Review Article

Factors affecting surgically induced astigmatism in manual small-incision cataract surgery

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Cataract is the most common cause of avoidable blindness in the world. While cataract surgery is continually evolving, manual small-incision cataract surgery (MSICS) still remains highly relevant, especially with the threat of the coronavirus disease 2019 (COVID-19) still looming large over the world. MSICS today has a renewed significance, since it does not involve the use of any advanced machinery and relies mainly on easily sterilizable instruments, thereby making it a safe and inexpensive option. A self-sealing valvular tunnel entry forms the basis of MSICS, and proper positioning and construction of the tunnel is imperative to the success of the surgery. With more and more people demanding spectacle independence after surgery, it becomes important to have a thorough understanding of the factors that may influence surgically induced astigmatism in MSICS. These include the incision location, size and shape, configuration of the sclero-corneal tunnel, pre-existing ocular pathology, role of sutures, amongst others. With proper knowledge, many of these factors can be modulated to achieve best results.

Key words: Astigmatism, cataract surgery, incision construction, MSICS, surgically induced astigmatism

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Cataract is the most common cause of avoidable blindness in the world[1] and tremendous advancements are being made in the field of cataract surgery. There has been a shift from extracapsular cataract extraction (ECCE) to phacoemulsification, and further to micro-incisional cataract surgery and femto surgery. However, in a developing country like India, manual small-incision cataract surgery (MSICS) still occupies a definitive place as a safe, stable, and highly economical means of cataract removal. It has an added benefit of less damage to the corneal endothelium, especially in cases of hard cataract, as are commonly encountered in rural India.[2,3] Furthermore, in this COVID era, MSICS has a renewed importance, given the safety concerns associated with the re-use of the phaco machine for different patients, and the higher risk of aerosol generation with the use of ultrasound energy.[4]

Wound construction is an important determinant to the final surgical success of any cataract surgery, even more so in MSICS. Over the years, it has been seen that in MSICS, wound construction varies, depending upon the type of technique used, the hardness of the nucleus, pre-existing astigmatism, and the condition of the patient's sclera and cornea. A better understanding of wound architecture and closure of incisions has contributed to better postoperative visual acuity, lesser complications, and greater popularity of MSICS. With more and more people expecting spectacle independence after the cataract surgery, appropriate modulation of wound construction in MSICS can also help to rectify some of the pre-existing astigmatism, improving postoperative quality of vision.

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Kratz[5] was the first surgeon to move the incision posteriorly from the cornea to the sclera. He believed that this would increase the appositional surfaces and thereby improve wound healing and reduce surgically induced astigmatism (SIA). Girard *et al*.[6] emphasized the importance of entering the anterior chamber through the cornea, thereby creating a corneal shelf, which helps prevent iris prolapse.[7] McFarland[8] recognized that in such incisions, the corneal shelf acted as a one-way valve, thereby making it self-sealing and paving the way for suture-less cataract surgery.

Haldipurkar *et al*.[9] went on to describe the basic properties of a reliable self-sealing incision, as detailed below:

1. Square incisional geometry, where the length and the width of the tunnel are roughly equal. These wounds have great wound strength and do not leak even at high IOPs [Fig. 1].
2. Relatively short external incision with a tunnel that flares to a larger internal incision
3. Geometric external incision shape that lends itself to stretching.

In this review, we discuss the role of the various factors likely to influence the wound construction and the subsequent and postoperative SIA in MSICS.[10,11] Apart from wound construction, the suture material and the technique used also play a role and are discussed at the end.

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Scleral cautery

A light scleral cautery is recommended at the incision site to avoid hyphema and subsequent inflammation. Excess cautery at or near the limbus can induce scleral shrinkage, leading to induced corneal steepening along the meridian of the cauterized area[12] [Fig. 2].

External incision

The size, shape, location, configuration, and depth of external incision can all have an effect on the final SIA. The length of the incision is the distance between its two ends, while the width of the tunnel is the distance between its external and internal incision.

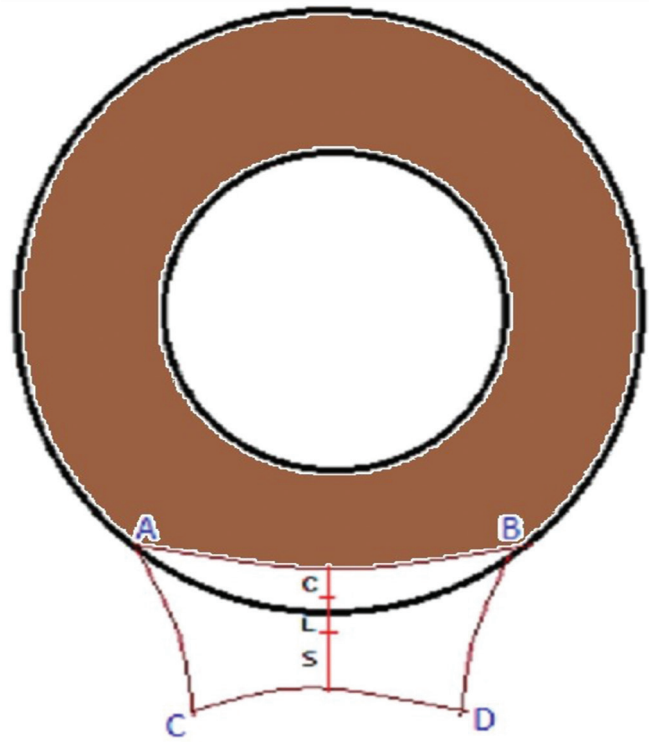

Figure 1: Square incisional geometry, where wound length (C to D) equals wound width (A to C). C: Corneal part of tunnel. L: Limbal part of tunnel. S: Scleral part of tunnel

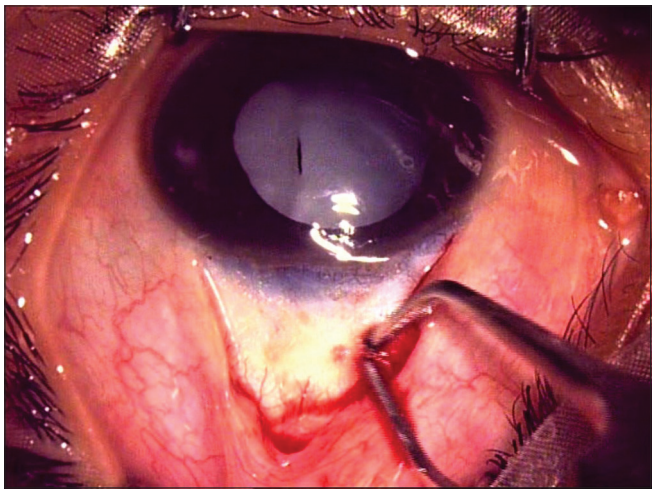

Figure 2: Adequate scleral cautery

It is shown that as the wound heals, progressive flattening occurs along the meridian in which the wound is centered.[13]

Gills and Sanders[14] concluded that corneal astigmatism is directly proportional to the cube of the length of the incision, and inversely proportional to the distance of the incision from the limbus.

Koch[15] described the "incisional funnel", outlining the relationship between incision length, shape, and distance from the limbus with the induced astigmatism. He explained the concept of an astigmatically neutral zone. The funnel represents an imaginary safe area where incision of any length can be placed with minimal SIA.

Size/Length

Size or length of the incision is defined as the straight-line distance between its two ends. It has been shown that while an incision of <3 mm is too small to alter the astigmatic profile appreciably, larger incisions cause more flattening, the degree of which increases with increase in incision size.[6,7]

Burgansky *et al*.[11] evaluated postoperative corneal astigmatism using 6-mm, 6.5-mm, and 7-mm incisions. They observed a mean SIA of 0.60 ± −30 diopter (D) for 6-mm incision, 0.75± −0.67 D for 6.5-mm incision and 1.36± −0.77 D for the 7-mm incision group, using vector analysis. They reported a statistically significant increase in mean SIA in the 7-mm incision group as against the 5-mm incision group (P = 0.002), and hence they advocated suturing of 7-mm incisions.

The incision size in MSICS also varies as per the hardness of the cataractous lens, being larger for grade IV sclerotic cataracts. Longer incisions and narrower tunnels are also preferred in cases with lower endothelial cell counts and in hypermature cataracts with doubtful zonular stability to minimize anterior chamber manipulations and facilitate easy nucleus delivery.

Smaller incisions require the surgeon to fragment large nuclei inside the scleral pocket before removing them. This is usually practiced in the modified Blumenthal method of nucleus delivery.[16,17]

However, the incision must be large enough to allow the intraocular lens (IOL) optic to pass through easily without traumatizing the tunnel. Commonly, an incision size of 5–6 mm is used for softer cataracts, increasing to 7–8 mm for harder nuclear cataracts.

Shape and configuration

The configuration of the external incision greatly influences postoperative wound stability and SIA. Various different shapes of external incision have been described [Fig. 3].

Smile Incision: This is a curvilinear incision that runs parallel to the limbus. It is easy to make but is the least preferred incision today since it results in significant flattening and is against the rule astigmatism. This incision mostly falls outside the astigmatism neutral incisional funnel.

Straight incision: This is a short and easy-to-make incision that may be astigmatism neutral if made posterior enough such that it falls within the incisional funnel. However, such

a posterior incision would need a wider tunnel and greater manipulation. It usually induces moderate astigmatism after surgery, if placed about 2 mm posterior to the limbus.[17]

Frown/Curved opposite to limbus: Singer[18] first described the frown incision in 1991, curved opposite to the natural limbal contour. He proposed that since the ends are curved away from the cornea, the wound would be more stable with minimum slide and hence lesser SIA. The frown incision is well suited for MSICS, with less SIA and a low tendency for wound-edge separation.[18,19]

Blumenthal side cuts: This is a straight incision with oblique cuts at both ends. This provides a large tunnel with minimal SIA.

Inverted V/Chevron: This incision was first described by Pallin,[20,21] as one in which two straight radial incisions converge and meet 2–3 mm away from the limbus. It induces minimum astigmatism and offers the longest total incision length for the same distance between its two end points. When the nucleus passes through the sclero-corneal tunnel, the incision assumes an oval shape. The maximal circumference of this oval opening is larger in the chevron incision due to longer incision length facilitating the delivery of a large nucleus. Furthermore, the fulcrum of the V provides easier access to the anterior chamber for instrument manipulation, and the termination of the scleral tunnel entry posterior to the cornea lessens the likelihood of corneal folds that may interfere with visualization during surgery.

Jauhari *et al*.[22] compared the SIA in various incisions in MSICS. They concluded that the mean SIA was minimum with inverted V/chevron incision (−0.88 ± 0.61 D × 90°) and maximal with straight incision, and difference between both the groups was statistically significant.

These findings were well supported in the study by Randeri *et al*.[23] in 2008 which concluding that 57.1% of patients showed astigmatism of <1 D in the chevron incision group. They attributed this to the triangular configuration of the chevron incision which is geometrically more stable, thereby causing minimal sliding of the tips of the incision. In their central frown incision group, most patients (42.9%) had an SIA between 1.25–2 D.

Location of external incision/Distance from the limbus

Keeping in mind Koch's incisional funnel, it's easy to see that the more the distance is of the external incision from the limbus, the lesser is the SIA. On the other hand, incision making and maneuverability become difficult as we go further from the limbus. Hence the ideal distance is around 2–3 mm behind the limbus.

Site of incision

Nowadays, all techniques of cataract surgery are being modified to give the best uncorrected visual acuity and early rehabilitation.

Classically, MSICS has been done using a superior sclero-corneal tunnel. In superior incisions, the weight of the eyelid and the effect of gravity tend to create a drag on the wound, further increasing the flattening effect caused by it. A temporal incision, on the other hand is free from such effects. Additionally, it is farther from the visual axis, making it more astigmatically neutral.[10,24]

It has been seen that with age, there is a gradual increase in against-the-rule (ATR) astigmatism. The flattening produced by a superior MSICS incision further adds to it. On the contrary, with-the-rule (WTR) astigmatism produced by a temporal incision helps to neutralize the pre-existing ATR astigmatism. Lastly, laterally placed incisions stabilize faster due to the

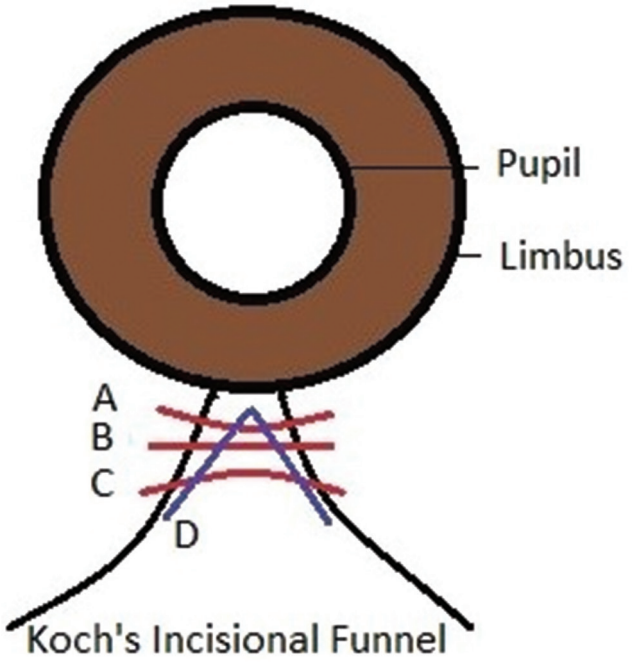

Figure 3: Koch's incisional funnel. A: Smile incision. B: Straight incision. C: Frown incision. D: Chevron incision

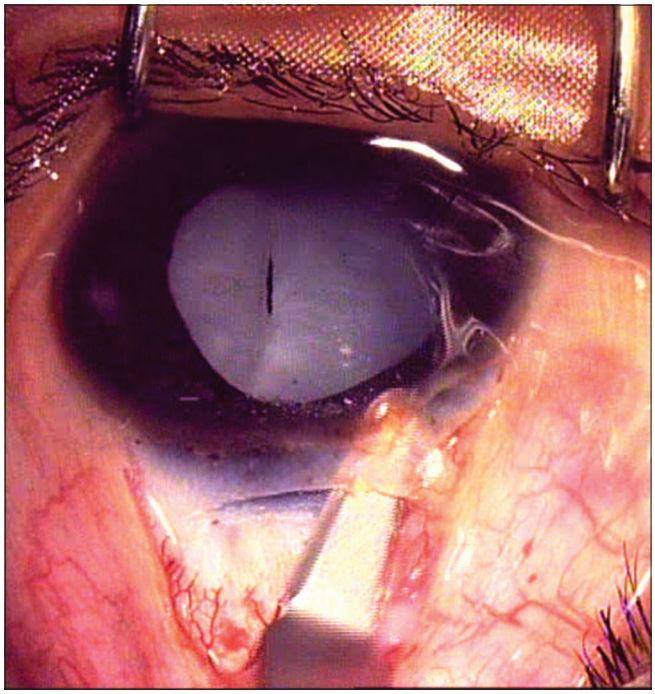

Figure 4: Appropriate depth of tunnel based on partial visualization of crescent knife

peculiar limbal anatomy of the temporal area. Kimura *et al*.[25] postulated that the arrangement of scleral fibers may also contribute to achieving a tight and least-astigmatic tunnel with an oblique superotemporal incision.

Gokhale and Sawhney,[24] in their study, compared the astigmatism induced by a superior, supero-temporal and temporal incision in MSICS. In all groups, the surgeon made a 6-mm frown incision 1.5 mm from the limbus. They observed that the postoperative astigmatism was highest in the superior incision group (1.45 ± 0.94 D), with an SIA of about 1.28 D at 2.9° (vertical flattening). Postoperative astigmatism in the superotemporal and temporal groups was 0.43 ± 0.27 D and 0.67 ± 0.65 D, respectively, with an SIA of 0.20 D at 23.7° in the superotemporal group, and of 0.37 D at 90° (vertical steepening) in the temporal incision group.

Mallik *et al*.[26] conducted a prospective study on a total of 108 eyes, assigning the ones with steeper vertical keratometry readings to the superior incision group, while those with horizontal steepening in the temporal incision group based on the assumption that some flattening of the meridian occurs on which the incision is given. They used a triplanar, frown-shaped incision, 6.5 mm in length, placed 1.5–2mm posterior to the limbus. No sutures were used. The mean SIA was found to be 1.45 ± 0.74 D in the superior incision group, while it was 0.75 ± 0.407 D in the temporal incision group. The difference between the two was statistically significant ($P < 0.001$), with the superior incision inducing 48.3% more astigmatism. Hence, they concluded that MSICS with temporal approach provided better stability of refraction, with significantly less SIA than the superior approach.

A study by Sekharreddy *et al*.[27] showed that the temporal MSICS induced lesser astigmatism compared to the superotemporal approach. However, unaided postoperative visual acuity was comparable and good in both the groups. Furthermore, Hoovayya[28] reported that MSICS performed with superotemporal scleral incision in comparison with superior scleral incision produced significantly less SIA with better stabilization of refraction.

Temporal incisions offer additional advantages like preservation of superior conjunctiva for future filtering surgery if needed, ease of approach to incision site, and avoidance of bridle sutures and resultant iatrogenic ptosis. There was a fear of increased infection as the incision is on the exposed part of the bulbar conjunctiva unlike the superior site that is protected by the upper lid. But a large series by Zawar *et al*.[29] demonstrated its safety and efficacy.

Depth of the scleral incision

Ideally, the external scleral incision should be about one-half to two-thirds of the scleral thickness, or about 0.3 mm deep. Superficial incisions run the risk of button-holing or tearing of the scleral flap. Deep incisions on the other hand, can cause disinsertion of the sclera, ciliary body injury, sagging down of the lower lip of the incision, a greater SIA (ATR) due to greater wound instability, and scleral flap recession with greater flattening of the cornea in the incisional meridian.[27] A rough estimate of the depth of the incision can be made by assessing how clearly the crescent knife is visible while dissecting [Fig. 4].

Sclero-corneal tunnel

After making the external incision, a sclero-corneal tunnel is dissected in conventional MSICS. The tunnel extends into the clear cornea, about 1 mm ahead of the vascular arcade. The width of the corneoscleral tunnel is the distance between the external scleral incision and the internal corneal entry. It should be ≥4 mm in size.[6,9]

These scleral tunnels are ideally supposed to be self-sealing. Also, they provide a greater wound healing surface, and thus are considered to be more stable from the refractive standpoint.[9]

In addition to the sclero-corneal tunnel, most surgeons dissect additional pockets at the corners. These pockets help to enlarge the internal opening of the tunnel by up to 25%, thereby helping accommodate larger and harder nuclei.[9] All scleral pocket incisions offer faster healing, greater stability, early visual restoration and superior astigmatism control.

Internal incision

This is the entry through the cornea into the anterior chamber. Both the location and the length of the internal incision can affect the SIA. An internal incision of >3 mm or one which disturbs the internal corneal alignment due to other factors (like sutures) is most likely to lead to SIA. Uniplanar, direct incisions made just anterior to Schwalbe's line are not self-sealing and would require suturing. Valvular incisions, which finally enter the anterior chamber around 2–3 mm ahead of Schwalbe's line, through a beveled wound create a corneal lip that rises up to close the wound as soon as the pressure in the chamber builds up. Valvular, self-sealing wounds have been shown to be the most physiological and stable.[30]

While making the internal incision, the surgeon must ensure that the Descemet membrane (DM) is cut in a very clean and regular manner using sharp instruments and in a straight line to minimize scarring and SIA. While making the cut, if the keratome is elevated too much it generally results in a smile-shaped incision whereas placing it downwards on the sclera results in a frown-shaped cut in DM. Blunt instruments run the risk of causing Descemet stripping or irregularity.

Few additional points to be considered while wound construction are

1. Pre-existing astigmatism: Up to a certain extent, wounds can be modified to minimize the pre-existing astigmatism for better postoperative visual acuity. Following the above-mentioned principles, Palanisamy *et al*.[31] conducted a study wherein they attempted to reduce the pre-existing ATR astigmatism in patients undergoing MSICS surgery. They concluded that a 6–7-mm, temporal, curvilinear incision (parallel to the limbus) provided maximum reduction in pre-existing astigmatism, and significantly better uncorrected visual acuity postoperatively. Hence, this may be an alternative to performing phacoemulsification without a toric IOL, especially in resource-poor settings.
2. Preoperative status of the cornea and sclera:
   - In patients with decreased endothelial counts and hard nuclei, we prefer longer external wounds and shorter tunnels for minimal manipulation and ease of nucleus delivery. A suture may be placed to minimize incision.

- In patients with severe scleral thinning or in diseases like ocular cicatricial pemphigoid (OCP)/Steven–Johnson Syndrome (SJS), high myopia, healed scleritis, and various connective tissue disorders, limbal or corneal incisions are preferred. Corneal tunnel incisions are also recommended in cases of pre-existing filtering blebs. Contraindications to corneal incisions are the presence of radial keratotomy scars extending to the limbus, peripheral ulcerative keratopathy, and advanced endothelial dystrophy.[32]

3. Denoyer *et al*.[33] suggested that in addition to the incision size, biomechanical properties of the cornea, like corneal hysteresis, also modulates SIA and optical changes. Hence the biomechanical features of the cornea should be taken into account preoperatively to better predict the refractive outcomes of cataract surgery.
4. The scleral bed should be dried with a cotton swab since making incision on a wet scleral bed can lead to splaying of scleral fibers, leading to postoperative irregular astigmatism.[34] The incision should be made in one pass using a sharp blade.
5. The anterior chamber should be maintained while dissecting the tunnel for ease of dissection and to achieve a regular smooth dissection.
6. A study by Sharma *et al*.[35] compared the difference in postoperative SIA amongst the different techniques of nucleus delivery employed during MSICS. They reported a mean SIA of 1.28 ± 0.72 D at 90° and there was no significant difference between the techniques.
7. Singh *et al*.[36] in their review suggested that in using smaller and tunneled incisions located temporally, the astigmatism caused by MSICS could be reduced to a great extent and thereby improve the uncorrected visual acuity of MSICS in the short-term as well.

Effect of sutures

Sutures help to hold wound edges in apposition and facilitate healing. With the introduction of better cataract surgical techniques, there came in new suture types microneedles and better suturing techniques which offered better control while suturing, with minimal tissue damage and inflammation and thereby minimizing SIA.

In case there is any doubt about the self-sealing effect of the incision, it should be sutured. Premature entry, ragged irregular tunnels, and wounds with very large external openings (>7 mm) should be sutured for postoperative stability and to prevent wound leak. Suturing is also a must in combined surgeries, severely obese patients, patients with a short neck, chronic cough, and in very young children.

Sutures induce astigmatism by altering the alignment of the internal corneal lip. All sutures induce some degree of immediate steepening that decreases with time as the suture loses strength and the wound remodels. The astigmatic effect of sutures has been extensively studied by Van and Waring.[37] The closer the suture is to the center of the cornea, the more steepening it will induce. Tighter and deeper sutures with longer bites and a greater number of sutures, will cause a greater WTR astigmatism.

Radial sutures pull the wound's edges to a new, non-physiological position, disturbing the internal alignment and inducing significant astigmatism. Horizontal sutures, on the other hand, lie tangential to the limbus and simply hold the roof and the floor together. They don't alter the corneal curvature significantly and induce minimal astigmatism.

Infinity/figure of 8 suture is one of the most preferred suturing techniques. An infinity suture has both horizontal and radial components. It gives a good wound apposition with minimal SIA. Eslami *et al*.[38] found postoperative SIA to be smaller in the group with infinity suture as opposed to the group with horizontal sutures. Agrawal[34] also recommends using infinity sutures for wound closure after MSICS.

SIA also depends on the suture material being higher with sutures like polypropylene, which is a synthetic material that does not degrade over time. Silk and nylon, on the other hand, decay faster and thus induce lesser long-term astigmatism. When these sutures are used, there occurs a gradually progressive flattening of the wound meridian that continues for years after surgery.

Masket[39] described a horizontal anchor suture that created physically stable and watertight incisions with minimal transient WTR astigmatism for all groups.

Conclusion

- In general, wound healing induces flattening and ATR astigmatism.
- A properly constructed scleral tunnel is self-sealing, increases the surface area for healing, and provides greater wound stability, thereby decreasing SIA.
- Longer and more anteriorly placed incisions induce more SIA.
- Chevron or frown-shaped incisions are more astigmatic neutral.
- Infinity sutures are preferred where one is needed to minimize SIA.
- Wound construction in MSICS can be modified on a case-by-case basis to tackle pre-existing astigmatism to some extent and obtain the best possible quality of vision.

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Conflicts of interest

There are no conflicts of interest.

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