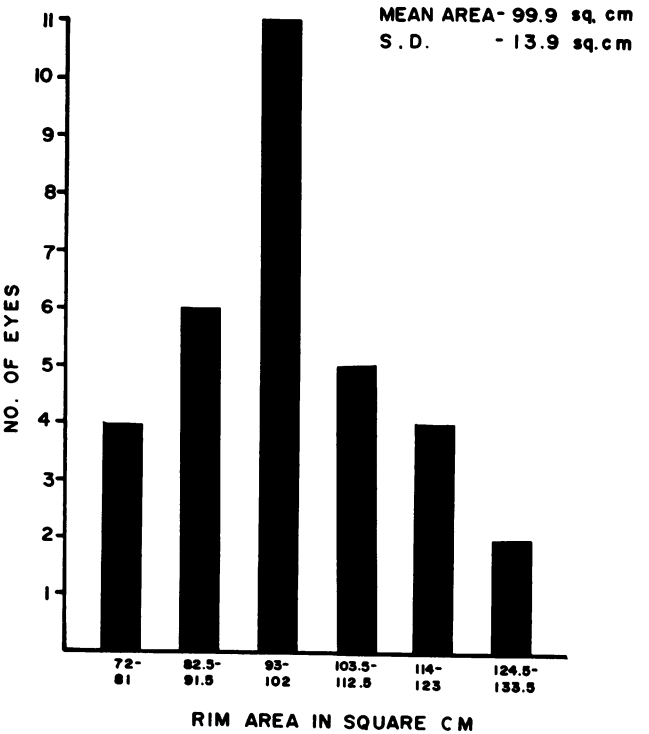

FIGURE 4
Rim area distribution.

DISCUSSION

A. OBSERVER VARIANCE

From analysis of variance between observers we are able to conclude that measurement error of the projected discs and cups is very small. Accordingly the results deduced from our measurements should give a true representation of cup, disc, and rim areas – within the limits imposed by the accuracy of projected slides as a measurement of the actual cup and disc size.

B1. DISTRIBUTION OF VARIABLES

The distribution figures for cup, disc, and rim show that the area of the optic cup is certainly the most widely variable of the three areas. Cup size varies between 2 and 53 sq. cm, with its standard deviation being as high as 66% per cent of its mean value.

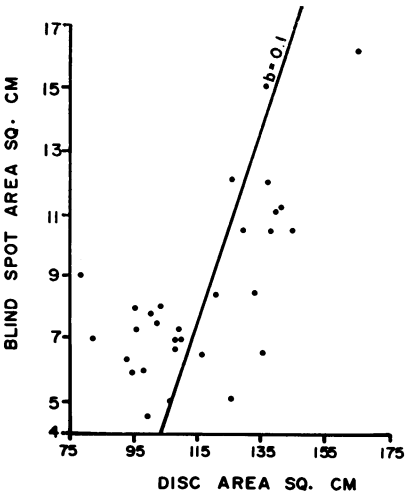

FIGURE 5
Blind spot: disc.

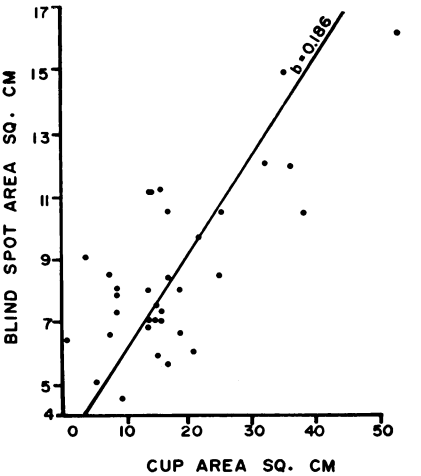

FIGURE 6
Blind spot: cup.

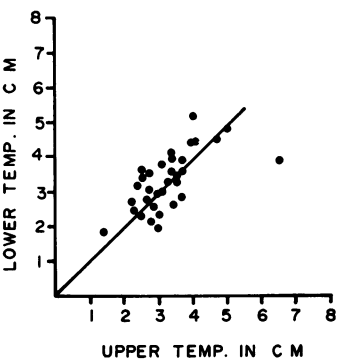

FIGURE 7
Rim symmetry.

Rim area, on the other hand, showed a standard deviation that was only 14 per cent of its mean value.

The bar graph shows the clustering of results in the 90 to 99 sq. cm grouping. Although we were not able to show an absolutely normal distribution for rim area, we did find that 75 per cent of our results (24 out of 32 subjects) did fall within one standard deviation of the mean – a figure very close to the 68 per cent seen in a normal distribution curve.

These figures certainly seem to indicate a fairly constant area of nerve fibres.

Certain problems could explain this discrepancy, such as:

1 the difficulty in interpreting physical statistics as applied to biologic measurements;
2 the uncertainty as to whether colour slide projection is an absolutely accurate representation of the components of the nerve head;
3 the increasing difficulty in obtaining accurate cup area measurements as the cup decreases in size; and
4 the interference of blood vessels in accurate cup measurement may have been the reason that rim distribution was not shown to be absolutely normal. Nevertheless there is no question that of the two variables – cup and rim – rim is certainly the more significant measurement in the assessment of the state of the nerve. Thus nerves with rim areas which vary more than one standard deviation from the mean should come under suspicion.

B2. CORRELATIONS OF CUP, DISC, AND RIM

Correlation coefficients between the optic cup and optic rim and optic disc reveal the following information:

The area of the optic rim is uncorrelated with the area of the optic cup – the correlation coefficient between rim and cup being only 0.15. This supports the contention that an apparently large cup does not necessarily represent any loss of viable nerve tissue at the nerve head. The lack of correlation between these two variables shows that in the normal eye a very large cup may be observed, and yet the amount of nervous tissue present may be the same as that in an eye with a very small cup.

Conversely, the area of the cup and the area of the disc are strongly correlated. This indicates an accommodation for a large genetic cup is made in the form of enlargement of the entire disc – possibly in an attempt to keep the rim area (that is, the nerve fibres present at the disc) constant. Disc area is equal to cup area plus rim area. If the cup area were increasing at the expense of the rim area, there would, of course, be no corresponding increase in the total area of the disc. Instead of this we find disc area steadily increasing as cup area increases, thus supporting the proposal that a fairly standard number of nerve fibres is present at the nerve head.

C. CORRELATIONS OF BLIND SPOT, CUP, DISC

The clinical applications of these findings are most evident in the data comparing the area of the blind spot to that of cup. There is a very

highly positive correlation between the area of cup observed and the size of the blind spot as plotted on the tangent screen. The blind spot corresponds to the total disc size. If a large cup is present, the blind spot must correspondingly be enlarged. If this is not found, then one could reasonably assume that some loss of rim tissue (viable nerve) has occurred, and the eye should be viewed with suspicion.

The high correlation between size of blind spot and size of disc is subjective confirmation of the accuracy of our objective method of measuring the disc, i.e., colour slides.

D. RIM SYMMETRY

Our final data concerned the measurement of rim symmetry. Our figures show a very high correlation between upper and lower temporal rim diameters. Their means and standard deviations are almost identical. Thus we have been able to establish that in the normal eye there should be rim symmetry – any measurements showing large deviations between upper and lower temporal diameters should not be accepted as normal. It is to be hoped that further studies will be able to determine whether asymmetry does develop in glaucomatous eyes, especially those in which the nasal step field defect is present.

CONCLUSIONS

1 The amount of rim tissue in the disc is found to be fairly constant in normal individuals.
2 The size of the optic cup varies tremendously.
3 Variation in area of the optic disc correlates with variation in area of the optic cup, the rim tissue remaining constant.
4 The size of the optic cup does not necessarily influence the amount of nervous tissue present at the disc; correlations between cup and rim is insignificant.
5 The important measurement in assessing the normalcy of the optic disc would appear to be the area of the optic rim.
6 In normal eyes the size of the blind spot plotted on the tangent screen varies directly with the size of optic cup observed. Thus clinical differentiation between a genetically enlarged cup and a pathologically enlarged cup may be possible by comparing the size of the blind spot with the size of the observed cup.
7 Normal eyes exhibit rim symmetry along the temporal margin. Deviation from this symmetry may offer another clue to abnormality.

REFERENCES

1. Tomlinson, A., and C.I. Phillips, Ratio of optic cup to optic disc in relation to axial length of eyeball and refraction, Brit. J. Ophthal., 53:765, 1969.
2. Armaly, M.F., The optic cup in the normal eye: Cup width, depth, vessel displacement, ocular tension and outflow facility, Amer. J. Ophthal., 68:401, 1969.
3. Armaly, Mansour F., and Roger E. Sayegh, The cup/disc ratio: The findings of tonometry and tonography in the normal eye, Arch. Ophthal., 82:191, 1969.
4. Ford, M., and M. Sarwar, Features of a clinically normal optic disc, Brit. J. Ophthal., 47:50, 1963.
5. Pickard, Ranson, A method of recording disc alterations and a study of the growth of normal and abnormal disc cups, Brit. J. Opthal., 7:81, 1923.
6. Tomlinson, A., and C.I. Phillips, Emergence point and angulation of disc vessels in the normal eye, Brit. J. Ophthal., 55:165, 1971.
7. Armaly, M.F., The correlation between apearance of the optic cup and visual function, Trans. Amer. Acad. Ophthal. Otolaryn., 73:898, 1969.
8. Pickard, Ranson, Variations in the size of the physiological cup and their relation to glaucoma, Proc. Roy. Soc. Med., 14:31, 1921.
9. Allen, Lee, Ocular fundus photography: Suggestions for achieving consistently good pictures and instructions for stereoscopic photography, Amer. J. Ophthal., 57:13, 1964.

DISCUSSION

DR MANSOUR F. ARMALY. As the optic nerve fibers converge to exit through the scleral foramen, they appear first at the retinal plane, then begin to turn posteriorly to exit through the lamina cribrosa. The point at which they begin to change direction is the boundary of the optic cup. This is not a color boundary between pink and white, but a directional change which can be readily seen with the ophthalmoscope using parallax, and is readily identified in stereo photographs but not directly seen in single photographs, be they black and white or color. This landmark has been used in my studies and those of others to describe the optic cup boundary. The authors instead measured the area of whiteness in the center of the cup, which may, indeed, be a significant parameter but is unquestionably different from the boundary of that described above and is usually either absent or much smaller in size and more difficult to delineate in a reproducible manner from one photograph to the next in the same eye. Thus these results of the authors constitute a new set of measurements of "whiteness" at the cup and cannot be readily compared with those of other authors.

The sample is restricted to 34 normal eyes with applanation pressures below 16 mm Hg. This obviously does not encompass the entire spectrum of normal, especially with the established relationship between C/D ratio and ocular pressure level in the normal eye. It would be important to obtain a truly representative sample in this regard and hopefully extend the study to include ocular hypertensives.

The obvious findings with regard to the blind spot size are most intriguing.

For, instead of the usual emphasis on enlargement of the blind spot, the authors' findings suggest that, if the cup is large but the blind spot is not, one should suspect loss of nerve fibers. This new slant is most important to validate and explore from the standpoint of clinical usefulness. Rim symmetry in the eyes studied is potentially a significant clinical observation. Similar reasoning has led Drs Kirsch and Anderson in Miami to emphasize the greater frequency of vetrical enlargement of the cup in glaucoma.

We have pursued various measures of quantitative descriptions of disc topography and have met with a lot of frustration that seems to center on properties of optic nerve fibers at the disc. At the optic disc light scatter is significantly greater than at the adjacent retina. Dr M. Barracks, in my laboratory, has shown that the line-spread function at the disc is two to three times larger than that at the adjacent retina. This property invalidates the uncompensated utilization of reflectance measurements to describe topography of the optic nerve head by methods otherwise highly sensitive and reliable when applied to the model eye. This property does not influence greatly the detection of the cup boundary from stereo photographs but interferes markedly with its detection from single photographs. This limitation is especially compounded when one wishes to detect the transition from pink to white on the disc. The area of whiteness in the cup, however, may be more significant clinically than the cup boundary. I hope the authors will extend their investigations to the ocular hypertensive and the glaucomatous patient.

Dr David O. Harrington. I found this paper by Drs Morin and McCulloch of great interest. One of the most difficult clinical evaluations in ophthalmology is the appearance of the disc in glaucoma and normal eyes. All of us attempt to make this measurement regularly on our patients when we suspect glaucoma or have borderline increases in intraocular pressure, borderline discs, and changes in the visual field.

I was particularly interested in the question of the blind spot studies in relationship to the disc cupping. There is some variation in blind spot size in normal individuals partly because of the gray zone, so-called, that surrounds the blind spot, the relative scotoma that was pointed out many years ago by Traquair and others and which is a definite clinical finding in a large number of cases. In measuring this gray zone it is necessary to use stimuli which are large enough to pass through the gray zone and into the absolute blind spot, and at the same time to get large enough magnification of the blind spot so that small variations can be plotted. This can be done best on the tangent screen at 2 m rather than at 1 m, using 2-mm or 3-mm targets rather than a 1-mm target, where the gray zone may vary considerably depending on the subjective responses of the patient. When you are measuring the absolute blind spot, therefore, you must enlarge it, and in my view the 2-m screen is the most clinically applicable instrument. Recently I have done a few studies on blind spot measurement with the Harms-Aulhorn static perimeter measuring threshold sensitivity at the edge of the blind spot. This seems to be a good

method. The only difficulty is that the blind spot area is so small on the fixed distance that is used in the static perimeter that very small variations are a little difficult to detect.

The other thing that interested me was the question of the relationship of the blind spot size to the disc in normal and glaucomatous eyes. For many years we have been taught (and I am guilty along with everybody else) to call an enlargement of the blind spot a characteristic field defect in glaucoma. Aulhorn has shown, by the use of static perimetry, that this is not true, and that the blind spot size most of the time has very little relationship to applanation pressures and even to the size of the cup unless a Bjerrum scotoma runs into the blind spot area.

So in the absence of defects in the visual fields in the Bjerrum area, the measurement of blind spot size is not necessarily of any great value in determining whether or not a disc is abnormal or normal in a normal or glaucomatous eye.

DR MCCULLOCH. I would like to thank the discussants for a very interesting discussion and addition to the thoughts in our paper. There are two or three points I would like to make.

One is that I would like to emphasize that these were all extremely normal individuals. Their refractive error was between -2 and $+2$. They were young, healthy people, with very normal ocular pressures. Even their keratometry readings were within sharp limits. So we weren't really in any way trying to diagnose glaucoma here. We were trying very hard, with a very select group, to define normals and to get at something that was normal before looking at glaucoma.

Second, concerning this problem of how to decide on the size of the pit in relation to the disc as a whole, there are several ways to do it, as Dr Armaly has quite correctly pointed out. We did try to do it with various black and white techniques, but we finally settled on a colour technique, which we showed. We considered photogrammetry, which we have available in our city because there is some know-how in the area. There are several large companies that do stereoscopic map work. We came back to the simple colour photograph because we could handle it. We chose as our criterion the change of colour rather than the change of the slope in the photogrammetry type of presentation. Also we realized it was a technique that is quite capable of being done by any ordinary ophthalmologist – by everyone in this room, by any proper glaucoma clinic – and therefore it was something that could be translated into clinical practice.

I think the fact that we had three observers measuring these areas, and that their results were comparable, showed that we had internal control and showed that this could be done by any group anywhere, and it would be presumed their results would hold together.

Concerning the size of the blind spot on the tangent screen, I am very appreciative of Dr Harrington's wise remarks. I think he is quite right that the

area of the blind spot as a diagnostic feature for glaucoma is in some question. I think perhaps our small work here may have brought a little light to that point, and made consideration of the area of the blind spot when related to the picture of the disc – that is, the rim, cup sizes – more significant than it has been in the past.

I think this is, shall I say, a new diagnostic tool that any of us could use in our glaucoma clinics, for we have photography available and can choose to set it up this way. This is a little like fluorescein angiography. If we put some fluorescein in a vein and look at the fundus we see the fluorescein picture. But if we put fluorescein in a vein and take a photograph, then we can sit down and analyze the details.

Similarly, if we set up a standard photographing procedure and do these measurements, in particular find the rim area, we have data which is significant in assessing and following cases of glaucoma.