Management of Pre-existing Astigmatism in Phacoemulsification

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List of abbreviations

AK: Astigmatic Keratotomy

ARC-T: Astigmatism Reduction Clinical Trial

ATR astigmatism : Against-The-Rule astigmatism

BCVA: Best Corrected Visual Acuity

BENT incision: Between Nine and Twelve o'clock incision

CCI: Clear Corneal Incision

CRIs: Corneal Relaxing Incisions

D: Diopters

ECCE: Extracapsular Cataract Extraction

FDAK: Full-arc Depth-dependent Astigmatic Keratotomy

ICCE: Intracapsular Cataract Extraction

IOL: Intraocular lens

LRIs: Limbal Relaxing Incisions

MVR : Micro-vitreoretinal blade

OCCIs: Opposite Clear Corneal Incisions

PAR Corneal topography system : Posterior Apical Radius Corneal Topography system

PEA: Pre-existing Astigmatism

PMMA lens implants: Polymethyl methacrylate lens implants

RLE: Refractive Lens Exchange

SIA: Surgically Induced Astigmatism

Sim K: Simulated K-reading

TOP maps: Total Optical Power maps

UCVA: Uncorrected Visual Acuity

VCI: Vertical Corneal Instability

WTR astigmatism: With-The-Rule astigmatism

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Introduction

Distinct vision without the need for eyeglasses or contact lenses has been one of mankind's goals. Advances in the technique of modern cataract surgery have created a new opportunity to provide sharp uncorrected vision for patients who undergo cataract surgery. Whereas most patients who are submitted to sutureless cataract surgery have excellent unaided vision postoperatively, patients with significant pre-existing astigmatism (PEA) cannot achieve the same results without correction of their cylindrical error.

Improved spherical and improved spherical and astigmatic outcomes are now well-recognized benefits of modern small incision cataract surgery. In fact, the term **refractive cataract surgery** (reducing pre-existing astigmatism simultaneously with cataract surgery) has grown in recent years. Available options include a clear corneal cataract incision along the steepest meridian with or without astigmatic keratotomy (AK), toric intraocular lens (IOL) implantation, opposite clear corneal incisions (OCCIs) and limbal relaxing incisions (LRIs) ***(Akura et al.,2000).***

The most basic approach for reducing PEA during cataract surgery is placement of the incision along the steepest corneal meridian taking advantage of the wound induced flattening. With small incision, the flattening is insufficient to correct existing astigmatism more than 1 diopter (D); moreover centering the incision on certain meridian is technically difficult ***(Matsumoto et al., 2001).***

The astigmatic reduction effect of clear corneal incisions (CCIs) is well documented. After CCIs, corneal topographic maps reveal that localized flattening of cornea central to the incision immediately occurs. Therefore, if the CCI is repeated diagonally opposite the initial incision, and if both incisions are placed on the steep meridian, symmetry will occur in the flattening of the steep meridian ***(Vass et al., 1996.*** This is the concept of opposite clear corneal incisions (OCCIs) proposed by Rosen. Obviously, the penetrating nature of OCCIs raises a question about their safety ***(Rosen, 2000).***

Toric IOL implantation has recently become available as a method of correcting PEA. This approach has the advantage of excellent optical quality but postoperative rotation of the toric IOL is a main concern. Leyland and co-authors reported that 18% of IOLs rotated more than 30 degrees ***(Leyland et al., 2001).*** An additional drawback to the use of toric IOLs is that cylinder adds of only 2.00 D and 3.5 D are currently available which correct 1.40 D and 2.30 D of astigmatism at the corneal plane respectively ***(Wang et al.,2003).***

Limbal relaxing incisions (LRIs) appear to have advantages over other different maneuvers. They cause less distortion and irregularity on corneal topographies and less variability in refraction. As they are placed at the limbus, they provide earlier stability in postoperative vision and carry a lower risk of inducing glare and discomfort. Precise placement on the axis is not as critical as in arcuate keratotomy because the incisions are longer and more peripheral. They are also more forgiving for incision's depth than arcuate keratotomy and are easier to perform. However, their results in correcting PEA are inferior to arcuate keratotomy ***(Muller-Jensen et al., 1999).***Budak and co-authers report that regression in astigmatic correction mostly occurs in eyes with more than 3.5 D of astigmatism and it mostly occurs between the first and third postoperative months ***(Budak et al.,1999).***

Arcuate keratotomies (AKs) are similar to radial keratotomies (RKs). They often create wounds that do not heal thus reducing PEA. AK incisions are placed within 3.0 to 3.5 mm from the center of the cornea ***(Akura et al.,2000)***.

Aim of the work

This study is carried out to evaluate three surgical incisions in correcting pre-existing astigmatism during phacoemulsification surgery: planned clear corneal incision along the steepest meridian, clear corneal cataract incision together with opposite clear corneal incision and clear corneal cataract incision together with astigmatic keratotomy.

Optical characters of the cornea

In the human eye, the cornea comprises approximately one sixth of the external surface of the eye and is responsible for two thirds of its refractive power. The ability of the cornea to refract light accurately depends not only on its clarity but also on the regularity and parallelism of its refractive surface.

Corneal zones:

Corneal shape is usually described as being aspheric. Typically, the central cornea is about 3 diopters (D) steeper than the periphery, something known as **the positive shape factor.** Clinically, the cornea is divided into zones that surround a fixation line and blend into one another. The central zone, of 1 – 2 mm in diameter, closely fits a spherical surface. Adjacent to the central zone is the paracentral zone, which is a 3 – 4 mm doughnut with an outer diameter of 7 – 8 mm. It represents an area of progressive flattening from the center towards the periphery. Together, the paracentral and central zones constitute the apical zone as used in contact lens fitting. The central and paracentral zones are primarily responsible for the refractive power of the cornea. Adjacent to the paracentral zone is the peripheral zone with an outer diameter of approximately 11 mm; then, the limbus with an outer diameter of approximately 12 mm.

The peripheral zone is also known as the transition zone as it is the area of greatest flattening and asphericity of the normal cornea. The limbal zone lies adjacent to the sclera and is the area where the cornea steepens prior to joining the sclera at the limbal sulcus. ***(Krachmer et al.,1997)***

The optical zone is the portion of the cornea that overlies the pupil. Physiologically, it is limited to 5.4 mm because of the Stiles-Crowford effect. The corneal apex is the point of maximal curvature typically temporal to the center of the pupil. The corneal vertex is the center of keratoscopic image that does not necessarily correspond to the point of maximal curvature at the corneal apex. ***(Leibowitz and Warning,1998)***

Central optical zone

The central optical zone of the average cornea has an anterior curvature of approximately +48.83 diopters (D) (radius 7.70 mm) and a semi rigid aplanatic posterior curvature of approximately -5.88 D (6.88 mm). This central zone is 4 mm in diameter and approximately 0.55 mm thick, and its anterior and posterior surfaces are parallel.

The radius of curvature of the anterior and posterior corneal surfaces and the index of refraction of the surrounding media determine its refractive power. Bending of the light is greatest when the change in index of refraction is greatest. The change from air to cornea is greater than that of the posterior surface of the cornea in contact with aqueous humor. The anterior surface of the cornea therefore is the most important refractive surface of the human eye. (***Troutman and Buzard, 1992).***

The refractive power is inversely proportional to the radius of curvature. All keratometers and keratoscopes measure the radius of curvature of the anterior surface of the cornea. Conversion of the radius of curvature to corneal power is made according to the formula:

$$P = \frac{(n2 - n1)}{\mathbf{R}}$$

Where:

P= Power in diopters

n 1= Index of refraction in air

n2 = Index of refraction of the cornea

R = Radius of curvature of the cornea

Most keratometers use the number 1.3375 as the index of refraction of the cornea **(Michaels,1985).**

Peripheral support zone and corneal optical ring

The corneal thickness progressively increases from 0.55 mm at the optical zone to about 1 mm at the limbus, ***the corneal optical ring.***

This ring corresponds roughly to the so-called surgical limbus and is characterized by curvature and tissue differences both distal and peripheral to it. A cataract incision 3 to 4 mm peripheral to this corneal ring (e.g. scleral tunnel) will have a minimal effect on the corneal curvature. In contrast, an incision made onto the corneal optical ring (surgical limbus) will induce a sometimes severe, always unstable, residual corneal astigmatism. A clear corneal cataract incision inside the ring can induce astigmatism. However, if it is accurately closed in its vertical dimensions, its effect on the corneal curvature is more predictable and stable than a limbal incision. In addition, it can be more readily modified, when it is necessary, to correct a preexisting astigmatic band than can a scleral tunnel incision.

The peripheral support zone functions primarily as a semi-rigid aplanatic support zone ending at the limbus. Any surgical modification of this peripheral support zone will directly affect the curvature of the central optical zone. Until recently, peripheral support zone curvatures could not be measured quantitatively. Now this peripheral area can be measured by one of several computerized topographic corneal mapping systems.
(Troutman and Buzard,1992).

Corneal shape

The visually significant area of the corneal surface is approximately the area corresponding to the size of the pupil. The diameter of the pupil decreases with age, thus a large variations exist between people in any age group.***(Maguire et al.,1987)***

The average anterior and posterior corneal powers are + 48.6 D and – 6.8 D respectively. To simplify it in clinical practice or in keratometer , a substitution with one refractive surface with the resulting corneal power of 42 - 44 keratometric diopters is often used. The average cornea changes little with age. It flattens about 0.5 D by the age of 30 years and steepens about 1 D by the age of 70 years.***(Rubin,1997)***

The normal cornea is prolate in shape i.e. steeper in the center than in the periphery. Oblate corneas are flatter in the center than in the periphery.***(Fedoral et al.,2006)***

Principles of astigmatism

Astigmatism is an ocular condition in which a point source of light, after passing through the optical system of the eye, is not focused as a point on the retina or any other plane. It is usually associated with spherical refractive errors. Astigmatism occurs because of unequal refraction of the light by the optical system of the eye in different meridia. Astigmatism may be induced by an error of curvature, of centering, a change of refractive index or by tilting. Curvature astigmatism is of primary interest to corneal and refractive surgeons. Curvature astigmatism is present in small degrees in just about everyone.***(Troutman and Buzard, 1992)*** .

Regular Astigmatism occurs when the steepest and flattest meridian are at right angle to each other and the blurred retinal image produced can be corrected by an appropriate cylindrical correction. Oblique astigmatism ,on the other hand, is a form of regular astigmatism in which the steepest and flattest meridia are more than 10 degrees away from the horizontal and vertical meridian.***(Duke-Elder S,1970)***

Simple myopic astigmatism occurs when the optical system of the eye is emmetropic in one meridian and myopic in the other. Compound myopic astigmatism occurs when the steepest and flattest meridian are focused anterior to the retina.

In simple hyperopic astigmatism, one meridian is emmetropic and the other is hyperopic. Compound hyperopic astigmatism occurs when both meridia are focused posterior to the retina. In mixed astigmatism, one meridian is focused anterior and the other focused posterior to the retina.

Irregular astigmatism is that type of astigmatism in which the amount of astigmatism changes along a given meridian and varies from one meridian to the other. It is usually secondary to an irregular corneal surface and the blurred image produced on the retina cannot be corrected by a cylinder.

In young people, the cornea is typically more curved in the vertical meridian, flattening slightly occurs with age, presumably from pressure of the upper lid. When the steeper meridian is vertical, the type of astigmatism here is said to be ***with the rule***

astigmatism. Conversely, when the steeper meridian is horizontal, it is termed ***against the rule astigmatism*** **(*Troutman and Buzard,1992).***

The posterior corneal surface also contributes to astigmatism. The astigmatic error of the posterior corneal surface is 0.25 to 0.50 D, and the principle meridian are usually oriented opposite to those of the anterior surface. Thus astigmatism arising from the anterior surface partially neutralizes that arising from the posterior surface.***(Poon and Taylor,1998)***