CHANGE ON THE HORIZONTAL AND VERTICAL MERIDIANS OF THE CORNEA AFTER CATARACT SURGERY*

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ABSTRACT

Purpose: To compare the course and magnitude of change on the horizontal and vertical meridians of the cornea after 5 different incisions for cataract: extracapsular cataract extraction (ECCE), 6 mm superior scleral tunnel (6Sup), 3 mm superior scleral tunnel (3Sup), 3 mm temporal scleral tunnel (3Temp), and 3 mm temporal corneal incision (3Cor).

Methods: Retrospective chart review of 665 cases of preoperative regular astigmatism. The preoperative keratometry (K) reading was subtracted from the postoperative K reading to determine mean net change on each meridian at 1 day, 1 week, 2 weeks, 1 month, 1.5 months, 2 months, 4 months, 6 months, and 12 months and at 6-month intervals thereafter. After the superior incisions, the temporal changes on each meridian are well described by an analytic model with an initial and final plateau. The changes after the temporal incisions are described by a linear equation.

Results: After each superior incision, the steepness and length of the transition from the initial to final plateau for each meridian depend on incision length. Considering the uncertainty of measuring K, the corneal meridians stabilized 4.5 months after ECCE, 1.2 months after 6Sup, and 0.3 months after 3Sup. No significant change was detected on the horizontal and vertical meridians after 3Temp and 3Cor.

Conclusion: The magnitude and the duration of changes on the horizontal and vertical meridians of the cornea after cataract surgery depend on both incision length and location. Small temporal incisions induce less change than superior incisions.

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INTRODUCTION

In 1864, Donders noted that “To the very ordinary causes of altered, and consequently irregular arching of the cornea, belongs the *extraction of cataract*.”[1] With the introduction of the keratometer in 1881, surgeons could measure corneal astigmatism reliably;[2] yet without techniques to control surgically induced astigmatism, clinicians showed little interest in the keratometer. At the 103rd meeting of the American Ophthalmological Society in 1967, Harold Beasley reported the keratometric changes after intracapsular cataract extraction (ICCE). One of the reasons for his study was to determine if changes in the procedure might “reduce the total astigmatism.”[3] Soon after this report, advances in ophthalmic surgery–the operating microscope, fine sutures and, later, the intraocular lens and phacoemulsification–stimulated interest in the effect of various incisions on postoperative astigmatism. This study compares the change in the horizontal and vertical meridians of the cornea after 5 different incisions for cataract: extracapsular cataract extraction (ECCE), 6 mm superior scleral tunnel for phacoemulsification (6Sup), 3 mm superior scleral tunnel (3Sup), 3 mm temporal scleral tunnel (3Temp), and 3 mm temporal corneal incision (3Cor).

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METHODS

This study is a retrospective review of 665 cases from a single surgeon’s practice (Table I). Some patients in the ECCE and 6Sup groups have been followed for more than 10 years after surgery, but the review of these groups is limited to the first 5 years after operation because the number of patients decreases with time. Review of the smaller incisions is limited to 4 years after 3Sup and 3Temp and 3 years after 3Cor.

SURGICAL TECHNIQUES

ECCE

A fornix-based conjunctival flap and a partial-thickness, posterior limbus incision were made superiorly from approximately the 10-o’clock to the 2-o’clock positions. The length of the incision was not measured routinely; incisions were assumed to have an average arc length of 12 mm. A double-armed 8-0 black silk suture was passed

TABLE I: PATIENT DATA

INCISION	PATIENTS				EYES		
	FEMALE	MALE	MEAN AGE (YR)	AGE RANGE (YR)	NO.	OD	OS
ECCE	80	48	74	40 - 93	163	94	69
6Sup	44	35	74	46 – 92	91	43	48
3Sup	66	50	73	38 – 92	141	72	69
3Temp	45	28	79	44 – 96	87	52	35
3Cor	85	56	74	43 - 97	183	97	86

across the wound nasally and temporally prior to completing the section with superblade and corneoscleral scissors. After delivery of the lens, cortical cleanup, and placement of the intraocular lens (IOL), the preplaced silk sutures were tied, and the wound was closed with additional interrupted sutures of 10-0 nylon. The silk sutures were removed when they became loose or exposed (generally about 6 weeks after surgery); few nylon sutures were removed unless they were loose and exposed.

Phacoemulsification

The sclerocorneal tunnels began approximately 1.5 mm posterior to the limbus. The clear corneal incision (3Cor) was initiated temporally with a 2.6 mm keratome. After capsulorrhexis and phacoemulsification, the incision was enlarged to accommodate a 6 mm polymethyl methacrylate (PMMA) IOL (6Sup) or a foldable IOL (3Sup, 3Temp, 3Cor). The incisions were not measured after IOL insertion and are assumed to be approximately 6 mm for the PMMA IOLs and 3 mm for the foldable IOLs. The 6.0 mm sclerocorneal tunnel was closed with 2 interrupted sutures of 10-0 nylon. The superior and temporal 3.0 mm sclerocorneal tunnels were not sutured or were closed with a single radial 10-0 nylon suture. No sutures were removed unless they became loose and exposed. The clear corneal incisions usually were hydrated. In rare cases, the corneal incision was closed with a single 10-0 nylon suture that was removed in a week.

DATA ANALYSIS

The series includes only eyes with regular preoperative astigmatism (major axis within 15° of 90° or 180°) and at least 3 reliable postoperative keratometry (K) measurements. Eyes with preoperative oblique astigmatism were excluded because of an insufficient number of patients for long-term analysis. Eyes that developed an inadvertent filtering bleb after surgery also were excluded. The cornea generally was too irregular for reliable keratometry immediately after ECCE; data for this group begin 2 weeks after surgery. K values were recorded on the first day after phacoemulsification. The ECCE, 6Sup, and 3Cor groups included eyes with both "with the rule" and "against the rule" astigmatism. Nearly all eyes in the 3Sup group had "with the rule" astigmatism preoperatively, and nearly all eyes in the 3Temp group had "against the rule" astigmatism preoperatively. The preoperative and postoperative keratometry readings from the clinical records were sorted (FileMaker Pro 4.1, FileMaker, Inc, Santa Clara, California) to the following postoperative times: 1 day, 1 week, 2 weeks, 1 month, 1.5 months, 2 months, 4 months, 6 months, and 12 months, and to 6-month intervals thereafter. Because patients do not return at precise intervals after surgery, these are average times. All patients returned on the first postoperative day. The 1- and 2-week times are within 3 days of the specified times, and succeeding times are the center of a gradually increasing interval. After 12 months, the time represents the center of a 6-month interval.

The preoperative horizontal K reading was automatically subtracted from the postoperative horizontal K reading, as was the preoperative vertical K reading from the postoperative vertical K reading. For this study, the horizontal axis ranges from 0° to 44° and from 135° to 180°, and the vertical axis from 45° to 134°. A positive result indicates that the meridian is steeper, and a negative result that the meridian is flatter. Mean changes at each time interval were exported into Excel 2000 (Microsoft, Redmond, Washington), Origin 6.0 (Microcal Software, Inc, Northampton, Massachusetts), and SPSS 9.0.0 (SPSS, Inc, Chicago, Illinois) for analysis and graphing.

The change in the horizontal and vertical K values after the 3 superior incisions is consistent with a transition from an initial plateau to a final plateau.[4,5] The analytical expression that follows was proposed originally to describe the change in surgically induced astigmatism after ECCE:

$$D(t) = D_i - (D_i - D_f)e^{(-\alpha/t^{\beta})} \quad (1) \qquad (1)$$

In this expression, D(t) is the diopters of change in the horizontal or vertical K value at time *t* after surgery, and D_i and D_f are the initial and final values of D(t). The parameters α and β determine the slope and extent of the ascending ($D_i < D_f$) or descending ($D_i > D_f$) portion of D(t). Best-fit parameters were calculated for the observed changes in horizontal and vertical K values after ECCE, 6Sup, and 3Sup.

The data for 3Temp and 3Cor are described by a linear equation:

$$D(t) = a + bt. \tag{2}$$

$\chi 2$ analysis showed that the fits were very good for all incisions. 95% confidence intervals were calculated for all curves.[6]

RESULTS

SUPERIOR INCISIONS

The data are given in Tables II through IV, and the resulting fitting parameters in Table VII. After each incision, the vertical and horizontal meridians return to their preoperative levels (D = 0) at similar times (Figs 1 through 6). The mean time for the horizontal and vertical meridians to return to their preoperative levels decreased with incision size: 3.2 months after ECCE, 1.2 months after 6Sup, and 1.0 month after 3Sup.

The horizontal and vertical meridians continue to change after returning to their preoperative levels. The compound error of 2 independent observations is $\sqrt{(Error_1)^2+(Error_2)^2}$. If the variability of each K measurement is 0.25D, the compound error is about 0.35D.[7] When the remaining change in K is less than this compound error, the cornea is assumed to have stabilized. Within the limits of measurement error, at 4.5 months after ECCE, 1.3 months after 6Sup, and 0.3 months after 3Sup, no further change can be detected.

The differences between D_i of the vertical and horizontal meridians and between D_f of these meridians are estimates of the initial and final net change in corneal astigmatism (Table VII, Fig 7). Incision length has more impact on the initial change in corneal astigmatism than on the final change. Each 3 mm increase in incision length adds almost 1.0D to the initial net change in corneal astigmatism but only about 0.15D to the final net change in corneal astigmatism (Fig 7).

TEMPORAL INCISIONS

Change on the horizontal and vertical meridians is described well by a linear fit (Tables V and VI). At the 95% confidence level, the slopes are consistent with zero (Figs 8 through 11, Table VIII).

DISCUSSION

When Donders[1] observed that cataract surgery contributes to corneal astigmatism, sutures were not used. One hundred years later, when John McLean discussed Harold Beasley's paper at the American Ophthalmological Society, he noted that even one suture "markedly reduced the astigmatism…"[3] He also thought that 2 sutures were better than 1 and that 3 were better than 2, but there was little improvement in final postoperative astigmatism with

TABLE II: CHANGE IN KERATOMETRY VALUES AFTER ECCE

	VERTICAL DATA		HORIZONTAL DATA		
MONTHS AFTER ECCE	**MEAN D***	**SD†**	**MEAN D***	**SD†**	**N‡**
0.5	1.9	1.07	-1.72	0.73	30
1	1.62	1.28	-1.4	1.1	102
1.5	1.27	1.29	-0.83	1.2	71
2	0.56	1.03	-0.29	1	108
4	0.03	0.94	0.17	0.86	62
6	-0.35	0.91	0.32	0.79	71
12	-0.34	0.85	0.38	0.83	82
18	-0.26	0.95	0.56	0.66	65
24	-0.37	0.76	0.64	0.76	54
30	-0.54	0.91	0.52	0.69	56
36	-0.41	0.94	0.6	0.73	51
42	-0.7	0.97	0.5	0.78	43
48	-0.54	0.86	0.68	0.75	53
54	-0.58	0.86	0.58	0.67	44
60	-0.67	0.78	0.62	0.71	68
Total					**960**

*Mean diopters of change.
†Standard deviation.
‡Number of data points.

TABLE III: CHANGE IN KERATOMETRY VALUES AFTER 6SUP

	VERTICAL DATA		HORIZONTAL DATA		
MONTHS AFTER 6SUP	MEAN D*	SD†	MEAN D*	SD†	N‡
0.03	0.64	0.9	-0.72	0.73	45
0.25	0.45	0.82	-0.52	0.7	67
0.5	0.24	0.73	-0.03	0.63	25
1	0.16	0.67	-0.02	0.55	68
1.5	0.03	0.64	0.26	0.45	35
2	-0.13	0.6	0.18	0.5	53
4	-0.19	0.6	0.19	0.45	45
6	-0.32	0.45	0.2	0.39	56
12	-0.38	0.49	0.15	0.37	54
18	-0.41	0.48	0.19	0.5	52
24	-0.48	0.45	0.22	0.4	50
30	-0.42	0.45	0.26	0.42	51
36	-0.52	0.52	0.23	0.48	39
42	-0.45	0.43	0.34	0.39	41
48	-0.46	0.47	0.35	0.48	38
54	-0.41	0.55	0.31	0.44	32
60	-0.34	0.47	0.45	0.43	26
Total					**777**

*Mean diopters of change.
†Standard deviation.
‡Number of data points.

TABLE IV: CHANGE IN KERATOMETRY VALUES AFTER 3SUP

	VERTICAL DATA		HORIZONTAL DATA		
MONTHS AFTER 3SUP	MEAN D*	SD†	MEAN D*	SD†	N‡
0.03	0.21	0.69	-0.72	0.73	126
0.25	0.18	0.63	-0.52	0.7	49
0.5	0.1	0.56	-0.03	0.63	77
1	0.05	0.51	-0.02	0.55	83
1.5	-0.07	0.41	0.26	0.45	47
2	-0.01	0.56	0.18	0.5	72
4	-0.09	0.45	0.19	0.45	67
6	-0.08	0.49	0.2	0.39	91
12	-0.12	0.5	0.15	0.37	85
18	-0.19	0.45	0.19	0.5	87
24	-0.13	0.5	0.22	0.4	66
30	-0.2	0.52	0.26	0.42	48
36	-0.15	0.58	0.23	0.48	48
42	-0.12	0.58	0.34	0.39	48
48	-0.12	0.54	0.35	0.48	36
Total					**1,030**

*Mean diopters of change.
†Standard deviation.
‡Number of data points.

more than 3 sutures.

Beasley used 3 preplaced and 2 postplaced 6-0 silk sutures for ICCE. Immediately after surgery, the majority of his patients had an increase in "with the rule" astigmatism, but by the last day of his study, day 46, the majority of the patients had "against the rule" astigmatism.[3] The development of finer sutures and the operating microscope gave surgeons more precise control of wound appo-

TABLE V: CHANGE IN KERATOMETRY VALUES AFTER 3TEMP

	VERTICAL DATA		HORIZONTAL DATA		
MONTHS AFTER 3TEMP	MEAN D*	SD†	MEAN D*	SD†	N‡
0.03	0.02	0.63	0.04	0.46	78
0.25	-0.09	0.62	0.05	0.51	30
0.5	0.03	0.47	0.05	0.36	48
1	0.08	0.57	0.07	0.51	68
1.5	0.23	0.48	0.1	0.69	32
2	0.17	0.54	0.48	0.38	53
4	0.12	0.5	0.15	0.36	45
6	0.08	0.52	0.15	0.45	48
12	0.04	0.43	0.08	0.36	50
18	0.12	0.42	0.11	0.42	52
24	-0.01	0.41	0.09	0.52	38
30	-0.01	0.5	0.17	0.54	36
36	0.17	0.53	0.21	0.54	33
42	0.03	0.41	0.22	0.51	28
48	0.11	0.46	0.21	0.65	23
Total					**662**

*Mean diopters of change.
†Standard deviation.
‡Number of data points

TABLE VI: CHANGE IN KERATOMETRY VALUES AFTER 3COR

	VERTICAL DATA		HORIZONTAL DATA		
MONTHS AFTER 3COR	MEAN D*	SD†	MEAN D*	SD†	N‡
0.03	0.12	0.59	-0.22	0.47	172
0.25	0.09	0.43	-0.14	0.41	95
0.5	0.1	0.51	-0.18	0.33	90
1	0.24	0.59	-0.07	0.44	126
1.5	0.11	0.49	-0.13	0.4	64
2	0.11	0.39	-0.09	0.4	87
4	0.1	0.41	-0.09	0.43	81
6	0.21	0.56	-0.01	0.43	83
12	0.12	0.42	0.1	0.36	84
18	0.19	0.74	-0.04	0.62	83
24	0.04	0.46	-0.06	0.34	88
30	0.08	0.39	-0.01	0.33	61
36	0.12	0.59	-0.09	0.47	34
Total					**1,148**

*Mean diopters of change.
†Standard deviation.
‡Number of data points.

sition.[8] However, these technical developments did not solve the problem of surgically induced change in corneal astigmatism. A careful prospective study of ICCE performed with a microscope and 8-0 silk sutures also showed that "with the rule" astigmatism increased immediately after ICCE but that "against the rule" astigmatism predominated in time.[8]

Sutures may not be the only factor leading to an increase in "with the rule" astigmatism immediately after an incision on the superior meridian.[3,8-11] Kondrot[12] showed that even after a small unsutured scleral incision on the superior meridian, "with the rule" astigmatism may rise initially, perhaps on account of tissue shrinkage from cautery, but by 1 year, "against the rule" astigmatism predominated.

TABLE VII: PARAMETERS FOR NONLINEAR FIT OF 3 SUPERIOR INCISIONS

	ECCE				6SUP				3SUP			
	VERTICAL		HORIZONTAL		VERTICAL		HORIZONTAL		VERTICAL		HORIZONTAL	
	VALUE	CI*	VALUE	CI*	VALUE	CI*	VALUE	CI*	VALUE	CI*	VALUE	CI*
D_i	1.91	0.32	-1.75	0.19	0.63	0.12	-0.71	0.18	0.21	0.07	-0.45	0.65
D_f	-0.53	0.13	0.58	0.07	-0.51	0.10	0.28	0.06	-0.16	0.05	0.49	0.43
α	2.22	1.0	1.77	0.51	0.75	0.19	0.32	0.19	0.7	0.34	0.63	0.39
β	1.63	0.61	1.67	0.39	0.69	0.24	1.31	0.63	0.83	0.51	0.34	0.49

*95% confidence interval.

TABLE VIII: PARAMETERS FOR LINEAR FIT OF 2 TEMPORAL INCISIONS

	3TEMP				3COR			
	VERTICAL		HORIZONTAL		VERTICAL		HORIZONTAL	
	VALUE	CI*	VALUE	CI*	VALUE	CI*	VALUE	CI*
a	0.07	0.07	0.07	0.03	0.14	0.05	-0.11	0.06
b	4E-05	0.003	0.003	0.001	-0.001	0.003	0.003	0.004

*95% confidence interval

The effect of an astigmatic keratotomy is based on the premise that change in curvature in one meridian is balanced by an equal and opposite change in the orthogonal meridian.[13,14] The “mean” behavior represented by the curves may be used to test the concept of a coupling ratio. At the 95% confidence level, the ratio of the absolute value of D_i of the vertical and horizontal meridians cannot be distinguished from 1 for ECCE, 6Sup, and 3Sup. Similarly, the ratio of the absolute value of D_f of the 2 meridians cannot be distinguished from one for ECCE and 3Sup, but at the 95% confidence level the absolute value of D_f for the vertical meridian is greater than that for the horizontal meridian for 6Sup (Table VII). However, the absolute value of mean change on each meridian is within one standard deviation at all time intervals after surgery (Tables II through IV). Although these data appear to be consistent with a coupling ratio of 1, the mean is not representative of individual behavior. The range of change on each meridian after each incision is sufficiently great that the concept of the coupling ratio has limited clinical use. The mean change after the superior incisions decreases with incision size, making the long-term refractive effect of the smaller superior incisions more predictable, but also less useful for eliminating preoperative “with the rule” corneal astigmatism. After both temporal incisions, the mean change is so close to zero that the surgeon cannot know if the incision will increase or decrease astigmatism on either meridian, however slightly.

In 1951 Floyd[9] noted that the greatest increase in corneal astigmatism after ICCE occurred during the first month and that a sharp drop generally took place during the second month. Cridland[15] showed that the postoperative change in refractive astigmatism may be approximated by an exponential decay. The keratometric data presented here for ECCE, 6Sup, and 3Sup confirm that the decay from D_i to D_f is exponential. As the size of the incision on the vertical meridian decreases, so does the absolute amount of change in corneal astigmatism and the time for the cornea to stabilize after surgery.

Why a 3 mm superior incision affects corneal curvature more than a similar temporal incision has not been explained. Viewed from the front, the typical human cornea is about 1 mm wider than tall.[16] Thus, superior incisions may be slightly closer to the corneal apex than temporal incisions. Moving a 3 mm incision further from the central cornea might be sufficient to reduce the change in corneal curvature to a level that is not detectable with keratometry. However, a larger incision would surely overwhelm the small astigmatic benefit of a 1 mm shift in position, and clinical studies of larger temporal incisions for ECCE and phacoemulsification indicate that they cause significantly less change in corneal curvature than comparable superior incisions.[17,18] Cravy[17] attributed the change after superior incisions to the distractive force of blinking. This and gravity may account for the difference in superior and temporal wounds, but it is also possible that the biology of the superior and temporal

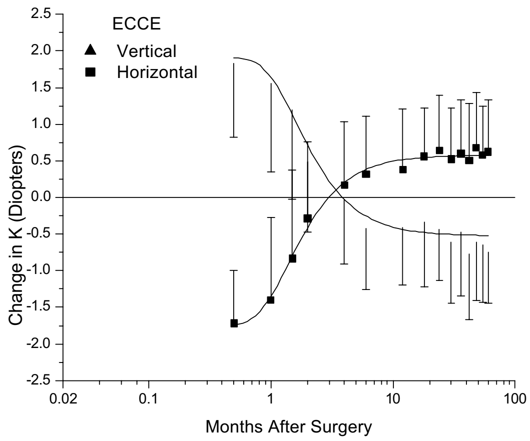

FIGURE 1

Semilogarithmic plot of mean and standard deviation of change on vertical and horizontal meridians after extracapsular cataract extraction (ECCE), with curves fit to the data.

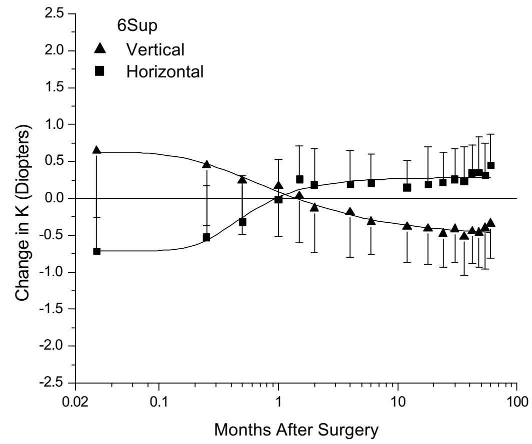

FIGURE 2

Semilogarithmic plot of mean and standard deviation of change on vertical and horizontal meridians after 6 mm superior scleral tunnel for phacoemulsification (6Sup), with curves fit to data.

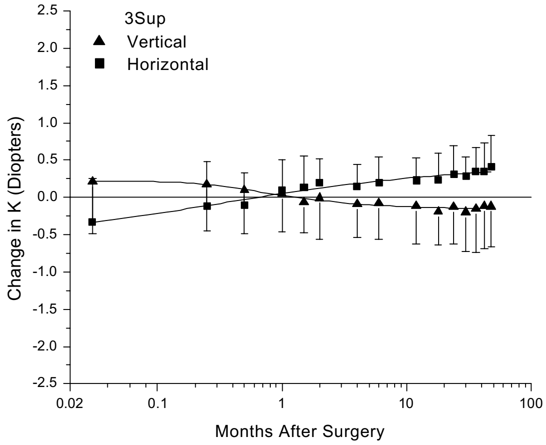

FIGURE 3

Semilogarithmic plot of mean and standard deviation of change on vertical and horizontal meridians after 3 mm superior scleral tunnel (3Sup), with curves fit to data.

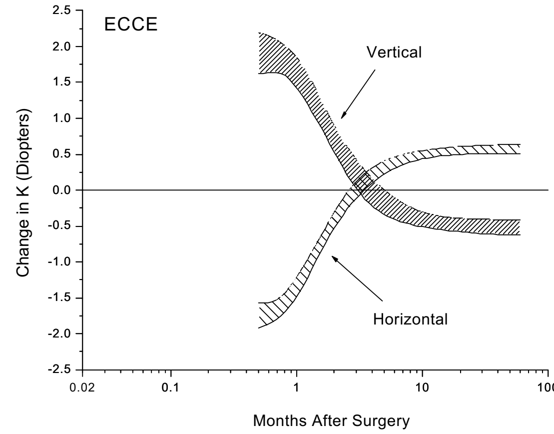

FIGURE 4

Semilogarithmic plot of 95% confidence intervals of the fits for change on vertical and horizontal meridians of cornea after extracapsular cataract extraction (ECCE).

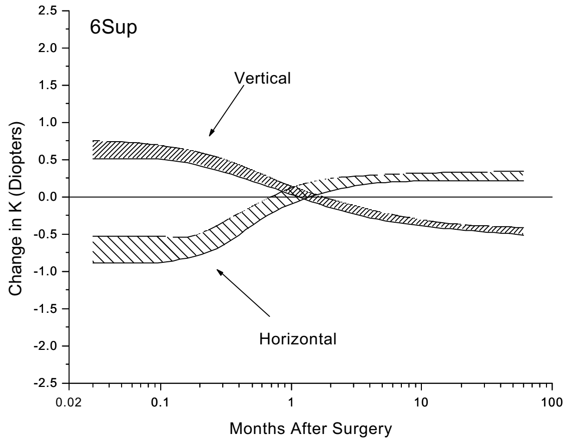

FIGURE 5

Semilogarithmic plot of 95% confidence intervals of the fits for change on vertical and horizontal meridians of cornea after 6 mm superior scleral tunnel (6Sup).

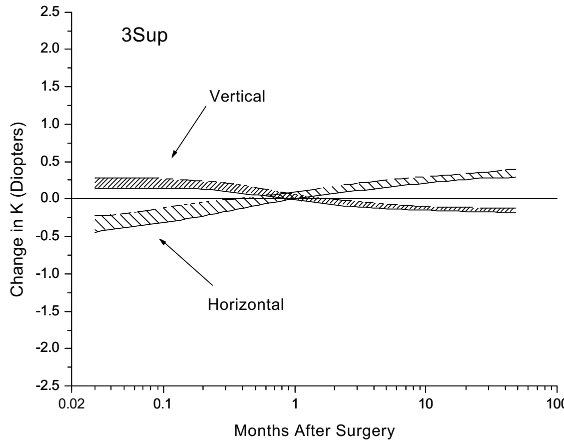

FIGURE 6

Semilogarithmic plot of 95% confidence intervals of the fits for change on vertical and horizontal meridians of cornea after 3 mm superior scleral tunnel (3Sup).

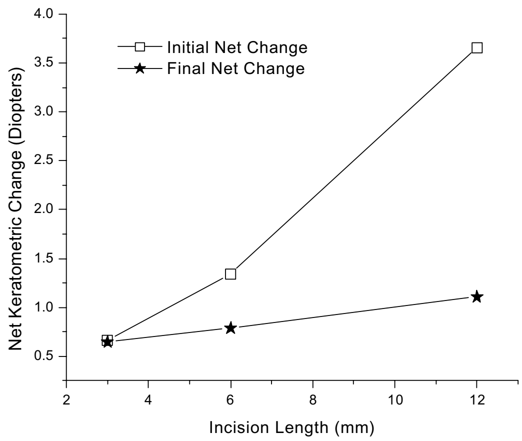

FIGURE 7
Relation of initial and final net change in corneal astigmatism and length of three superior incisions.

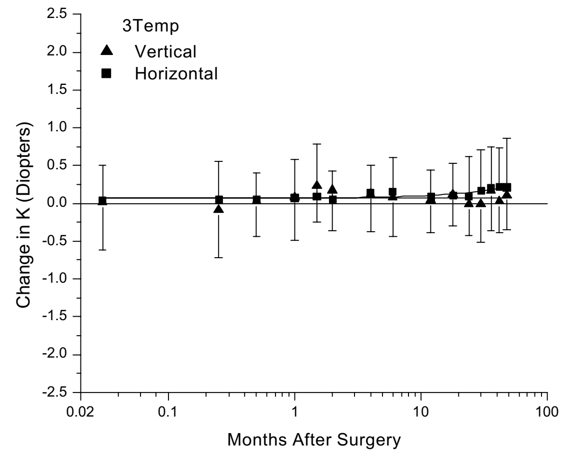

FIGURE 8
Semilogarithmic plot of mean and standard deviation of change on vertical and horizontal meridians after 3 mm temporal scleral tunnel (3Temp), with linear fits to data.

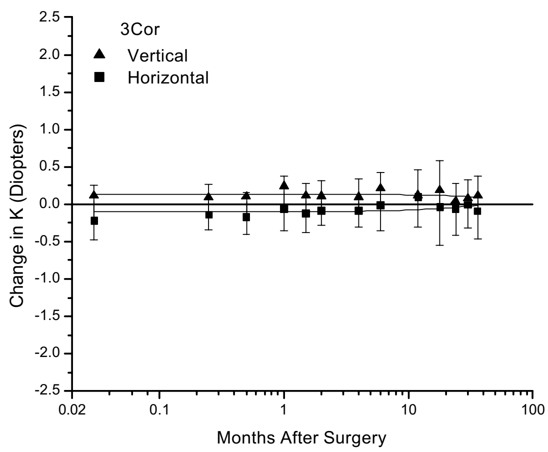

FIGURE 9
Semilogarithmic plot of mean and standard deviation of change on vertical and horizontal meridians after 3 mm temporal corneal incision (3Cor), with linear fits to data.

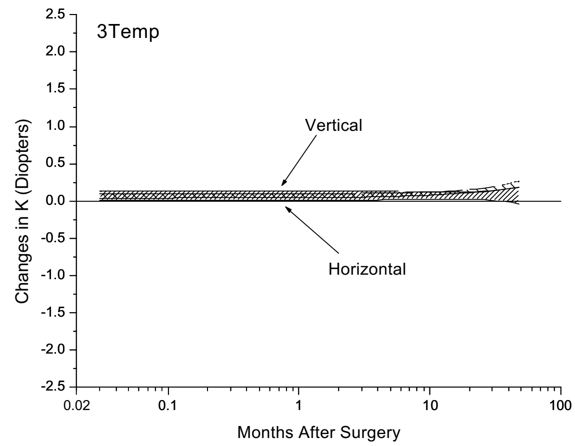

FIGURE 10
Semilogarithmic plot of 95% confidence intervals of the fits for change on vertical and horizontal meridians of cornea after 3 mm temporal scleral tunnel (3Temp).

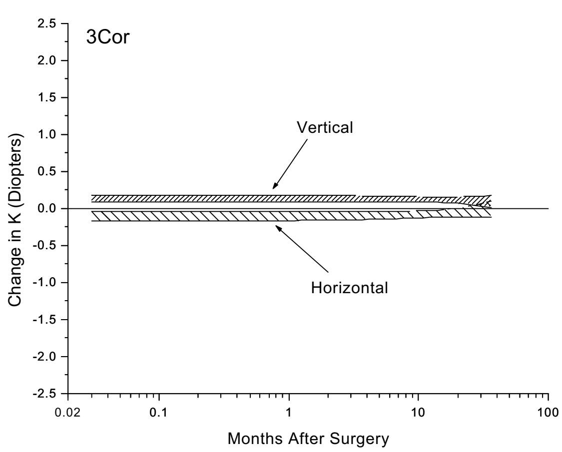

FIGURE 11
Semilogarithmic plot of 95% confidence intervals of the fits for change on vertical and horizontal meridians of cornea after 3 mm temporal corneal incision (3Cor).

cornea and limbus differs. It has long been known that the fine structure of the peripheral cornea differs from the central cornea, but it is not known if wound healing of the temporal cornea differs from that of the superior cornea.[19]

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DISCUSSION

DR DOUGLAS D. KOCH. Thank you for the opportunity to discuss this interesting work. Dr Merriam and colleagues have in effect attempted to provide an astigmatic history of cataract surgery over the past 20 years. Their study confirms what cataract surgeons today accept as dogma: that small temporal incisions induce the smallest amount of surgically induced astigmatism and maximize astigmatic stability.

The most remarkable aspect of this study is the diversity of incisions and duration of follow-up for the patients included in their report. In the ophthalmic literature there are no studies that match or even approach the authors' accomplishments in these 2 areas. This study is also the first to mathematically describe the rate of astigmatic change for various incision types.

As a retrospective study, this report has several drawbacks. The authors report on 665 patients, but the total pool of patients from which these are drawn is not provided. If a large number of patients were lost to follow-up, this could bias their results. This problem could be ameliorated somewhat if the authors provided an analysis of the same cohort of patients preoperatively and at each key postoperative interval.

There are some uncertainties regarding data acquisition. This study is based on keratometry readings that were presumably obtained only once per visit by a variety of technicians; this certainly could introduce variability in their data. In addition, the surgical techniques were obviously not strictly controlled. For example, some of the superior 3 mm incisions were sutured, whereas others were left unsutured. Another potential variable is that incision size was not actually measured. The authors indicate that the smallest superior and temporal incisions were 3 mm in size, but the technology for achieving incisions this small has generally not been available until recently. I therefore suspect that these incisions were 3.5 mm and perhaps even 4 mm in length. This might be a minor quibble, but it has relevance as we try to understand the impact of reducing small incisions by small amounts, such as 0.3 to 0.5 mm.

A major concern with this study is their basic methodology for data analysis. The authors use an unorthodox and scientifically imprecise method for recording and analyzing keratometric astigmatism. They included only patients whose initial astigmatic meridian was within 15° of 90° or 180°, thus presumably excluding a large number of patients. More importantly, postoperative keratometry values were recorded as either superior or horizontal, depending upon their orientation relative to the 45°-135° meridians. The magnitude of error introduced by this methodology could be large. For example, a patient with astigmatism of 42 x 44 at 90 would be recorded identically to a patient with astigmatism 42 x 44 at 136°, which generates approximately a one-diopter error at both the horizontal and vertical meridians.

There are now scientifically validated methodologies for analyzing astigmatic data. In the January issue of the Journal of Cataract & Refractive Surgery, we published 8 papers that describe state-of-the-art techniques in this area.[1-8] Two fundamental aspects of these analytical approaches are particularly relevant to Dr Merriam's work.

First, with vector analysis one can calculate astigmatic changes with-the-wound and against-the-wound.[9] For this type of analysis, the authors could graph the data as they have done in their study, substituting for the existing data the scientifically accurate with-the-wound and against-the-wound changes. This would permit the inclusion of all patients preoperatively and would ensure accurate analysis of all postoperative astigmatic changes, regardless of the location of the steep and flat meridians.

Secondly, aggregate analysis of the surgically induced changes in astigmatism over time can be calculated.[10] This type of vector analysis would enable the authors to demonstrate the mean magnitude and direction of the astigmatic changes for each incision type at each postoperative interval. With bivariate analysis[3-5] of these data, the authors could statistically compare incision types and determine when stability was achieved for each.

I believe that Dr Merriam's study can provide important new information regarding the astigmatic effects of various cataract incisions, despite the problems inherent in the retrospective nature of this study. I encourage him to re-analyze the data using the more scientific rigorous methodology that is now available. I congratulate Dr Merriam for this interesting and valuable study.

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[Editor's note] DR JAMES C. BOBROW felt that vector analysis would be a more accurate way to look at the data. He asked if one really wanted to achieve the same astigmatism as existed prior to surgery rather than to place the incision to minimize or eliminate pre-existing astigmatism. He also wondered about long term results, having noted in his own patients a tendency to develop increasing astigmatism in the horizontal meridian with time.

DR JOHN C. MERRIAM. I would like to thank Dr Koch and Dr Bobrow for their thoughtful comments. Doug and I had a conversation by email before the meeting, and I anticipated some of his comments today. This is indeed a retrospective study. Although we have a large database, I am not sure if we have sufficient numbers of patients in each group to do a long-term "cohort" study, as he suggested. Unless the cohort was large, one would still wonder if it was representative of the general patient population. Dr Koch asked if there were several technicians: I performed all of the keratometry readings for this study. He also noted that the phaco groups include some wounds that were sutured and that we did not actually measure each incision. The 6 mm phaco incisions routinely had 2 simple vertical 10-0 nylon sutures, and the 3 mm wounds were closed with a single suture only when there was concern about a wound leak. We have looked at the effect of a single suture on these small wounds and found that the long-term development of astigmatism is the same. All the incisions for a 6 mm IOL and some 3 mm incisions were measured with a caliper. With experience, I stopped measuring the incision routinely for foldable lenses. The actual size of the incisions in each group surely did vary a little, but we do not think that this is a significant factor. The sclera and cornea are elastic, and any intraoperative measurement of internal wound length is subject to error. The final induced changes from the superior 3 and 6 mm incisions are so close that we do not think we can measure the effect of slight variability in the length of these incisions. Whatever the range of incision length, we demonstrated no significant change from the temporal incisions.

Dr Koch has suggested some alternative ways to analyze our data. We already have looked at our data in a number of ways, including vector analysis and some axis-based techniques of assessing surgically induced astigmatism. These results will be the subject of a future report. He expresssed concern that this study included only patients with regular pre-operative astigmatism. We excluded patients with pre-operative oblique astigmatism because we suspect that these eyes may behave differently after incisions on the horizontal and vertical meridians and the number of such patients in each group was not large enough for long-term analysis. His main concern was that the potential for error is great when the axis is close to 45° or 135°. To our knowledge, this is the first study to consider the variability of the K reading as experimental error. I generally measure K's once before other routine office procedures, but I often measured the K's 2 or more times during a single office visit. Both the value of the K reading and its axis may vary, sometimes surprisingly. It seems misleading to us to worry about the effect of a 1° or 2° shift in axis when one cannot measure the axis with such precision in routine clinical practice. However, if the number of data points close to 45° or 135° were large, Dr Koch is correct that the potential for error in the curve fittings might be significant. Fortunately there are relatively few patients, even with the larger incisions, who have such oblique astigmatism after surgery. Of the 4577 data points in this study, only 18 have an axis between 40° and 50° or between 130° and 140°. Twelve of these points are from the ECCE group, 4 from 6Sup, and 1 each from 3Sup and 3Temp. The potential for error from these patients is nil. The results of curve fittings are indistinguishable whether they are all excluded, all included with the vertical group, or all included with the horizontal group. After Dr Beasley's paper in 1967, Dr Sloane from Boston, whose book on optics I used as a resident, commented on how quickly the cornea became regular after intracapsular extraction. Certainly there is less induced oblique astigmatism after today's smaller incisions than after ICCE.

Dr Bobrow wondered whether we could use these incisions to change pre-operative corneal astigmatism. We have looked at that question with our data set, and we don't find that the astigmatic effects of the superior incisions are reliable enough to be truly predictive. He also mentioned that he thinks that corneal astigmatism may continue to change for 10 or more years after surgery. Some of the patients who had ECCE have been followed for more than 15 years, although the data presented here were limited to 5 years. To compare all of the incisions will require years of data accumulation. However, after 5 years we think that it is important to consider the effect of age because the cornea does change with age. To distinguish the effect of the incision from the effect of age requires large numbers of patients and controls and is not a simple matter.