KERATOMETRY USING THE GOLDMANN TONOMETER

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SUMMARY

Keratometry using the Goldmann tonometer is a reliable and readily available guide to corneal astigmatism following cataract surgery. In regular corneal astigmatism the Goldmann tonometer rings are distorted into skewed ellipses. The axis of the cylinder can be measured by rotating the tonometer head until an undistorted ellipse is obtained. The power is then assessed by comparison with standard ellipses. The difference in the intraocular pressure readings (mmHg) in the two principal meridians was also a good guide to the presence of astigmatism. Goldmann keratometry was performed by a single masked observer in 71 patients 8 weeks after routine extracapsular cataract surgery. This was compared with Javal–Schiotz keratometry performed by an independent observer. In 83% of patients the axis was measured to within 20°. The 95% confidence interval for the power was ±2.90 DC; and 87% of patients would have sutures removed appropriately.

Significant astigmatism acquired during cataract surgery is often due to over-tightening of one or more sutures.[1] These must be accurately identified then removed if the optimum visual result is to be achieved.[2] A technique used to identify tight sutures should be able to detect when 3.00 DC or more of corneal astigmatism is present,[1,2] and to locate the axis to within 20° (the approximate distance between sutures).

The aim of this study was to determine whether the Goldmann tonometer could measure corneal astigmatism sufficiently accurately to be of use in determining which sutures, if any, should be removed following cataract surgery. Existing techniques include refraction and keratometry, which may be more time-consuming or more technically demanding. Astigmatism measured by Goldmann tonometry was compared with results of conventional keratometry.

Our technique depends upon the observer's ability to distinguish a circle from an ellipse, and whether an ellipse is skewed or symmetrical. A second study was therefore performed to determine the certainty with which observers could distinguish a circle from ellipses of different dimensions.

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PATIENTS AND METHODS

The main study group comprised 71 patients who had undergone routine extracapsular cataract extraction with posterior chamber lens implantation at The Oxford Eye Hospital. The majority of procedures were performed through corneal sections, and all were closed with interrupted 10.0 monofilament nylon sutures.

At the outpatient appointment 8 weeks following surgery, keratometry was performed on all patients using a Javal–Schiotz keratometer. The astigmatism was recorded as 'keratometric power' and 'keratometric axis'.

Assessment of the power and axis of astigmatism was then made using the Goldmann tonometer, by a single observer who had no prior knowledge of the keratometry measurements. Keratometry using the Goldmann tonometer is performed as follows. The tension of the tonometer is adjusted as for measuring the pressure, and the shape of the rings is noted. If astigmatism is present the rings appear either skewed or elliptical (Fig. 1). The axis of the corneal astigmatism is assessed by repeating the process, with the tonometer head rotated successively through 30°. The orientation of the tonometer head producing the most symmetrical ellipse is nearest to the axis of the corneal astigmatism. Further small rotations of the tonometer head can be made until the rings are no longer skewed, and a reading of the orientation in degrees is taken from the scale on the side of the tonometer head ('observed axis').

A series of standard ellipses was computer-generated

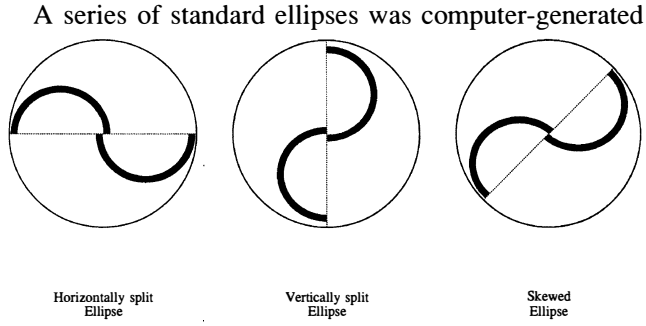

Fig. 1. *Appearance of the Goldmann rings in a patient with +3.00 corneal astigmatism at 90°. When the tonometer head is orientated along the principal meridians (0° and 90°) the ellipses are symmetrical and split along their long (horizontal) or short (vertical) axis. When the tonometer head is at any other orientation, the ellipses are skewed.*

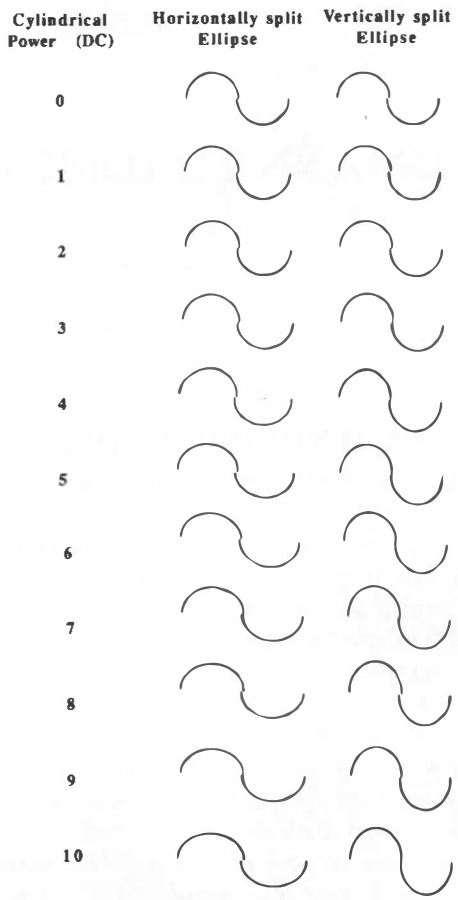

Fig. 2. *The series of standard ellipses with which the appearance of the rings on Goldmann tonometry were matched to determine the 'observed power' of the astigmatism.*

showing the configuration of the rings when 0 to 10 DC astigmatism is present (Fig. 2). When attached to the slit lamp beside the patient's head the standard 0 DC ellipse appears the same size as the rings seen on Goldmann tonometry of a spherical cornea. For construction of the other ellipses, the average corneal power was taken to be 40 DS. The difference between the horizontal and vertical diameters of the constructed ellipses was altered by one-fortieth for each dioptre of astigmatism. Ellipses split both along their long axes ('horizontally split ellipses') and their short axes ('vertically split ellipses') were constructed.

The power of the corneal astigmatism was assessed by comparing the shape of the rings when orientated along the two principal meridians with the series of standard ellipses ('observed power'). The pressure readings in these two dimensions were also taken ('power by pressure difference').

With experience there is a reduction in the number of manoeuvres required to attain the result. After practice, the procedure takes about 3 minutes.

A second study was performed to determine with what accuracy an observer could distinguish a split-circle from a split-ellipse. Twenty normal subjects were given a sheet bearing 40 computer-generated horizontally and vertically split ellipses representing 0–5 DC astigmatism. These were orientated at 0°, 45° and 90° for all powers, with additional ellipses at 30° and 60° for the 2 and 3 DC powers. They graded each shape as: 0, definitely a circle; 1, probably a circle; 2, probably an ellipse; 3, definitely an ellipse. The score for each shape was calculated as the total of the grades given by all subjects, expressed as a percentage of the maximum possible score. Therefore a score of 0 means that all subjects were sure that the shape was a circle, and a score of 100 means that all subjects were certain that the shape was an ellipse. The scores of the same ellipse at all orientations were amalgamated.

RESULTS

Javal–Schiotz keratometry and Goldmann keratometry were performed in single eyes of 71 patients 8 weeks following cataract extraction. One elderly patient was uncooperative, and therefore the results of 70 patients are presented.

Of the 70 patients there were 2 in whom astigmatism could not be detected by Goldmann tonometry. On Javal–Schiotz keratometry these pateints had astigmatism of 0 DC and 1.5 DC. There were 2 other patients in whom it was noted that the axis was very difficult to detect. One had an axis error (keratometric axis–observed axis) of 30° with only 1 DC of astigmatism. The other had an axis error of 35° in the presence of 3.5 DC on keratometry, but it was noticed that the eye was very soft, and the pressure was measured at 4 and 5 mmHg in the two principal meridians. The technique can be very sensitive. For example there was 1 patient with only 0.5 DC on keratometry in whom the axis was determined to within 5°.

Scatter diagrams of the cylinder measured by observation (Fig. 3) and by pressure difference (Fig. 4) were plotted against the cylinder on keratometry. The line of equality is the line on which all points would lie if there was total agreement between the two methods. The corre-

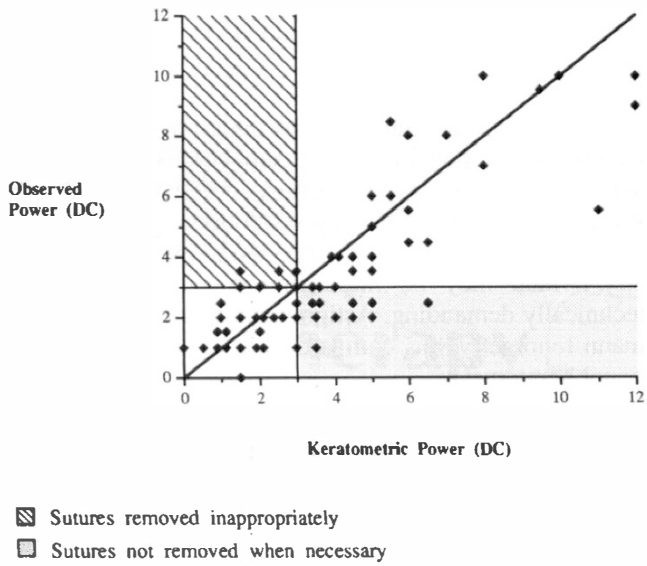

Fig. 3. *Scatter diagram of the power of corneal astigmatism determined by comparison with standard ellipses against the power determined by Javal–Schiotz keratometry. The line of equality is shown.*

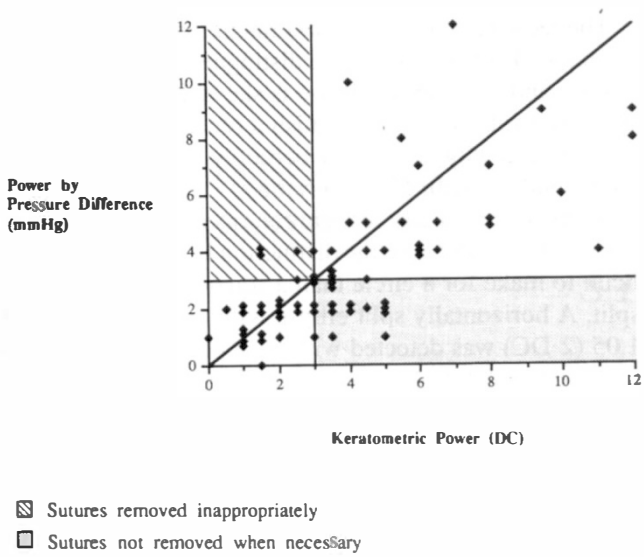

Fig. 4. *Scatter diagram of the difference between the intraocular pressure readings in the two principal meridians against the power of corneal astigmatism determined by Javal–Schiotz keratometry. The line of equality is shown.*

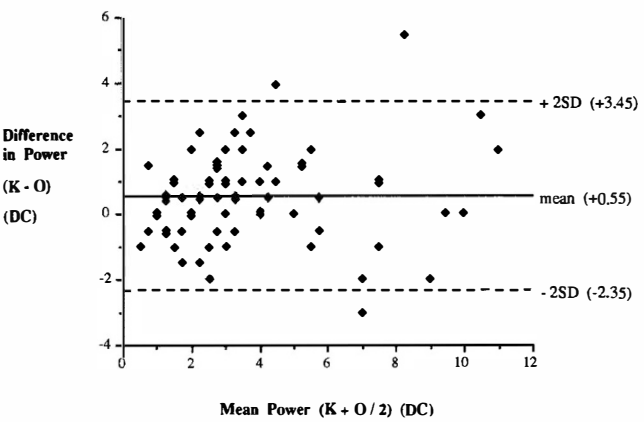

Fig. 5. *Scatter diagram of the power error (difference between the power determined using the Goldmann tonometer and by Javal–Schiotz keratometry) against the mean of the two methods. The 95% confidence intervals are shown. The shaded area shows where sutures may have been removed from the wrong axis.*

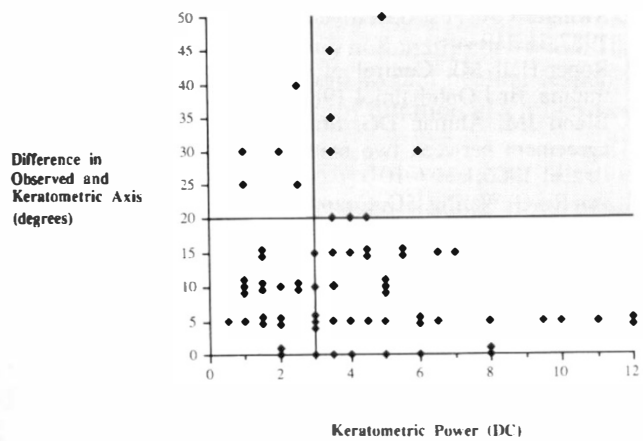

Fig. 6. *Scatter diagram of the axis error (difference between the axis determined by the Goldmann tonometer and by Javal–Schiotz keratometry) against the power determined by Javal–Schiotz keratometry. The frequency of the different axis errors can be seen.*

lation coefficients are $R^2 = 0.72$ for observed power and $R^2 = 0.48$ for power by pressure difference, but this may not be an appropriate measure of agreement between two methods.[3]

It is more informative to plot the difference in the power of the astigmatism measured by observation (O) and by keratometry (K) against the mean power for each patient (Fig. 5). The mean difference in measurements is 0.55 DC, with observation measurements tending to be lower than those resulting from keratometry. The difference between the observed and the keratometric power is on the whole less in the cases of lower astigmatism. The 95% confidence interval is ±2.90 DC for the observed power.

The mean difference between pressure difference and keratometric power is 0.70 DC, with the pressure difference tending to give the lower reading. Pressure difference is slightly less accurate than observation for determining the power of the astigmatism, the 95% confidence interval being ±4.00 DC.

Following cataract extraction, sutures need to be removed if there is astigmatism of +3.00 DC or greater. On the basis of observed power alone there were 3 patients (4%) who would have had sutures removed unnecessarily (K<3.00 DC, O≥3.00 DC); and 11 patients (15%) whose sutures would not have been removed when indicated (K≥3.00 DC, O<3.00 DC) (Fig. 3).

If the indication for suture removal is 'observed keratometry of 3.00 DC and greater, or pressure difference of 3 mmHg and greater', only 5 patients (7%) would have failed to have had sutures removed when indicated; and 4 patients (6%) would have had sutures removed unnecessarily.

The difference between the observed and the keratometric axis ('axis error') was plotted against the power by keratometry (Fig. 6). From this the accuracy of the indications for suture removal could be assessed.

Interrupted sutures in a corneal or limbal section are approximately 20° apart. The error in the axis (difference between the observed and keratometric axis) was 10° or less in 44 patients (63%) and 20° or less in 58 patients (83%). There were 9 patients with an error of greater than 20°, but 5 of these had astigmatism of less than 3 DC and

Table I. Ability of 20 observers to distinguish ellipses of different dimensions from circles. Ellipses were recognised if their power was 1 DC and greater if split horizontally, or 4 DC and greater if split vertically

Astigmatism (DC)	Vertically split ellipse	Horizontally split ellipse	Mean average
0			32
1	33	53	43
2	27	51	39
3	42	79	60
4	60	89	70
5	75	91	83

Scores are expressed as percentages. Score of 0, all subjects were certain the shape was a circle; score of 100, all subjects were certain the shape was an ellipse.

Table II. Ability of 20 observers to distinguish ellipses from circles does not vary consistently with the orientation of the shape

Orientation:	0°	30°	45°	60°	90°
2 DC ellipse					
Horizontally split	23	38	58	60	73
Vertically split	32	18	25	32	23
3 DC ellipse					
Horizontally split	68	85	88	75	78
Vertically split	40	45	50	45	32

Scores are expressed as percentages. Score of 0, all subjects were certain the shape was a circle; score of 100, all subjects were certain the shape was an ellipse.

therefore did not need sutures removing anyway. The smaller the astigmatism, the more difficult it is to detect the axis correctly.

The results of the second study are shown in Table I, which lists the scores for ellipses split horizontally and vertically, and the average of the two. A score of over 50 means that subjects tended to think that a shape was an ellipse rather than a circle. This was the case for horizontally split ellipses of 1 DC or greater, and vertically split ellipses of 4 DC or greater. An ellipse is much easier to detect and quantify when split horizontally rather than vertically. This was also our experience when performing Goldmann keratometry. It was felt during the main study that the technique was most accurate when the axis was near either 0° or 90°, but the second study showed no consistent difference in the ability to identify a given shape at different orientations (Table II).

DISCUSSION

The results of extracapsular capsular cataract extraction can be compromised by induced surgical astigmatism. The most significant cause of acquired post-operative astigmatism is altered corneal contour due to inappropriate suture tension or, more rarely, wound misalignment.[1,4] The intraocular lens implant contributes very little to post-operative astigmatism. This is because it is of uniform refractive index; and to produce significant astigmatism it has to be tilted by more than 20° or markedly displaced, both of which can be detected on slit lamp examination.[5]

Following cataract surgery,[6] astigmatism is minimised by adjustment of sutures under topical anaesthesia at the slit lamp, once the wound has healed. Interrupted sutures may be removed from the steepest axis of the cornea, or a continuous suture can be eased round towards that meridian.[7]

Refraction is the only means of assessing the astigmatism of the whole eye, but Misson[8] has shown that results are not significantly different from the anterior corneal astigmatism measured by keratometry. The correlation for axis was stronger than that for power. Both the Javal–Schiotz keratometer and the Goldmann tonometer take readings from a central area of the cornea approximately 3 mm in diameter, and therefore assume that the astigmatism is symmetrical.

The technique using the Goldmann tonometer depends upon the observer's ability to distinguish a circle from an ellipse, and whether an ellipse is skewed or symmetrical. A normal subect can distinguish a rectangle with a sides ratio of 1.05 with about 95% certainty, 1.1 with 99% certainty, and 1.2 with 100% certainty.[9]

In our second study recognition rates were not quite as high, probably because the distinction is slightly more difficult to make for a circle than a square, especially when split. A horizontally split ellipse with a diameter-ratio of 1.05 (2 DC) was detected with 53% certainty; and a diameter-ratio of 1.1 (4 DC), with 89% certainty.

CONCLUSIONS

Assessment of astigmatism by Goldmann tonometry is an easily learned technique. It reduces the need for keratometry and refraction in the early post-operative period following cataract surgery. The technique is sufficiently accurate to enable sutures to be removed appropriately.

Best results are achieved if the indication for suture removal is: 'either the observed power is 3 DC and greater, or the pressure difference between the two major meridians 3 mmHg and greater'. The observed power is most accurately assessed using the horizontally split ellipse. If the eye is very soft (e.g. less than 6 mmHg) Goldmann readings underestimate the astigmatism, and in those cases conventional keratometry should be performed.

Key words: Astigmatism, Cataract surgery, Goldmann tonometry, Keratometry.

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