

Ocular dimensions in low tension glaucoma

Compared with open-angle glaucoma and the normal

A. TOMLINSON AND D. A. LEIGHTON

Department of Ophthalmology, Manchester Royal Eye Hospital

Pathological excavation of the optic disc in the apparent absence of raised ocular tension was first described by von Graefe (1857), and since then it has aroused interest among ophthalmologists; various names have been given to it and these have reflected ideas about its aetiology. Schnabel (1885) described a cavernous optic atrophy which he believed had resulted from progressive diminution of blood supply to the optic disc, a view supported by Wolff (1947). Sjögren (1946) considered that open-angle glaucoma and low tension glaucoma were one and the same condition. Lyle (1957) suggested that the terms pseudo-glaucoma and low tension glaucoma should be replaced by arterosclerotic optic atrophy.

Duke-Elder (1949) has stated that low tension glaucoma tends to occur in myopic eyes. Perkins (1959) and Winstanley (1959) commented on a high incidence of myopia (36 per cent., of whom a quarter were > -4 D sph.) in cases of low tension glaucoma. This may indicate that large eyeballs are unduly prone to glaucomatous field defects. Tomlinson and Phillips (1969) reported a correlation between cup-to-(optic) disc ratio and eyeball axial length, large eyeballs tending to have a high cup-to-disc ratio, *i.e.* a relatively large optic cup.

Armaly and Sayegh (1969) suggested that eyes with large optic cups (*i.e.* a high cup-to-disc ratio) appear to be more susceptible to the development of visual field defects than those with small optic cups. It also seems likely that a large *disc* rather than a large cup is more susceptible to a raised intraocular pressure. This may explain the high prevalence of myopia in cases of low tension glaucoma. Armaly (1963) has shown that patients with open-angle glaucoma and low tension glaucoma share a similar ocular hypertensive response after 6 weeks' dexamethasone drops, suggesting that the two conditions are related.

The purpose of this investigation was to find out whether the eye in low tension glaucoma differed in its major dimensions as well as in its applanation tension from either the normal eye or the eye in open-angle glaucoma.

Methods

SUBJECTS These comprised 33 persons:

- | | |
|-------------------------|--------------|
| 1. Low tension glaucoma | } 11 of each |
| 2. Open-angle glaucoma | |
| 3. Normal controls | |

Each patient with low tension glaucoma was carefully matched for sex, age, and refractive error with one patient with open-angle glaucoma and one normal control. The mean ages and refractive errors within the three groups are given in Table I. Age matching was within the range +9 to -13 years. Refractive error (best sphere) matching was done for one eye only and was within the range ± 1.5 D sph. The eye which gave the better match for refractive error was selected for assessment. In cases in which all the diagnostic criteria were not fulfilled in one eye, the other eye was selected for matching. None of the eyes included had had an operation.

Table I Mean values in low tension glaucoma, open-angle glaucoma, and normal controls. Eleven subjects in each group

(Comparisons made on a matched-pairs basis by Student's t test)

Group	Age (yrs)	Refractive error	Maximum applanation tension	Vertical corneal radius	Corneal diameter	Corneal thickness	Anterior chamber depth	Lens thickness	Vitreous length	Axial length	Cup/disc area ratio	Cup/disc diameter ratio
Low tension glaucoma	71.7	-0.93	19.4*†	7.83*†	11.17	0.55	3.13	4.82	15.93†	23.87	0.58*	0.74*
Open-angle glaucoma	68.0	-0.66	33.1†‡	7.56†	11.13	0.57	3.01‡	4.95	15.12†	23.08	0.52‡	0.69‡
Normal controls	68.0	-0.57	15.6*‡	7.58*	11.27	0.55	3.43‡	4.69	15.54	23.65	0.35*‡	0.57*‡

Significant difference found between
Minimum acceptable level $P < 0.05$

{ low tension glaucoma and normal controls *
normal controls and open-angle glaucoma ‡
low tension glaucoma and open-angle glaucoma †

(1) *Low tension glaucoma*

A search was made for patients with low tension glaucoma attending the glaucoma clinic. Criteria used were:

- (a) Pathological cupping of the optic disc,
- (b) A visual field defect typical of glaucoma,
- (c) Maximum recorded applanation tension not exceeding 23* mm.Hg,
- (d) Anterior chamber angle not considered liable to closure on gonioscopy.

Thirteen patients who fulfilled these criteria were found, but two had to be excluded because they were highly myopic (-11 and -24 D sph.) and no normal controls could be found for them. Of the remaining eleven, seven were females and four males. The mean age was 71.7 yrs (range 58 to 85) and the mean refractive error -0.93 D sph. (range +3.25 to -7). Only one eye was affected in two of the eleven cases. Repeated measurement of the applanation tensions for at least one morning had been done in ten of the eleven patients.

(2) *Open-angle glaucoma*

Diagnostic criteria were the same as for low tension glaucoma above, except for:

- (c) Maximum recorded applanation tension *greater* than 23 mm.Hg.

The mean age was 68 yrs (range 60 to 82), and the mean refractive error -0.66 D sph. (range +4 to -6). Only one eye was affected in two of the eleven cases. In three of these patients the applanation tensions were measured repeatedly during at least one morning.

(3) *Normal control subjects*

Five of these were from the outpatient clinic. They had attended because of:

- | | | |
|--|---|--------|
| (i) Vitreous floaters | } | 2 |
| (ii) Macular degeneration | | |
| (iii) Meibomian cyst | } | 1 each |
| (iv) Corneal ulcer in one eye (other eye used) | | |

*A level of 24 mm.Hg approximates to the mean plus twice the standard deviation for subjects of like age, *i.e.* 60-69 years examined in a population survey by Armaly (1965): males $16.33 + (3.80 \times 2) = 23.93$ mm.Hg; females $16.79 + (3.79 \times 2) = 24.37$ mm.Hg

The other six normal controls were from the refraction clinic. Applanation tensions were recorded on one occasion only from each of the normal controls.

The mean age of the eleven control subjects was 68.0 yrs (range 56–75) and the mean refractive error -0.57 D sph. (range $+3$ to -5.5).

OCULAR DIMENSIONS

The following were measured from the matched eye of each subject:

- (i) Corneal radius with the Zeiss keratometer.
- (ii) Corneal diameter from a colour photograph of the anterior surface of the eye.
- (iii) Corneal thickness with the No. I attachment for the Haag-Streit 900 slit lamp.
- (iv) Anterior chamber depth with the No. II attachment for the Haag-Streit 900 slit lamp.
- (v) Lens thickness
- (vi) Vitreous body length
- (vii) Axial length from the addition of (iv), (v), and (vi).
- (viii) Cup to disc area and diameter ratios measured from a stereoscopic fundus photograph taken by a successive technique using the Zeiss fundus camera (Tomlinson and Phillips, 1969).

Treatment with pilocarpine and tosmilen bromide drops was stopped 48 hours and 2 weeks respectively before the ocular dimensions were taken. Wilkie, Drance, and Schulzer (1969) showed that a reduction in the depth of the anterior chamber could result from treatment with miotic eye drops.

Results

Table I shows the means of the measurements taken for each of the three groups of patients. The matched pairs Student's *t* test, *i.e.* for related samples, was used to analyse the differences between the three matched groups. Table II shows that no significant differences were found between the ages or refractive errors of the three groups of subjects.

Table II Differences in age and refraction of the three samples

(Comparisons made on a matched-pairs basis by Student's *t* test)

Differences		Age			Refraction (dioptries)		
		Mean	<i>t</i>	<i>P</i>	Mean	<i>t</i>	<i>P</i>
Comparison	Low tension glaucoma versus open-angle glaucoma	3.7*	2.001	0.05 < <i>P</i> < 0.10	0.27†	1.076	0.30 < <i>P</i> < 0.40
	Low tension glaucoma versus normal controls	3.7*	2.005	0.05 < <i>P</i> < 0.10	0.36†	1.450	0.10 < <i>P</i> < 0.20
	Open-angle glaucoma versus normal controls	0	0	> 0.90	0.09†	0.248	0.80 < <i>P</i> < 0.90

* former older than latter
 † former more myopic than latter
 For *P* = 0.05, *t* = 2.228

OCULAR TENSION

Fig. 1 (overleaf) shows bar charts of the mean applanation tensions in the three groups. Significant differences for all three comparisons were found, *i.e.* low tension glaucoma patients (mean = 19.4 mm.Hg) had significantly higher applanation readings than the normal subjects (mean = 15.6 mm.Hg; *t* = 3.927; 0.001 < *P* < 0.01). Open-angle glaucoma patients (mean = 33.1 mm.Hg) had significantly higher applanation readings than either the low tension glaucoma cases (*t* = 5.810; *P* < 0.001) or the normal controls (*t* = 7.639; *P* < 0.001).

CENTRAL CORNEAL THICKNESS

No significant differences between the three groups were found, although thicker corneae were found in the patients with open-angle glaucoma than in the normal controls ($t = 1.944$; $0.05 < P < 0.10$).

CORNEAL DIAMETER

Again no significant differences were found, but a slightly smaller corneal diameter was found in cases of open-angle glaucoma than in normal controls ($t = 0.989$; $0.30 < P < 0.40$).

VERTICAL CORNEAL RADIUS

This was significantly flatter (*i.e.* greater corneal radius) in the low tension glaucoma sample than in either the open-angle glaucoma sample ($t = 3.772$; $0.001 < P < 0.01$) or the normal controls ($t = 2.640$; $0.02 < P < 0.05$) (Fig. 2). The same trends were found in horizontal corneal radius but they did not quite reach significance.

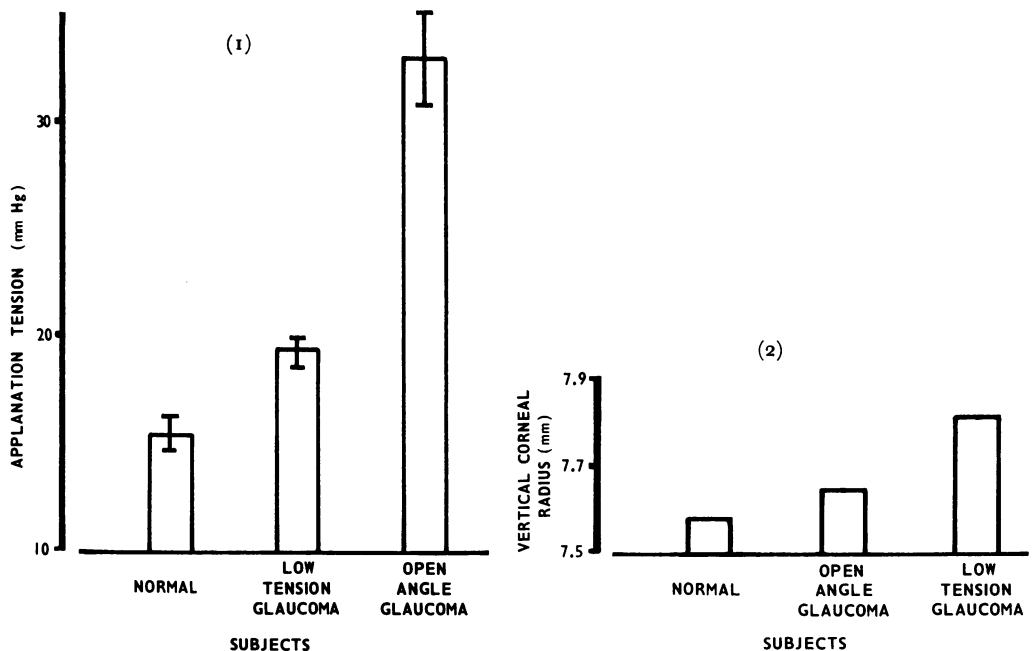


FIG. 1 Bar charts of mean applanation tensions in normal subjects and cases of low tension glaucoma and open-angle glaucoma, eleven subjects in each group. Each of the eleven patients with low tension was carefully matched for sex, age, and refractive error with one patient with open-angle glaucoma and one normal.

Mean applanation tensions were:

Normal Subjects	..	..	..	..	..	15.6 mm.Hg
Low tension glaucoma	..	..	..	..	..	19.4 mm.Hg
Open-angle glaucoma	..	..	..	..	..	33.1 mm.Hg

Applanation tensions were significantly greater in low tension glaucoma than in normal subjects ($0.001 < P < 0.01$), and significantly greater in open-angle glaucoma than in either low tension glaucoma ($P < 0.001$) or normal subjects ($P < 0.001$).

FIG. 2 Bar charts of mean vertical corneal radius in normal subjects, and cases of open-angle glaucoma and low tension glaucoma, eleven subjects in each group. Although the subjects had been carefully matched for sex, age, and refractive error, the vertical corneal radius was significantly greater in low tension glaucoma than in either open-angle glaucoma ($0.001 < P < 0.01$) or normal subjects ($0.02 < P < 0.05$).

ANTERIOR CHAMBER DEPTH

Open-angle glaucoma cases (mean depth 3.01 mm.) had significantly shallower anterior chambers than normal subjects (mean depth 3.43 mm.; $t = 2.356$; $0.02 < P < 0.05$). Anterior chamber depth in open-angle glaucoma was similar to that found in low tension glaucoma (mean depth 3.13 mm.). The difference in anterior chamber depth between the latter eyes and those of the normal controls was not quite significant ($t = 1.816$; $0.05 < P < 0.10$) (Fig. 3).

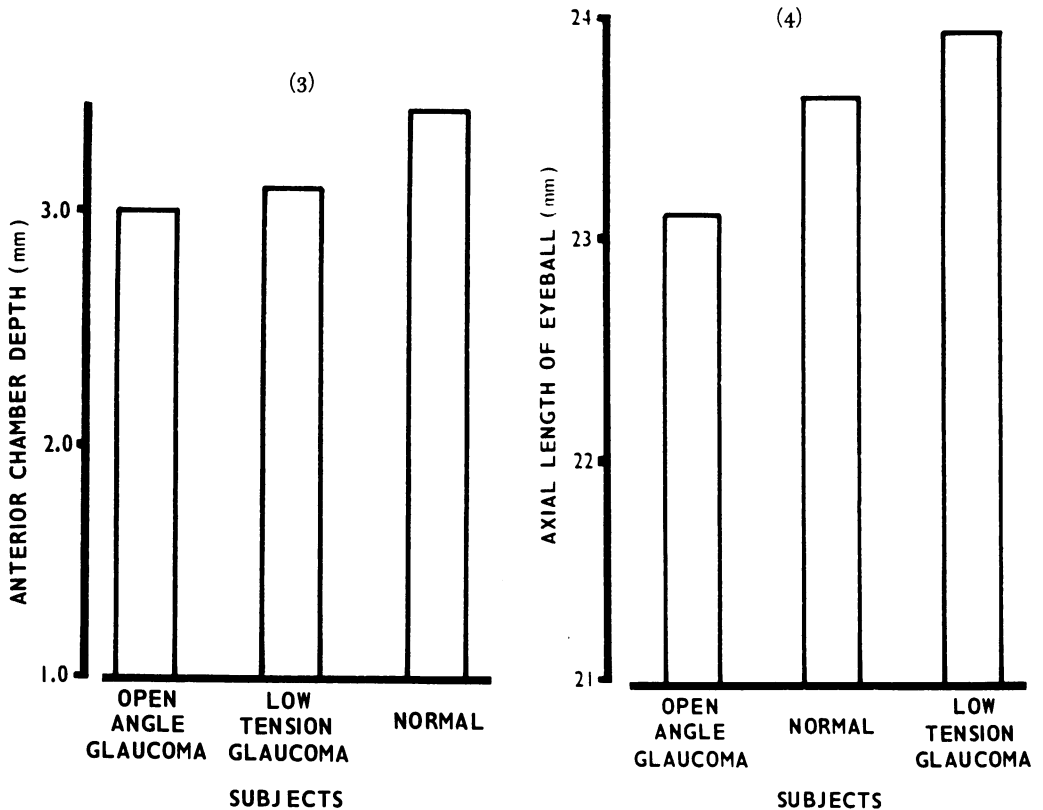


FIG. 3 Bar charts of mean anterior chamber depth in cases of open-angle glaucoma and low tension glaucoma, and normal subjects, eleven in each group. Although the subjects had been carefully matched for age, sex, and refractive error, the anterior chamber depth was significantly less in open-angle glaucoma than in normal subjects ($0.02 < P < 0.05$)

FIG. 4 Bar charts of mean axial length of eyeball in cases of open-angle glaucoma, normal subjects, and low tension glaucoma, eleven subjects in each group. Although the subjects had been carefully matched for sex, age, and refractive error, a greater axial length was found in low tension glaucoma than in open-angle glaucoma, but the difference was not quite significant ($0.05 < P < 0.10$). Vitreous length was, however, significantly greater in low tension glaucoma than in open-angle glaucoma ($0.02 < P < 0.05$)

LENS THICKNESS

No significant differences were found, but lenses were somewhat thicker in cases of open-angle glaucoma than in normal subjects ($t = 1.217$; $0.20 < P < 0.30$)

VITREOUS LENGTH

This was significantly greater in low tension glaucoma than in open-angle glaucoma (means 15.93 and 15.12 mm. respectively; $t = 2.270$; $0.02 < P < 0.05$). The mean vitreous body length of normals was between those of low tension glaucoma and open-angle glaucoma.

AXIAL LENGTH OF EYEBALL

Findings were similar to those for vitreous length, *i.e.* a greater axial length was found in low tension glaucoma than in open-angle glaucoma (means 23.87 and 23.08 mm. respectively), but the difference was not quite significant ($t = 1.826$; $0.05 < P < 0.10$). Values in normal controls were again intermediate (mean 23.65 mm). (Fig. 4, see p. 101).

CUP/DISC RATIO

The mean was greater in low tension glaucoma and open-angle glaucoma than in normal controls: horizontal cup/disc diameter ratio, $t = 5.239$ and 4.430 ; $P < 0.001$ and $0.001 < P < 0.01$ respectively; cup/disc area ratio, $t = 5.161$ and 4.952 ; $P < 0.001$ each. Although the mean cup/disc ratio was greater in low tension glaucoma than in open-angle glaucoma, the difference was not significant: horizontal cup/disc diameter ratio, $t = 1.356$; cup/disc area ratio $t = 1.359$; $0.20 < P < 0.30$ in each case.

Discussion and Conclusions

Of the eleven cases of low tension glaucoma, seven were female and four male. Perkins (1959) and Winstanley (1959) found twice as many females as males.

Ocular tensions in low tension glaucoma and open-angle glaucoma clearly differ from one another only in the degree of elevation in ocular tension, because cases of both conditions had significantly higher ocular tensions than the normal controls. It should be noted that the patients had been carefully matched for sex, age, and refractive error. These are all factors which can influence ocular tension. Presumably ocular tension does play an important part in the pathogenesis of "low tension" glaucoma, although a multifactorial aetiology seems especially likely. Use of the term "low tension" glaucoma is questionable because it may be understood to imply a lower ocular tension than normal, when clearly in these data it was higher. *It seems reasonable to suggest that treatment of low tension glaucoma, like that of open-angle glaucoma, should be directed towards a reduction in ocular tension by medical or, when indicated, surgical methods.* In general, of course, the lower the intraocular pressure, the more difficult it is to achieve a reduction in ocular tension.

The patients with low tension glaucoma were slightly older by 3.7 years than either the patients with open-angle glaucoma or the normal controls. The greater vertical corneal radius in low tension glaucoma than in either open-angle glaucoma ($0.001 < P < 0.01$) or normal subjects ($0.02 < P < 0.05$) could therefore have been due to the age difference because vertical corneal radius is probably the major component of the change from "with-the-rule" to "against-the-rule" corneal astigmatism with increasing age (Weale, 1963). However, regression analysis showed that the age difference did not account for the differences in vertical corneal radius. The differences found in axial length between the three groups may partly explain the differences in corneal radius. Hence, in spite of the close matching for refractive error (see Table II), axial lengths were greater in low tension glaucoma than in open-angle glaucoma, though the difference was not quite significant

($0.05 < P < 0.10$). Evidently this difference in axial length, which would have tended to make low tension glaucoma eyes relatively more myopic than open-angle glaucoma eyes was neutralized by the significantly greater corneal radius in low tension glaucoma compared to open-angle glaucoma ($0.001 < P < 0.01$). A significant correlation between greater axial length and greater corneal radius was found when the low tension and open-angle glaucoma groups were combined ($N = 22$; correlation coefficient $+ 0.486$; $0.01 < P < 0.05$).

Similarly, the tendency towards hypermetropia in open-angle glaucoma arising from a relatively short axial length compared to that in low tension glaucoma would also be partially neutralized by a relatively greater effective dioptric power of the lens because of its more anterior position (the anterior chamber was relatively shallow in open-angle glaucoma) and the slightly greater thickness of the lens.

It is difficult to see how the vertical corneal radius can be of importance in the aetiology of low tension glaucoma. An increasing vertical corneal radius with age is the major component of the change from "with-the-rule" to "against-the-rule" corneal astigmatism, and this is probably due to a progressive loss of orbital tissue (Weale, 1963). The greater vertical corneal radius in low tension glaucoma could conceivably be due to a premature backwards displacement of the eyeball due to loss of orbital tissue which might be associated with a diminution in blood supply to the orbit and its contents. A greater axial length, with which a greater vertical corneal radius could be correlated ($0.01 < P < 0.05$), is more likely to be concerned in the aetiology of low tension glaucoma because greater axial length is associated with a higher cup/disc ratio (Tomlinson and Phillips, 1969—see later discussion).

Perkins (1959) and Winstanley (1959) have pointed out that, in patients with low tension glaucoma, who are often myopic, a relatively high radius of corneal curvature would tend to give an erroneously low estimate of intraocular pressure with the Schiötz tonometer and that therefore a low ocular rigidity should result. Our results which showed that corneal radius was significantly greater in low tension glaucoma than in either open-angle glaucoma ($0.001 < P < 0.01$) or normal subjects ($0.02 < P < 0.05$) support this view. Axial length in low tension glaucoma was found to be greater than in open-angle glaucoma, though not quite significantly so ($0.05 < P < p.10$). The greater axial length would also tend to give a lower ocular rigidity (Luyckx, 1967; Leighton and Tomlinson, 1971) in low tension glaucoma than in open-angle glaucoma. It follows that, especially in suspected low tension glaucoma, applanation tonometry should be preferred to Schiötz tonometry.

The shallower anterior chamber in open-angle glaucoma than in normal controls agrees with the findings of Rosengren (1931), and Törnquist and Brodén (1958). The miotic treatment which patients with low tension glaucoma and open-angle glaucoma had been receiving was stopped, in the case of pilocarpine drops 48 hours and in that of tosmilen bromide drops 2 weeks, before the eye measurements were taken. By criteria from Wilkie, Drance, and Schulzer (1969), the time without treatment before our measurements were taken may not have been quite adequate, although we considered that a longer period would have been unjustifiable. Accordingly, the shallower anterior chambers in cases of open-angle and low tension glaucoma may have been partly due to previous treatment with miotic eye drops.

A high outflow resistance is, however, associated with shallowness of the anterior chamber (François, Rabaey, Neetens, and Evens, 1958; Nihard, 1962; Barkhoff and Kaizik, 1969). The connection between a shallow anterior chamber and high outflow resistance is difficult to see, although the anterior chamber depth is age-dependent (Weale, 1963). Outflow

resistance has also been reported to be age-dependent by Weekers, Watillon, and de Rudder (1956), Becker (1958), and Boles-Carenini and Cambiaggi (1957), although Grant (1951), de Roeth and Knighton (1952), and Spencer, Helmick, and Scheie (1955) reported that it was not so.

Axial length of eyeball was greater in low tension glaucoma than in open-angle glaucoma but the difference was not quite significant. The significantly greater length of the vitreous body in low tension glaucoma than in open-angle glaucoma indicates that the posterior segment of the eye was bigger in the former, would tend to have a higher cup/disc ratio (similarly great axial eyeball length correlates with high cup/disc ratio—Tomlinson and Phillips, 1969), and would therefore be more susceptible to glaucomatous cupping (Armaly and Sayegh, 1969).

Sjögren (1946) commented on the deeper excavation of the optic disc in low tension glaucoma than in open-angle glaucoma. We found a higher cup/disc ratio in low tension glaucoma than in open-angle glaucoma, though the difference was not significant. The moderate elevation in ocular tension that we found in low tension glaucoma was probably associated with a greater amount of excavation of the optic disc than would have been the case in open-angle glaucoma, because in the patients with low tension glaucoma the large axial length of eyeball probably contributed to a relatively high cup-to-disc ratio before the onset of glaucoma. Conversely, patients with open-angle glaucoma would probably have had lower cup-to-disc ratios before the onset of glaucoma than those with low tension glaucoma, and hence their greater elevation in ocular tension was relatively more important in the production of pathological disc excavation than the moderate elevation in ocular tension found in low tension glaucoma.

Summary

Eleven cases of low tension glaucoma were each carefully matched with one open-angle glaucoma patient and one normal control for sex, age, and refractive error. The ocular tensions of both the low tension and open-angle glaucoma groups were significantly higher than those of the normal controls ($P < 0.01$; $P < 0.001$ respectively). Open-angle glaucoma and low tension glaucoma therefore only differed from each other in the degree of elevation of ocular tension and their treatment should therefore be similar.

Vertical corneal radius was greater in low tension glaucoma patients than in either open-angle glaucoma patients or normal controls ($P < 0.01$; $P < 0.05$ respectively). However, a greater vertical corneal radius was associated with greater axial length ($P < 0.05$).

Anterior chambers were significantly shallower in the open-angle glaucoma patients than in normal controls ($P < 0.05$).

A greater length of vitreous body was found in cases of low tension glaucoma than in open-angle glaucoma ($P < 0.05$). This may well indicate a greater liability to glaucomatous field defects in low tension glaucoma than in open-angle glaucoma because of an association between greater vitreous length and a high cup/disc ratio.

References

- ARMALY, M. F. (1963) *Arch. Ophthalm. (Chicago)*, **70**, 492
 ——— (1965) *Ibid.*, **73**, 11
 ——— and SAYEGH, R. E. (1969) *Ibid.*, **82**, 191
 BARKHOFF, E. R., and KAIZIK, O. (1969) *Klin. Mbl. Augenheilk.*, **155**, 518
 BECKER, B. (1958) *Amer. J. Ophthalm.*, **46**, 731

- BOLES-CARENINI, B., and CAMBIAGGI, A. (1957) *Ibid.*, **44**, 395
- DUKE-ELDER, S. (1949) "Textbook of Ophthalmology", vol. 4, p. 4317. Kimpton, London
- FRANÇOIS, J., RABAËY, M., NEETENS, A., and EVENS, L. (1958) *A.M.A. Arch. Ophthal.*, **59**, 683
- GRAEFE, A. VON (1857) *v. Graefes Arch. Ophthal.*, **3**, pt 2, p.456
- GRANT, W. M. (1951) *A.M.A. Arch. Ophthal.*, **46**, 113
- LEIGHTON, D. A., and TOMLINSON, A. (1971) *Brit. J. Ophthal.*, **55**, 607
- LUYCKX, J. (1967) *Ophthalmologica*, **153**, 355
- LYLE, D. J. (1957) *Proc. roy. Soc. Med.*, **50**, 937
- NIHARD, P. (1962) *Exp. Eye Res.*, **1**, 229
- PERKINS, E. S. (1959) *Proc. roy. Soc. Med.*, **52**, 429
- DE ROETHH, A., and KNIGHTON, W. S. (1952) *A.M.A. Arch. Ophthal.*, **48**, 148
- ROSENGREN, B. (1931) *Acta ophthal. (Kbh.)*, **9**, 103
- SCHNABEL, J. (1885) *Arch. Augenheilk.*, **15**, 311
- SJÖGREN, H. (1946) *Acta ophthal. (Kbh.)*, **24**, 239
- SPENCER, R. W., HELMICK, E. D., and SCHEIE, H. G. (1955) *A.M.A. Arch. Ophthal.*, **54**, 515
- TOMLINSON, A., and PHILLIPS, C. I. (1969) *Brit. J. Ophthal.*, **53**, 765
- TÖRNQUIST, R., and BRODÉN, G. (1958) *Acta ophthal. (Kbh.)*, **36**, 309
- WEALE, R. A. (1963) "The Aging Eye", pp. 5, 13. Lewis, London
- WEEKERS, R., WATILLON, M., and DE RUDDER, M. (1956) *Brit. J. Ophthal.*, **40**, 225
- WILKIE, J., DRANCE, S. M., and SCHULZER, M. (1969) *Amer. J. Ophthal.*, **68**, 78
- WINSTANLEY, J. (1959) *Proc. roy. Soc. Med.*, **52**, 433
- WOLFF, E. (1947) *Trans. ophthal. Soc. U.K.*, **67**, 133