# Corneal topography outcomes of cataract surgery

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**Background**: The number of patients undergoing cataract surgery in Australia has increased significantly over the past five years. This is at least partly related to technical improvements in phacoemulsification resulting in greater intra-operative safety. However, phacoemulsification does not necessarily lead to the best optical outcome from cataract surgery. This paper reviews the interaction between cataract surgery and corneal topography and uses case reports to discuss the planning of cataract surgery based on pre-operative refraction.

**Discussion**: Corneal astigmatism induced by cataract surgery may be considered in two main groups, that caused by the incision and that caused by sutures. The location and length of the incisions, wound construction and the manner of wound closure determine the corneal topographic outcome of cataract surgery. Since the incisions vary for extracapsular cataract extraction (ECCE) and phacoemulsification cataract extraction (PECE), they induce different patterns of corneal topographic change. Each procedure has its advantages, but PECE tends to change the topography less, leading to more rapid visual rehabilitation. However, PECE does not always result in less final astigmatism. Practitioners should consider their role in the management of cataract patients to include planning the best type of surgery and the best post-surgical intervention for an optimal optical outcome.
(*Clin Exp Optom* 1996; 79: 6: 235–245)

## Cataract surgery

Cataract surgery has evolved over the past 15 years to be an extremely safe and effective procedure, providing near-normal physiological vision and an extraordinarily low surgical risk of adverse outcome. The development of ultrasonic phacoemulsification (PE), the advent of small incision surgery and foldable intraocular lenses (IOL), improved IOL power calculation formulae, local anaesthetic and day-case surgery have been important advances. The result has been an explosion in the number of procedures performed. In the United States, a person reaching full life expectancy is more likely to have undergone a cataract extraction than any of the other nine most common surgical procedures.[1,2] The improved safety and effectiveness of cataract extraction has led to surgery being performed on patients with minimal levels of cataract and minimal visual disability. The accuracy of the refractive outcome is especially critical in these patients, since they may judge the outcome of surgery as much in terms of unaided vision as of best corrected vision. This has driven substantial research into minimising refractive error after cataract surgery. Post-operative refractive error comprises spherical error, determined by IOL selection, and astigmatic error which depends on corneal topography. The purpose of this paper is to discuss corneal outcomes of cataract surgery, based on a series of case reports.

**Incisions**

1. A circumferential incision causes flattening in the corneal meridian perpendicular to the incision
2. Longer incisions cause a greater flattening effect
3. Incisions closer to the visual axis cause a greater flattening effect

**Sutures**

4. Suturing the same circumferential incision will oppose this flattening
5. If the sutures are too loose the cornea will still flatten in the meridian perpendicular to the incision
6. If the sutures are too tight the cornea will still steepen in the meridian perpendicular to the incision

Table 1. Six refractive principles of incision-based corneo-scleral surgery
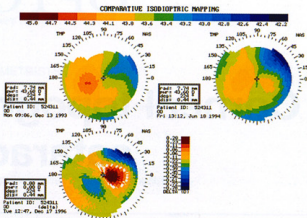


Figure 1. Corneal topography for Case 1, before (above left) and after (above right) ECCE with difference map (below left). The difference map is almost spherical, indicating an astigmatically neutral procedure

## Refractive principles of incision-based corneo-scleral surgery

Corneal topography is influenced by surgical incisions and their closure (Table 1). Any vertical incision into the cornea will flatten the immediate area.[3] The pattern of topographical change to the remaining cornea depends on the location and direction of the incision. Cataract surgery invariably involves circumferential (linear or curved) incisions, so this discussion will be limited to such incisions.

A circumferential wound causes flattening in the corneal meridian perpendicular to the incision and steepening in the corneal meridian parallel to the incision (where a meridian is a line passing from the limbus through the centre of the cornea). The magnitude of the corneal flattening effect increases as the location of the incision approaches the visual axis,[4] so that corneal sections induce more astigmatism than scleral incisions. The magnitude of the corneal flattening effect also increases with the length of the incision.[5,6]

The cornea flattens directly over any sutured incision.[3] Suturing of an incision provides an opposing influence to the topographical changes induced by an incision alone. A loosely sutured circumferential wound causes flattening in the corneal meridian perpendicular to the incision and steepening in the corneal meridian parallel to the incision.[3] A tightly sutured circumferential wound causes steepening in the corneal meridian perpendicular to the incision and flattening in the corneal meridian parallel to the incision.[3,7]

## Extracapsular cataract extraction and phacoemulsification

Extracapsular cataract extraction (ECCE) and phacoemulsification cataract extraction (PECE) are currently the two most widely performed types of cataract surgery in Western society.[8] Each is conducted with different types of wound construction and each may be carried out at various locations using various incision sizes. Each permutation will typically induce different corneal topographical changes. This can be best illustrated with a series of case reports.

## CASE REPORTS

The patients described in these cases all underwent cataract surgery in the Department of Ophthalmology, Flinders Medical Centre, and were followed in the ophthalmology outpatients clinic.

## Case 1

A 65-year-old woman with nuclear and posterior subcapsular cataract underwent an ECCE with IOL implantation. A 9 mm superior scleral-based incision was closed with six 10-0 nylon sutures. The pre-operative refraction was: +0.50 (6/60). At three months post-operatively, refraction was: plano (6/6). The patient was very happy with the outcome of the operation. No sutures were removed. This is an excellent example of an astigmatically neutral result with ECCE (Figure 1).

## Case 2

A 70-year-old man with cortical cataract underwent an ECCE with IOL implantation. A 9 mm superior scleral-based incision was closed with six 10-0 nylon sutures. The pre-operative refraction was: +2.75/-1.00 x 87 (6/12). At three months post-operatively refraction was: +0.25/-0.75 x 40 (6/4.5). The patient was very happy with the outcome of the operation. All sutures remained in place at three months. The tight wound closure had induced with-the-rule astigmatism (Figure 2) which suture removal would have reduced but the magnitude of the astigmatism did not justify intervention. Further-
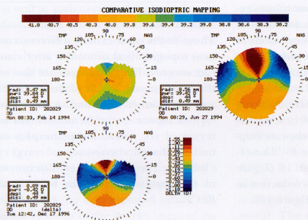
Figure 2. Corneal topography for Case 2, before (above left) and after (above right) ECCE with difference map (below left). The incision is scleral, centred at 12 o'clock with six nylon sutures still in place at three months post-operatively. The difference map indicates a significant increase in with-the-rule astigmatism. This suggests tight wound closure
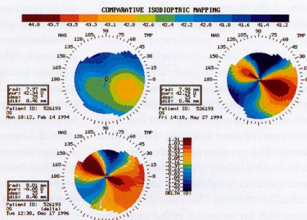
Figure 3. Corneal topography for Case 3, before (above left) and after (above right) ECCE with difference map (below left). The incision is scleral centred at 12 o'clock with six nylon sutures still in place at three months post-operatively. The difference map indicates a significant increase in against-the-rule astigmatism. This is due to loose wound closure
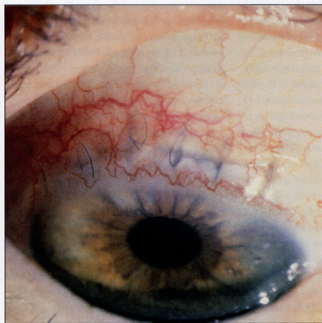


Figure 4. Inflammation and scleral necrosis at the ECCE wound site in Case 4
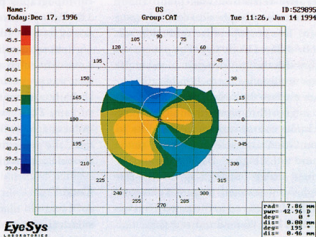
Figure 5. Post-operative corneal topography for Case 4. The wound melting seen in Figure 4 has induced 3.00 to 4.00 D of against-the-rule astigmatism
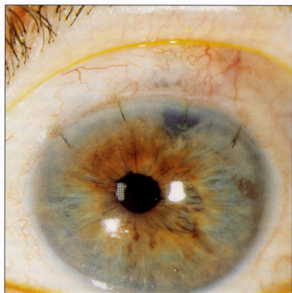
Figure 6. A corneal incision was used for ECCE in Case 5 due to a pre-existing trabeculectomy bleb
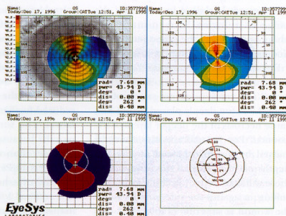


Figure 7. Post-operative corneal topography for Case 5. The four tight corneal sutures seen in Figure 6 have induced 4.00 D of with-the-rule astigmatism
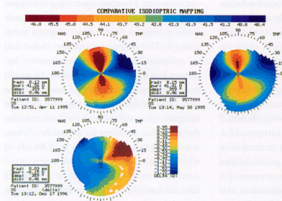


Figure 8. Corneal topography for Case 5, 10 weeks post-operatively (above left) and 16 weeks post-operatively (above right) with difference map (below left). The with-the-rule astigmatism gradually reduces throughout the post-operative period even with the sutures in place



Figure 9. The sutures seen in Figure 6 have been removed. The narrow beam shows that the corneal wound has healed without gaping and the old trabeculectomy bleb is raised and therefore functioning

Figure 10. Corneal topography for Case 5, before (above left) and five minutes after (above right) suture removal with difference map (below left). Suture removal induces an instantaneous reduction in with-the-rule astigmatism



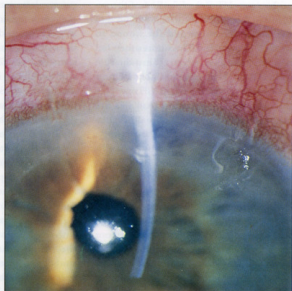Figure 11. Corneal topography for Case 6, before (above left) and after (above right) PECE with difference map (below left). The incision is scleral, centred at 11 o'clock with one nylon suture still in place at three months post-operatively. The difference map indicates a slight increase in against-the-rule astigmatism. However, this has negated pre-existing with-the-rule astigmatism, resulting in spherical topography
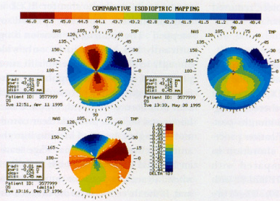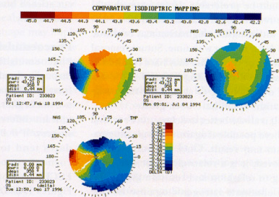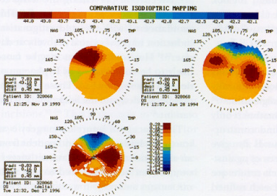


Figure 12. Corneal topography for Case 7, before (above left) and after (above right) PECE with difference map (below left). The incision is scleral, centred at 11 o'clock and unsutured. The difference map indicates a significant increase in against-the-rule astigmatism

the greatest effect on reducing with-the-rule astigmatism.

In Case 5, the removal of sutures at 16 weeks post-surgery resulted in 1.50 D of with-the-rule astigmatism. This is a reasonable outcome, although less astigmatism would be preferable. However, it should be remembered that the residual 1.50 D of with-the-rule astigmatism may continue to decay further with time. Suture removal a week or two earlier may have resulted in less with-the-rule astigmatism, but the risk of overshooting to against-the-rule astigmatism would have been greater.

It is always better to delay suture removal where possible if against-the-rule astigmatism may result. Once the suture is removed, it is a relatively major undertaking to refashion and resuture the wound to eliminate iatrogenic against-the-rule astigmatism.

## Technique for suture removal

Before removing sutures, a single drop of topical local anaesthetic should be instilled into the inferior conjunctival cul-de-sac. Sutures can be cut with a sterile single-use 27-gauge (or similar) needle. Sutures should be cut at one of the two entry points to the eye, leaving a long end and a short end. The long end can be grasped with fine flat-faced suture forceps and removed. This prevents any portion of exposed suture being drawn back into the eye. It is best for the long end to include the suture knot so that, on removal, the bulky knot will not be dragged downwards through the cornea. This is best avoided as it unnecessarily stresses the wound and makes the suture more difficult to remove.

If the cut suture remains buried under the conjunctiva it need not be removed, but exposed sutures should be removed. Cut sutures are always left in place when an argon laser is used to cut sutures subconjunctivally. This has the advantage of not disturbing the conjunctiva, resulting in less discomfort and probably a lower risk of infection. Administration of prophylactic broad-spectrum antibiotics post-suture removal may also reduce the risk of infection but this is based more on theoretical grounds than on clinical evidence.

Nevertheless, topical prophylactic antibiotics post-suture removal are part of the expected standard of care. The same principles for suture cutting and removal apply to both interrupted and continuous sutures but continuous sutures need to be cut at each bite and each piece removed individually.

## Phacoemulsification

Phacoemulsification cataract surgery through scleral incisions will induce less corneal astigmatism than ECCE in the first two weeks after surgery but there is no significant difference at three months post-surgery.[13,25,26] Phacoemulsification procedures tend to cause less alteration in corneal topography compared with ECCE[27] (compare Figures 11 and 12 with Figures 1, 2, 3, 5, 7, 8 and 10). There are even fewer changes with smaller incisions.[28,29] The astigmatism induced by PECE tends to be stable after one month, if not earlier.[30,31] It is the smaller impact of PECE on corneal topography and the refractive stability that leads to more rapid visual rehabilitation.[32,33] However, the final astigmatic result is more important than the transient shift in astigmatism. Small scleral-based incisions used with PECE tend to cause corneal flattening anterior to the wound with coupled steepening 90 degrees away.[34] Therefore, incisions located between 11 and 1 o'clock tend to cause against-the-rule astigmatism. Significant post-surgical against-the-rule astigmatism is common after PECE.[35]

The danger in sutureless phacoemulsification, larger incisions, and incisions which gape slightly, is induced clinically significant against-the-rule astigmatism.[36-38] In Case 7, the induced astigmatism is only moderate due to good wound construction. Poorly constructed wounds also give a greater risk of high degrees of against-the-rule astigmatism.[37,38] Such results are undesirable in these days of such refined control of refractive outcome. There is no point in working within the confines of a small incision and taking the risk of using foldable or injectable lenses to minimise refractive error if poor wound construction, especially if unsutured, leads to high amounts of against-the-rule astigma-

tism. High amounts of against-the-rule astigmatism may be related to patient dissatisfaction, if the patient did not have against-the-rule astigmatism preoperatively.[39,40]

Good wound construction for PECE is conceptually similar to that for ECCE in that the incision should be 'planed' or 'stepped'. The width of the incision is significantly less as it need be only wide enough to fit the phacoemulsification probe and allow its manipulation. The incision begins with a perpendicular incision into cornea or sclera, followed by a horizontal incision through clear cornea and an angled, bevelled incision into the anterior chamber. The final stage leaves an internal corneal lip which seals itself when intraocular pressure returns to normal. If the three incisions are distinct, the tissue planes tend to remain in apposition to one another and to heal without significant change in corneal shape. If the incisions tend to blend into each other, the tissue planes tend to slide and corneal topography will be significantly altered.[41]

There is much debate about both the need to suture PECE incisions and which type of suture, if used, is best. Radial and X sutures are thought to induce with-the-rule astigmatism and delay visual recovery.[41] Horizontal sutures are thought not to induce with-the-rule astigmatism but are effective in preventing the trend toward against-the-rule astigmatism.[42,43] This avoidance of with-the-rule astigmatism induction improves visual recovery at day one.[42,44] Horizontal sutures may be more likely to be complicated by hyphaema or delayed filtering blebs.[41] These problems may be avoided with the horizontal anchor variant.[45]

The concept of sutureless surgery is attractive to both surgeon and patient from an aesthetic standpoint. Cataract surgery wounds can be constructed to seal without sutures and remain watertight.[41] However, sutureless PECE tends to cause more astigmatism than sutured procedures.[46] The amount of astigmatism induced varies, with the better results in the order of an average 0.50 D against-the-rule astigmatism, although often higher.[47,48] Good wound construction, a smaller incision, a

frown incision and the incorporation of a corneal lip may keep this astigmatism to a minimum.[49-52]

Frown incisions induce less astigmatism than horizontal incisions of the same chord length.[51,53] The curved incision provides the same working space as a linear excision of the same chord length, but with a smaller angular subtense if the size of the section is viewed from the visual axis. It is the angular subtense of the incision that determines the amount of astigmatism produced. Therefore, the curved incision provides less astigmatism. A 4 mm horizontal incision may induce similar topographical changes to a 7 mm frown incision.[53,54]

Clear corneal phacoemulsification is especially prone to causing against-the-rule astigmatism.[31,55] At six weeks post-surgery, a 3.5 mm clear corneal section will induce 0.50 +/- 0.50 D against-the-rule and a 5.2 mm section will induce 1.25 +/- 0.75 D against-the-rule.[31] Temporal incisions induce with-the-rule instead of against-the-rule astigmatism, but, on average, of lower magnitude.[31] There is some evidence that temporal incisions are more stable, possibly due to less lid pressure but the induced astigmatism is still about 1.00 D.[55-57]

Wound location is another important variable in determining the corneal topographical outcome of cataract surgery. Most surgery is performed with the incision centred at 12 o'clock, which is aesthetically desirable to hide the wound site and ergonomically practical for the surgeon. There are other options. Superio-lateral incisions induce less corneal topographical change than superior incisions.[58-60] This is thought to be due to eyelid pressure distorting a superior wound more than a superio-lateral wound. Lateral incisions, which induce with-the-rule astigmatism, are most often proposed for cases with pre-operative against-the-rule astigmatism.

## Planning astigmatically neutral surgery

It is an axiom of good surgery to always perform the same procedure in the same way. Variations in method are more likely to lead to misadventure. However, pre-operative astigmatism varies, so different approaches are required to minimise astigmatism in different cases. The refractive outcome may be enhanced by minor alterations to wound design, location or closure.[61] Because PECE and ECCE cause different changes to corneal astigmatism, the pre-existing corneal shape may imply that one procedure is more likely to give minimal postoperative astigmatism than the other. It is important to note that many surgeons prefer routine PECE for its other, non-optical advantages such as working within a closed system and superior control by the surgeon during the procedure.

### PRE-EXISTING CORNEAL WITH-THE-RULE ASTIGMATISM

Low levels of with-the-rule astigmatism (less than 2.00 D) can be managed by either ECCE or PECE. Using a superior incision and ECCE, minimal suture tension and early suture removal are the simplest and best tactics for reducing pre-existing with-the-rule astigmatism. For less than 1.00 D, a scleral PECE will give a good result, but for 1.00 to 2.00 D a clear corneal incision will be required to give enough neutralisation. In Case 6, mild with-the-rule astigmatism is eliminated with a superiorly located, horizontally sutured, phacoemulsification procedure (Figure 11). In cases of high (greater than 2.00 D) with-the-rule astigmatism, ECCE may be the procedure of choice for best refractive outcome. An increase in ECCE wound length or a corneal section may also be helpful. A superior clear corneal incision with PECE may induce some with-the-rule neutralisation, which will be most pronounced with a larger, unstitched wound. However, this approach sacrifices any opportunity to modify the postoperative course with suture removal and is thus more 'hit and miss'.

Lateral incisions for ECCE and tight sutures which are not removed are viable alternatives where there is pre-existing with-the-rule astigmatism. However, it is difficult to justify the risks involved in changing technique or incision site. Unless lateral incisions are routine, one of the alternatives for superior incisions is preferable. Incision-derived astigmatism is more reliable than suture-induced astigmatism since sutures can break or erode. The result may be to exaggerate pre-existing astigmatism. Hence, superior incisions are best for with-the-rule astigmatism and lateral incisions can be considered for against-the-rule astigmatism.

### PRE-EXISTING CORNEAL AGAINST-THE-RULE ASTIGMATISM

Superiorly located PECE incisions, no matter what suture technique is employed, do not help neutralise pre-existing against-the-rule astigmatism. Superiorly located ECCE incisions can be used to neutralise pre-existing against-the-rule astigmatism by closing the wound tightly and avoiding suture removal. This may backfire if early suture release occurs, but it has the advantage of being a minimal, and therefore lower risk, modification to the procedure if the surgeon is accustomed to superior incisions.

Lateral limbal incisions for PECE and ECCE have been recommended for neutralising pre-operative against-the-rule astigmatism.[56,62,63] The technique was most effective for cases with high pre-operative against-the-rule astigmatism when combined with suture cutting. Cases with high pre-operative against-the-rule astigmatism had a greater reduction in against-the-rule astigmatism with the ECCE procedure.[62] This lateral ECCE is preferred for reducing high levels of pre-existing against-the-rule astigmatism. Higher levels of astigmatism can also be managed with longer incisions, incisions closer to the visual axis and more loosely sealed wounds.[18, 63]

### PRE-EXISTING CORNEAL OBLIQUE ASTIGMATISM

The same principles apply for oblique astigmatism. Unsutured clear corneal PECE has been proposed to minimise pre-existing corneal astigmatism by placing the incision in the steepest corneal meridian and using a larger wound for higher amounts of astigmatism.[31,64] There have been reports of long-term against-the-rule drift after oblique axis surgery.[65] Extracapsular procedures may be just as beneficial

if it is practical to move the incision site to the steepest meridian and aim for loose wound closure or early suture removal. Large levels of astigmatism may again be better neutralised with ECCE, longer incisions and early suture removal.

### ZERO PRE-EXISTING CORNEAL ASTIGMATISM

Absence of pre-existing astigmatism indicates astigmatically neutral surgery, so that any type of cataract surgery can be used. This optimal optical outcome is more likely with incisions further from the visual axis, carefully constructed, shorter in length and sutured so that the post-operative course may be modified if necessary.

It should be remembered that zero astigmatism is not a necessary result. Some simple myopic astigmatism may be beneficial to the patient by providing assistance in near vision without substantially degrading distance vision.[66] The primary goal should be to avoid amounts of astigmatism which are troublesome to the patient. Ideally, this should be less than 1.00 D and with-the-rule.[67] However, more may be tolerable and less is not necessarily better.

### CONCLUSION

Computerised videokeratoscopy is an excellent medium for observing the impact of cataract surgery on corneal topography. ECCE and PECE induce different patterns of corneal topographic change, which can be easily understood in terms of several simple refractive principles of incision-based corneo-scleral surgery. When the incision is located superiorly, corneal astigmatism caused by the incision is against-the-rule astigmatism and corneal astigmatism induced by sutures is with-the-rule astigmatism.

The pattern of topographic change depends not just on which procedure is employed but also on variations in technique, such as wound construction, location and length of incision, suture type, pattern and technique. Neither ECCE nor PECE provides a better optical outcome in the long term. Each procedure has its advantages.

PECE tends to change corneal topography less, leading to more rapid visual rehabilitation, while ECCE allows the surgeon more scope to plan astigmatically neutral surgery in cases of pre-existing astigmatism of greater than 2.00 D. ECCE sutures should not be removed before 12 weeks post-operatively, but if they are removed earlier, prescription of new spectacles should be delayed a further four weeks. Sutures are best not removed unless the level of with-the-rule astigmatism is greater than 3.00 D or is symptomatic. PECE does not necessarily provide a better optical outcome than ECCE, especially with clear corneal incisions, sutureless surgery or poor wound construction.

Practitioners should consider their role in the management of cataract patients to include planning the best type of surgery for the optimum optical result and the post-surgical intervention for the best outcome.

### ACKNOWLEDGEMENT

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