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Astigmatism following cataract surgery

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SUMMARY The changes in corneal curvature were determined at regular intervals over a one-year period following intracapsular cataract extraction by microsurgical techniques. During the first postoperative month photokeratometric measurements showed rapid changes in astigmatism associated with large changes in the direction of the axis. Thereafter astigmatism against-the-rule predominated. Data from the small group of patients who underwent surgery in which the technique of phacoemulsification was used show that the smaller changes in corneal curvature are attributable to the smaller incision size and reduced number of sutures. With patients who underwent intracapsular extraction a comparison has been made between the effects of large and small section sizes, and a procedure is outlined whereby surgically induced astigmatism may be minimised.

Donders[1] first showed that an unwelcome consequence of cataract surgery is an alteration in corneal curvature. Studies on corneal astigmatism related to intracapsular cataract surgery have been numerous (for a comprehensive review of the work since 1941 see Funder *et al.*[2]). The older surgical techniques started without sutures at the turn of the century. Both these and later techniques employing one or 2 large gut sutures caused a predominance of astigmatism against-the-rule. This was due to the wound gaping or stretching vertically, which increased the circumference of the globe, causing a flattening in this meridian. In addition there was steepening of the horizontal meridian. In the past decades there has been increasing use of the operating microscope for cataract surgery. At a congress in 1969 an audience poll showed 3% using this instrument, in 1971[3] the figure was 30%; in 1975[4] 83% used it routinely or occasionally; by 1978[5] it was de rigueur. Together with the development of finer suture materials surgeons now have far greater control over the optical outcome of the operation.

However, there are widely disparate views on the causes and correction of postoperative astigmatism. They relate mainly to the methods of incision and closure and the effects on corneal curvatures. There is controversy over the incision size and location, the depth of sutures, the material, and the technique of suturing. There is evidence that the more peripheral the section the less effect there is on surgically induced astigmatism.[6] (Troutman's[7] use of a '160° corneal incision and use of 10–0 nylon sutures through the full thickness of the wound' apparently gives similar optical results.) Changes attributable to the suture material have been observed,[8,9] as has a rotation in the axis of astigmatism.[10] Singh and Kumar[11] found no appreciable difference between surgically induced astigmatism with pre- or post-placed sutures. The results of phacoemulsification show that within one month of surgery the mean induced astigmatism is less than 0·5 D.[12–15]

The present investigation examined the effects on surgically induced astigmatism of one routine incision and closure technique with microsurgical techniques and a fine suture material. The aim, therefore, was to analyse the magnitude and duration of the changes in corneal curvature, induced by intracapsular extraction, over a one-year period. In addition a parallel study was done on patients who had undergone extraction by the technique of phacoemulsification, on the asumption that smaller changes may occur owing to the small incision size and reduced number of sutures.

Materials and methods

Patient sample. The total number of eyes in the intracapsular cataract extraction series was 37 (36 patients). Their ages varied from 53 to 94 years, mean 75 yr (standard error 1·4). In the phacoemulsification series the number of eyes was 6, in the age range 48–77 years, mean 62·2 yr (standard error 3·8).

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Surgical procedure. Cataract extractions were carried out by 3 surgeons using similar techniques with the Zeiss Mark 6 operating microscope. The patients were under general anaesthesia. In brief the intracapsular surgical technique involved making (1) a limbus based conjunctival flap; (2) a 2-step corneoscleral incision, located at the posterior margin of the limbus, into the anterior chamber; (3) single iridectomy at about 12 o'clock; (4) weakening the zonule with 5% alpha-chymotrypsin; and (5) removing the cataract with an Amoils cryoprobe. Two of the surgeons used two preplaced 8–0 virgin silk sutures after making the initial incision and then completed the incision with scissors. The third surgeon used 2 postplaced sutures. The sutures were placed to a depth of two-thirds of the corneal tissue. After removal of the cataract further cornealscleral sutures were inserted as was felt necessary.

Surgeon A performed 18 extractions, cutting a section size between 120–139° in 11 cases and favouring the use of 3 sutures. Surgeon B performed 13 extractions, within an evenly distributed range of section size from 110 to 160°, on 7 cases, inserting 4 sutures. Surgeon C used a larger incision, 140–160°, in his 6 extractions.

The phacoemulsification technique involved (1) making a limbus-based flap; (2) entering the anterior chamber in one stroke with a Pearce-Hoskins knife; (3) incising the anterior capsule with a keratome; (4) prolapse of the lens nucleus into the anterior chamber; (5) emulsification with the Kelman Cavitron phacoemulsifier; (6) removal of the cortical remnants by irrigation and aspiration; (7) making a small peripheral iridectomy; and (8) closure of the wound with one 8–0 virgin silk suture. Silk was also used to close the conjunctival flap.

In all cases, after the wound had been satisfactorily closed, but before the conjunctival flap had been sutured, one eyepiece of the operating microscope was replaced with another containing a protractor graticule. The magnification of the zoom lens was adjusted until the graticule just overlay an image of the limbus. The section angular size and suture positions were measured, all by the same person.

Keratometry. A photokeratometer was used. Because even the physiological cornea is not a truly spherical surface, alignment of the eye and optical system is always critical. A fixation target was presented to ensure that the same part of the cornea was always examined. Use of subsidiary illumination enabled us to film the pupil and iris with such contrast as to be able to identify frames showing misalignment caused by poor fixation of the patient. These were rejected. The magnification of the keratometer was determined with a millimetre scale. The corneal curvature was calculated from projection of the frames and the geometry of the situation. The same person measured all the film frames, thus minimising the personal error. Measurements were made in the horizontal, vertical, and 2 oblique meridians within the optical zone (1·5 mm corneal section) and in a more peripheral region (4 mm corneal section).

Photokeratometry was carried out preoperatively, one and 2 weeks after surgery, one month postoperatively, thereafter monthly for 9 months, and finally at one year after surgery. Where possible measurements were also taken of the nonoperated eyes at each visit as controls. In addition data were obtained from 4 young adults with normal vision.

Results

Intracapsular extractions. The subdivision of the data into categories according to incision size and number of sutures is shown in Table 1. Because of the small samples, a comparison of the keratometric results obtained for a particular section size and set number of sutures would not be statistically valid.

Meridian of corneal astigmatism. Preoperatively 53% of the patients had astigmatism against-the-rule (i.e., the meridian of maximum power was horizontal), and, as most of the patients were elderly, this is in accord with the senile changes in corneal astigmatism.[16] One week postoperatively the 2 principal meridians were randomly distributed, but thereafter the steeper curvature of the horizontal meridian not only reasserted itself but was evidenced in 80% of the sample. Conversely, in similar proportions the vertical meridian was flattest, i.e., mirror-imaging the meridian of steepest curvature.

Changes in the radii of curvature. Fig. 1 shows the mean radii of curvature of the corneal cap during the postoperative period. Taken in conjunction with Table 2 it can be seen that the mean values mask other types of change which occurred (Fig. 2). Cases are shown where the radius in one meridian decreased while the other increased (Figs. 2A and C), where both increased (Fig. 2B), and where both decreased (Fig. 2D). The 'classical' postoperative

Table 1 *Intracapsular extraction sample, subdivided on incision size and number of sutures*

Incision size (degrees)	*Number of sutures*				*Total*
	3	*4*	*5*	*6*	
100–109	1	—	—	—	1
110–119	4	1	—	—	5
120–129	6	—	—	—	6
130–139	6	5	1	—	12
140–149	1	3	2	—	6
150–159	—	3	3	1	7
Total	18	12	6	1	37

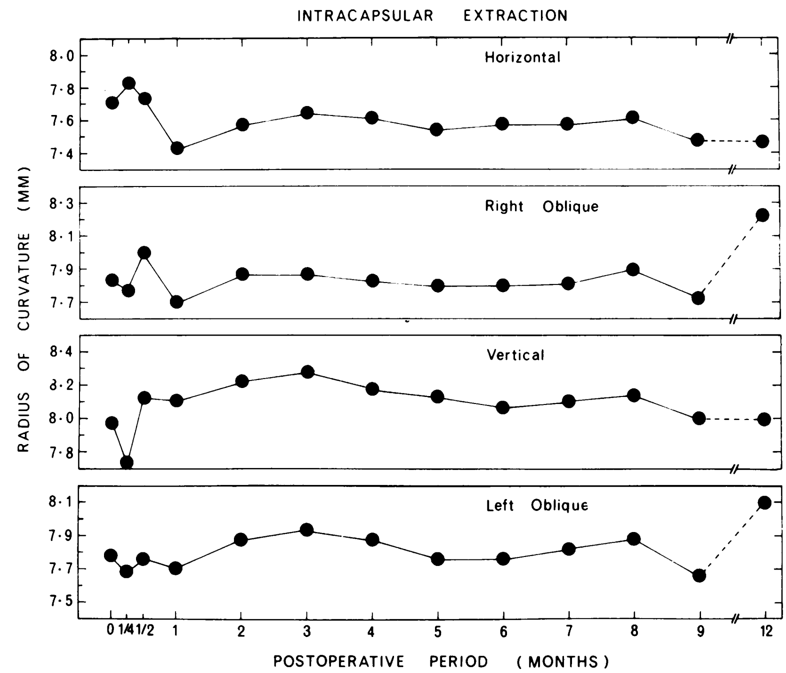

Fig. 1 *Intracapsular extractions. The mean radii of curvature in each of the 4 meridians of the corneal cap, during the postoperative period. Zero on the abscissa refers to the mean radii preoperatively.*

astigmatism, where the horizontal radius decreased and the vertical radius increased, was found in only 6·5% of the sample immediately postoperatively, though it was present in 42·3% of the patients by the first postoperative month.

Comparison of the pre- and postoperative radii for each meridian showed a high positive correlation. Paired *t* test analyses showed no significant differences in a comparison of data of the left and right oblique meridians. In the horizontal meridians most of the pre- and postoperative mean values differed significantly ($p<0·01$) up to 12 postoperative months; in the vertical meridian the data were not significantly different from 5 postoperative months onwards.

The more peripheral corneal region (i.e., 4 mm corneal section) showed smaller changes (Fig. 3). Pre- and postoperative data in 3 of the meridians studied, namely, the 2 obliques and vertical, were not significantly changed, even immediately postoperatively. Pre- and postpaired data did differ in the horizontal meridian but only up to the first postoperative month.

Influence of section size and number of sutures. The mean postoperative radii of curvature, where the section size was smaller (100–129°) with 3 sutures and larger (140–160°) with more than 3 sutures respectively, are shown in Fig. 4. The smaller section size data showed statistically significant changes up to the eighth postoperative month in the vertical meridian, whereas the results differed from the preoperative values only up to one month postoperatively in the horizontal meridian. Thus the radius of curvature in the vertical meridian increased, apart from the early postoperative changes, and furthermore this corneal flattening persisted. Conversely, the mean data of the patients who had the larger section showed little variation in the vertical meridian, but steepening of the curvature in the horizontal meridian which was still statistically significantly different from the preoperative state one year later.

Phacoemulsification. During the 2-year period of this study 6 patients underwent cataract surgery by

Table 2 *Intracapsular extractions. Percentage distribution of the groups showing the 4 types of surgically induced astigmatism, categorised one week postoperatively. Also tabulated are the mean power differences in the horizontal (D_H) and vertical (D_V) meridians (i.e., preoperative power minus the power one week postoperatively)*

Percentage of sample where the radius of curvature in the				
Postop. period	*H inc V dec (Fig. 2A)*	*H inc V inc (Fig. 2B)*	*H dec V inc (Fig. 2C)*	*H dec V dec (Fig. 2D)*
1 week	45·2	19·3	6·5	29·0
2 weeks	11·8	35·3	35·3	17·6
1 month	0	19·2	42·3	38·5
6 months	0	22·2	38·9	38·9
Mean D_H	1·72	1·56	−0·38	−0·77
Mean D_V	−2·25	0·84	0·92	−2·67

inc=Increased. dec=Decreased.

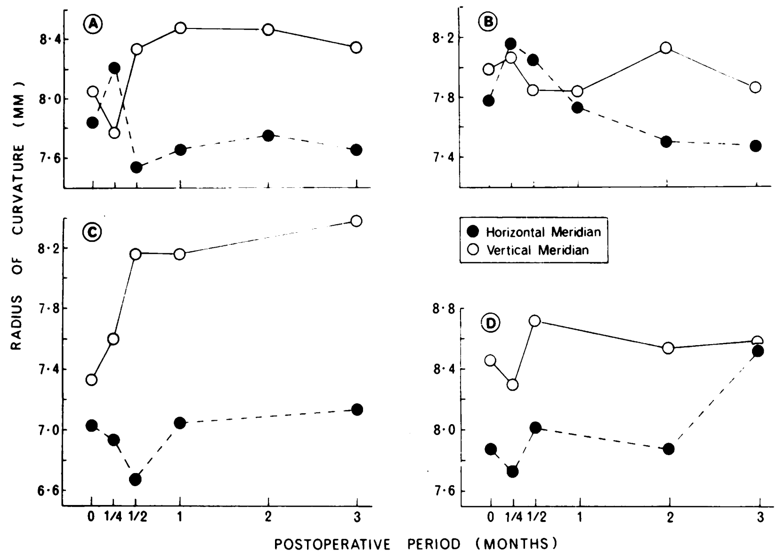

Fig. 2 *Intracapsular extractions. Examples of the 4 types of surgically induced changes in radii, observed one week postoperatively.* A: *The horizontal radius of curvature increased, while the vertical radius decreased.* B: *Both the horizontal and vertical radii of curvature increased.* C: *The horizontal radius decreased, while the vertical radius increased.* D: *Both the horizontal and vertical radii decreased.*

phacoemulsification. The smaller variation in the mean radii of curvature (Fig. 5) lend weight to the assumption that postoperative changes would be smaller than comparable intracapsular data.

Direct comparison of the 2 techniques. Patient AB presents an example of the 2 techniques. The right extraction was intracapsular, incision size 155° and closed with 4 corneoscleral sutures. The left lens was removed by phacoemulsification, section size 25° with one centrally placed suture. The same surgeon operated on both eyes within one week. The results (Fig. 6) show the much larger changes that occurred in corneal curves following the intracapsular extraction, i.e., a large section as opposed to a small one. Preoperatively the corneal astigmatism was 1·41 D in the right eye, 1·37 D in the left, the horizontal meridian being the most powerful in each case. Table 3 gives the results at the postoperative periods of one week and one year. They show that immediately after operation the phacoemulsification operation had caused an increase that was less than 50% of that induced by intracapsular extraction. After one year

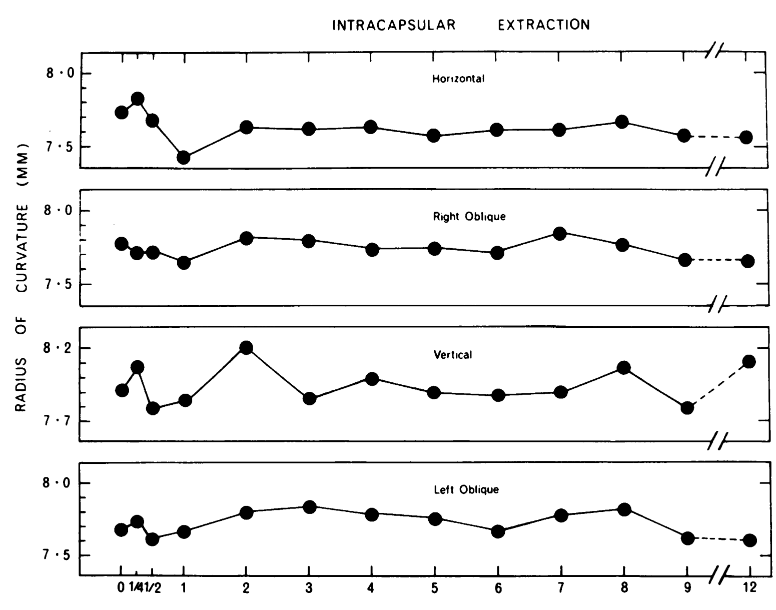

Fig. 3 *Intracapsular extractions. The mean radii of curvature in the 4 meridians in the more peripheral corneal section, as a function of time postoperatively.*

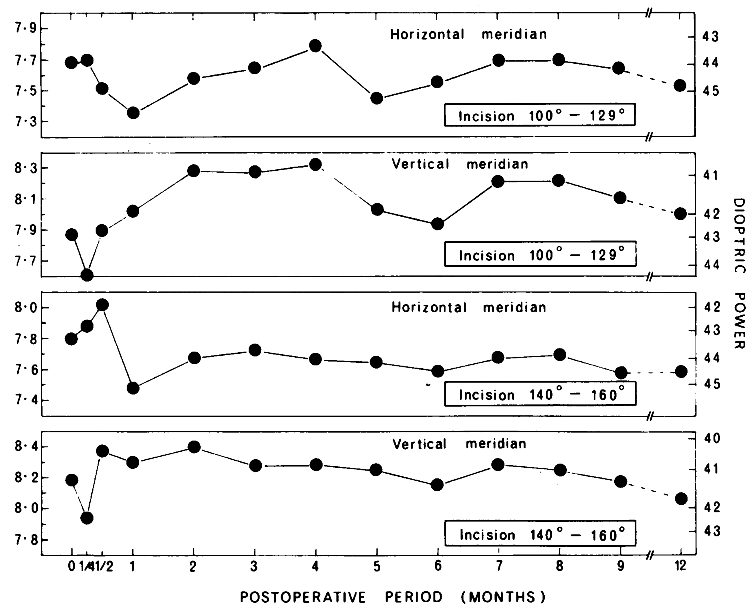

Fig. 4 *Intracapsular extractions. The effect of section size. The horizontal and vertical mean radii of curvature and dioptric power, measured at the corneal cap, of the sample where the incision size was 100–129° (top 2 Figures) and where the incision size was larger, 140–160° (lower 2 Figures).*

the left and right eyes had induced astigmatism of 0·5 D and 1·85 D respectively.

Control data. No significant changes occurred in corneal curvature in the sample of control data, either in the group consisting of patients' unoperated eyes or in the 'normal' group.

Discussion

In the patients who underwent intracapsular cataract extraction surgery has significantly increased the number of those in whom astigmatism against-the-rule predominates in the long term, as compared with their preoperative condition. The mean values of the radii (Fig. 1) in the horizontal meridian initially show a flattening followed by a steepening up to one month after the operation, and thereafter tend to remain stable although steeper than the preoperative state. The radii in the vertical meridian mirror-image the horizontal but revert almost to the preoperative values. Apart from the immediate postoperative changes, little of consequence occurred in the oblique meridians. Analysis of the mean values of the radii in the horizontal and vertical meridians revealed changes other than those shown in Fig. 1 (Table 2). Thus both radii of the major meridians may increase, or decrease, or one increase while the other decreases (Fig. 2). 'Classical' astigmatism, where the horizontal radius decreases and the vertical radius increases, was present in only 6·5% of the sample immediately postoperatively but increased to 42·3% by one month.

One may postulate that the large changes in curvature, shown in Figs. 2A and C, may be the result of excessive tissue handling during suturing, resulting in more postoperative oedema than in groups B and D; it was not associated with the work of a particular surgeon.

A paired comparison of the preoperative and resultant astigmatism in the patients who had intracapsular extraction showed significant differences at all serial intervals. However, analyses of the paired samples one month vs. 3 months, one month vs. 6 months, and so on, were not significant. This indicates that, although the corneal contours would not resume preoperative values, changes occurring after one month were small. Furthermore, the paired data 1 week vs. 2 weeks postoperatively were statistically different from zero ($p<0.02$), but not significant for 2 weeks vs. 1 month.

Studies on the placement of sutures used in corneal incisions have shown that it is advantageous to place silk sutures at midstromal level, as more deeply placed sutures can lead to necrosis of the tissue and

Table 3 *Comparison of astigmatism of patient in Fig. 6. Intracapsular extraction in right eye, phacoemulsification in left eye*

	Intra-capsular (D)	*Phaco-emulsification (D)*
Preoperative	1·41	1·37
1 week postop.	5·96	0·69
Induced	4·55	2·06
1 year postop.	3·26	1·85
Induced	1·85	0·50

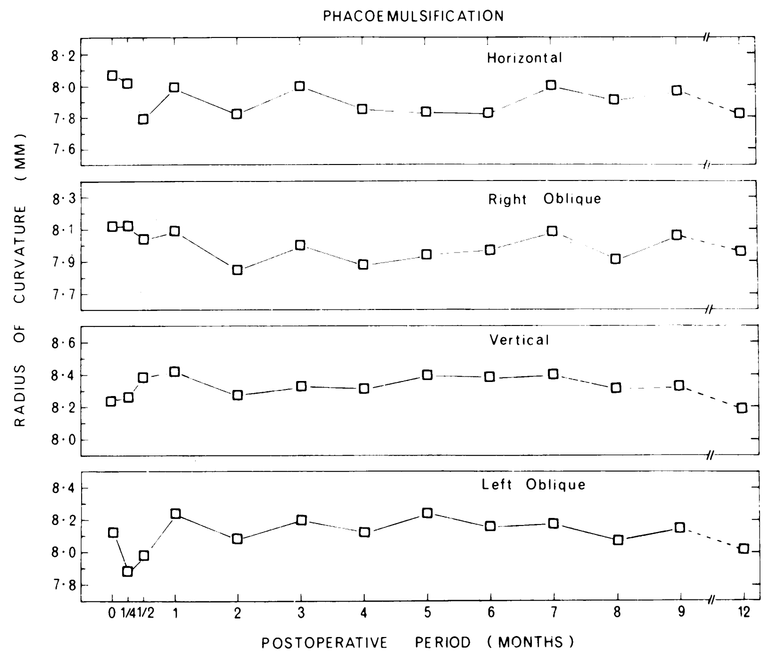

Fig. 5 *Phacoemulsification extractions. The mean radii of curvature in each of the 4 meridians, during the postoperative period. Zero on the abscissa refers to the mean radii preoperatively.*

proliferation of epithelium along the suture tract.[17 18] However, Flaxel and Swan's[19] histological examination of human post-mortem material has demonstrated that, after cataract extraction, limbal wounds under limbal-based flaps heal by ingrowth of the subepithelial connective tissue between the stromal wound edges. This ingrowth begins by 8 days and is complete, in that it extends through the entire thickness of the wound, about 15 days after surgery though the limbal wound is still weak. Thus the fact that the first signs of stability of the corneal curvature in this sample was demonstrated at 2 postoperative

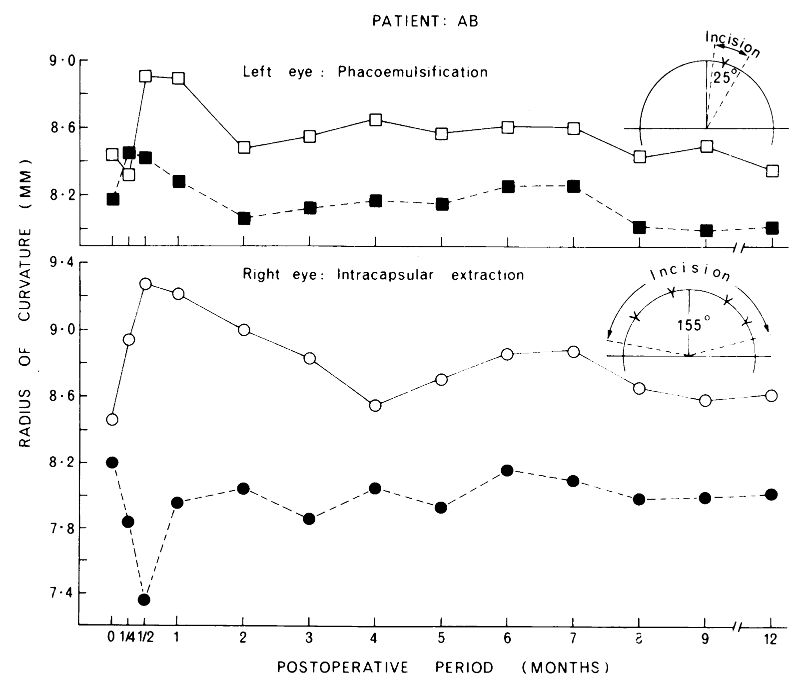

Fig. 6 *Mean radii of curvature of the left and right eye of patient AB during the postoperative period. The incision sizes and positions of the sutures are shown in the insets. Filled and unfilled symbols refer to the horizontal and vertical radii of curvature respectively. Left eye: phacoemulsification (squares). Right eye: intracapsular extraction (circles).*

weeks may result from the completion of this ingrowth.

Use of alpha-chymotrysin. Kirsch[20] performed postoperative Schiøtz tonometry and found that a transient rise in intraocular pressure may occur, with the greatest rise usually on postoperative days 2 to 5 and of average duration 7 days. Such a rise may account for some of the early postoperative changes, since a raised intraocular pressure can reasonably be expected to interfere with wound apposition. Kirsch[21] has further shown that wound healing problems occur almost 3 times more frequently in cases where alpha-chymotrysin is used than in a parallel control group. Soll[22] gives an incidence of between 50 and 60%.

Use of virgin 8–0 silk suture material. When alpha-chymotrysin is used the tensile strength of virgin silk is reduced by 20–25% between the second and the fourteenth days.[23] This may result in a stretching effect which could cause slight misalignment of the section. Pearce[24] compared postoperative astigmatism with the use of different suture materials, indicating that there is a reduction in the astigmatism from 1·72 D with virgin silk to 0·9 D with monofilament nylon. Similar results were obtained by Wyman.[25] This variation in performance may account for some of the changes observed in the present series.

Of interest is the patient who had an intracapsular extraction in one eye and phacoemulsification in the other (Fig. 6). The indications here are that with a small section, a single suture, and minimal tissue handling the resultant changes in curvature are reduced.

Comparison of the data concerning the effect of section size and consequent number of sutures provides a clue to the surgical control of astigmatism. In cases where the smaller section was made, 100–129°, it was the curvature of the vertical meridian which became flatter than the preoperative state and remained so, whereas in the horizontal meridian the radius did not vary appreciably. Conversely, cases where a larger section was cut, 140–160°, and more sutures used, the curvature in the vertical meridian varied little, but the steeper horizontal steepened and tended to remain steeper than in the preoperative state. These long-term changes on corneal curvature may most easily be explained by the process of crimping. When considering a large section, it is as if one were placing the index finger and thumb at 3 o'clock and 9 o'clock respectively on the limbus, and gently pinching. This has the effect of steepening the curvature in the horizontal meridian, with little effect on the vertical. With small section sizes as well as phacoemulsification the pinching effect will have less of a purchase and consequently less effect on corneal curves.

One might suggest that cataract surgery would cause minimal change in corneal curvature, or even purposely induce surgical astigmatism in order to reduce the pre-existing astigmatism, if the following procedure were followed. Prior to surgery the cornea should be measured keratometrically to determine the amount and axis of astigmatism. The best incision to use in order to minimise postoperative surgically induced astigmatism can then be determined. The smaller incision will have a tendency to flatten the curvature of the meridian about which the incision is centred, whereas the effect of the larger incision is to increase the curvature in the meridian at right-angles to the centre of that incision. Thus the orientation of the incision, its size, and the consequent number of required sutures could be adjusted in an attempt to give the optimum result. Since the net result with the usual superior incision is to produce astigmatism against-the-rule, to a lesser or greater degree patients with astigmatism with-the-rule before the operation have the advantage. This may partly explain the excellent postoperative results of Kelman's [14] phacoemulsification study, since of the 500 cases examined 73% were under 60 years of age. The majority of patients undergoing intracapsular extraction are elderly, in whom preoperative astigmatism against-the-rule predominates. Nevertheless, if the surgeon were willing to cut a section temporally if necessary, he could determine the meridian of greatest curvature and centre the incision in that region. A small incision would probably cause a flattening in that meridian, thereby lessening the power to match the least curved meridian. A large incision would have the effect of steepening the previously flattest meridian, thereby increasing the power. Control of such astigmatism would be of benefit to the patient whether he is fitted with spectacles, contact lenses, or intraocular lens implant.

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