Introduction

Approximately 70% of the general cataract population having at least 1.00 D of astigmatism, and approximately 33% of patients undergoing cataract surgery are suitable for treatment of preexisting astigmatism ***(Nichamin, 2006; Comez and Ozkurt, 2012).***

Today, cataract surgery is regarded as a refractive surgery, mainly aiming emmetropia, and this makes eliminating corneal astigmatism is critical ***(Nordan, 1995; Comez and Ozkurt, 2012).***

There are many techniques for treating the pre-existing corneal astigmatism during cataract surgery like on axis phacoemulsification incision with or without opposite clear corneal incision, relaxing corneal incisions, toric intra ocular lens implantation and laser vision correction ***(Azar, 2008) (Bhalla et al., 2016).***

During phacoemulsification it is possible to reduce the pre-existing corneal astigmatism by creating a clear corneal phacoemulsification incision at the steep corneal axis, to profit the flattening effect of the incision which can help to reduce the astigmatism along that axis. It is possible to add more relaxing effect by modifying the width (The larger the incision the more relaxing effect it will induce), type (limbal parallel incision has more relaxing effect than straight incision, and straight incision has more relaxing effect than frown incision), shape and the localization of the incision. This approach is usually sufficient for correcting astigmatism less than 1 D in most eyes ***(Armeniades et al., 1990; Comez and Ozkurt, 2012).***

But sometimes this technique may not be easy if the steep meridian is superonasal.

Another technique is by creating an opposite side clear corneal incision (OCCI), the corneal incisions here are made on opposite sites 180 degrees apart, on the steep meridian of cornea. It is based on the supposition that a healing tissue forms between those incisions which results with flattening of the cornea.

On the other hand, higher degrees of astigmatism is necessitating to use an alternative method like corneal relaxing incisions “CRI”, limbal relaxing incision “LRI”, astigmatic keratotomy “AK” ***(Comez and Ozkurt, 2012).***

Corneal relaxing incisions parallel to the limbus may treat slightly higher amounts of astigmatism (1-3 D), but it usually induces irregular corneal topography. CRIs can be single or paired, straight or arcuate.

Limbal relaxing incision appears to be a quick and easy technique, and since it is done at the limbus it appears to cause less post-operative refractive variability, and it also causes less topographic irregularity, with lower cost.

It is done by performing two small incisions at the limbus, that produce flattening effect on the meridian along which they are performed due to the tissue addition effect together with the steepening of the orthogonal meridian ***(Comez and Ozkurt, 2012).***

Astigmatic keratotomy is done by performing radial or transverse corneal incisions which can be straight, or arcuate. The incisions were done manually or with a machine keratome, but there are many limitations for both of these techniques like: imprecision, presence of skip lesions, and reproducibility of the incision depth and length, irregular astigmatism, corneal perforations, overcorrection and under correction.

The recent and more preferred technique for astigmatic keratotomy is the femtosecond laser technology. By this technique the desired shape, length of arc, and incision depth are all well controlled in astigmatic keratotomy. Many studies have reported higher predictability and lower complications rate with this technique ***(Daneshvar and Mian, 2012).***

Toric intra ocular lens (IOL) implantation during cataract surgery is another way for treating astigmatism. It is a reliable way for correction of moderate to high astigmatism, with the advantage of predictability.

Aim of the Work

To evaluate the efficacy and safety of on axis corneal incision with or without opposite clear corneal incision to correct preoperative corneal astigmatism during uncomplicated phaco-emulsification surgeries.

Chapter (1): Astigmatism

Astigmatism is defined as a meridian-dependent type of refractive error which is present in most human eyes, in which the incident parallel rays of light fail to focus as a single point on the retina to produce clear vision. Instead, a toric effect is introduced and the rays form a strum's conoid with two focal lines that are separated from each other by a focal interval ***(Elder, 1993) (Rabbets, 2007).***

Epidemiology:

Astigmatism (more than 0.5 diopters) is a common refractive error, accounting for approximately 13% of the refractive errors in the human eyes ***(Raed et al., 2007).***

It is commonly presented clinically, having prevalence rates of 30% or more depending on the age or the ethnicity ***(Saw et al., 2006) (Kaimbo and Kaimbo, 2012).***

The prevalence of astigmatism in Caucasians is ranged from 28% among individuals in their forties to 38% among individuals in their eighties. This prevalence is less in the Americans than Caucasians, and 20% higher in males than females ***(Katz et al., 1997).***

Different studies reported that 64.4% - 79.5% of patients undergoing cataract surgery had corneal astigmatism less than 1.50 D, and 22.2% - 27.9% patients had corneal astigmatism of 1.50 D or more ***(Ferrer-Blasco et al, 2009) (Khan and Muhtaseb, 2011) (Chen et al, 2013).***

Types of astigmatism

Total astigmatism can be divided into: corneal (or keratometric), lenticular, and retinal. Most of the astigmatism is corneal in origin. The lenticular astigmatism is usually a result of uneven curvature and different refractive indices within the lens ***(Abrams, 1993).***

Corneal Astigmatism

Astigmatism than occurs due to unequal curvature along the two principal meridians of the anterior cornea.

1. Regular astigmatism:

The two principal meridians are perpendicular to each other. The refractive power varies regularly from one meridian to the next, and each meridian has a uniform curvature at every point across the entire pupil. The corneal topography of regular astigmatism shows a symmetrical bow tie pattern ***(AAO, 2007).***

The regular astigmatism can be classified according to the direction of the axis into:

- With the Rule: the flattest meridian is nearer the horizontal than the vertical (90±30º) as shown in **Figure 1 A.**

- Against the rule: the flattest meridian is nearer the vertical than the horizontal (0±30º) as shown in **Figure 1 B.**

- Oblique astigmatism: the principal meridians are >30º from the vertical and the horizontal meridians as shown in **Figure 1 C.**

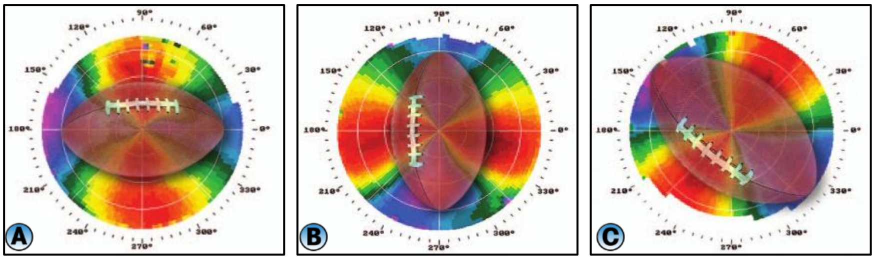

Figure (1): Presentation by football for: A with the rule, B against the rule, and C oblique astigmatism respectively ***(Gills, 2002)***

2. Irregular Astigmatism:

The two principal meridians are not perpendicular to each other, or there are other rotational asymmetries that are usually not corrected with conventional ophthalmic lenses.

Internal astigmatism

It can be due to irregular curvatures of the anterior and posterior surfaces of the lens, decentration or tilting of the lens, and differing refractive indices across the crystalline lens.

Regarding retinal astigmatism, from historical point of view, directional variability in photoreceptor arrangement was proposed as a source of astigmatism ***(Mitchelle et al, 1967)***; in other words, functional retinal elements may be more abundant or thicker in one axis than the other ***(Shlaer, 1937)***. More recently, a tilted retina was simulated and it was observed to manifest as some degree of cylindrical error ***(Flüeler and Guyton, 1995).*** This could be the result of unequal lengthening of the sclera in different meridians during axial growth.

Chapter (2): Diagnosis of astigmatism

Total astigmatism is measured by autorefractometer. Corneal astigmatism can be assessed by different methods like: Keratometry, Placido discs, corneal topography and tomography.

Lenticular astigmatism is calculated as subtraction of corneal one from total astigmatism.

Keratometry

A keratometer is a device that measures the radius of curvature of a small portion of the central cornea assuming it to be spherical, radially symmetrical, and with a constant radius of curvature. The radius is calculated using geometric optics with considering the cornea as a spherical reflecting surface, based on the fact that the front surface of the cornea acts as a convex mirror ***(Horner et al., 1998)***, although the cornea is described as ellipsoid (the true apical radius is steeper than measured, and steeper than the peripheral cornea).

Quantitative data in the standard keratometer are based on only 4 points in the central 3 millimeters ring mire of the cornea. Keratometry is not valid when high accuracy is required or peripheral areas should be measured, and when the cornea differs from being a spherocylindrical surface lens, the keratometer doesn’t measure it precisely.

There are two main types of keratometer: the manual and the automated keratometers.

1. Manual Keratometer:

Keratometer is based on 2 concepts: fixed image size with variable object size (fixed doubling, like Javal-Schiötz keratometer), or fixed object size with variable image size (variable doubling, like Bausch and Lomb keratometer).

In Javal-Schiötz Keratometer the doubling is fixed, and the separation of mires is varied by moving them symmetrically around a circular course approximately concentric with the cornea ***(Rabbets, 2007).***

In the traditional pattern one of the mires is green and the other is red, as shown in **Figure 2**, and they should be set an apposition to measure the steeper and flatter meridian (two position keratometer), and any overlap produces yellow. In off axis position regarding to the cornea, the black central line of one mire image will become out of alignment with its fellow on the other mire. Scissoring distortion may also be apparent.

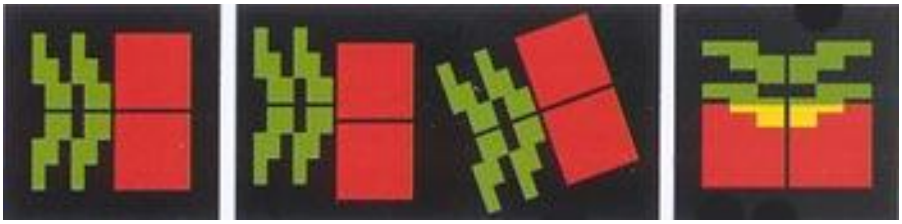

Figure (2): The mires of Javal-Schiötz keratometer.

Only central pair of images is used when measurements are made. When the two control images just meet, the scales associated with the mire separation indicate the correct corneal radius and diopteric power of the cornea. Radius of curvature first found in one meridian, then entire optical system rotated 90 degrees about its central axis. Measurement of radius of curvature in second meridian which is perpendicular to the first one is then made in similar way.

When the corneal astigmatism is present, there's overlapping of the mires or they may move further apart, each step of mire equals 1 Diopter of corneal power, thus the number of steps overlapped gives approximate degree of astigmatism. When oblique astigmatism is present, mires are horizontal, central bisecting lines of images are not aligned. The instrument is rotated until the control lines are aligned. Scale associated with instruments rotation indicates in degrees one meridian of oblique astigmatism. Corneal radius or power is then measures in this meridian and also in the meridian 90 degrees to it as usual ***(Eikenberry et al., 2010).***

Another keratometer which is commonly used is the Bausch and Lomb keratometer. Mire separation (the object size) is fixed here and the doubling is variable (the image size measured), it is typical one position keratometer ***(Rabbetts, 1998) (Eikenberry et al., 2010).***

In this keratometer a lamp blub is illuminating the circular mire, and there are three images of the mire seen in the eyepiece, a central image and two other images doubled in mutually perpendicular directions as shown in **Figure 3 A.** Unless in correct focus the central image appears slightly doubled as shown in **Figure 3 B**. There are plus and minus signs surrounding the circular mires which are used as measurement marks. When correct alignment of the meridian has been established, by adjusting the doubling the two radius settings can be made in sequence, when adjacent minus and plus signs are brought into exact coincidence. There’s also a fixation point for the patient that sees a reflection of his own eye.

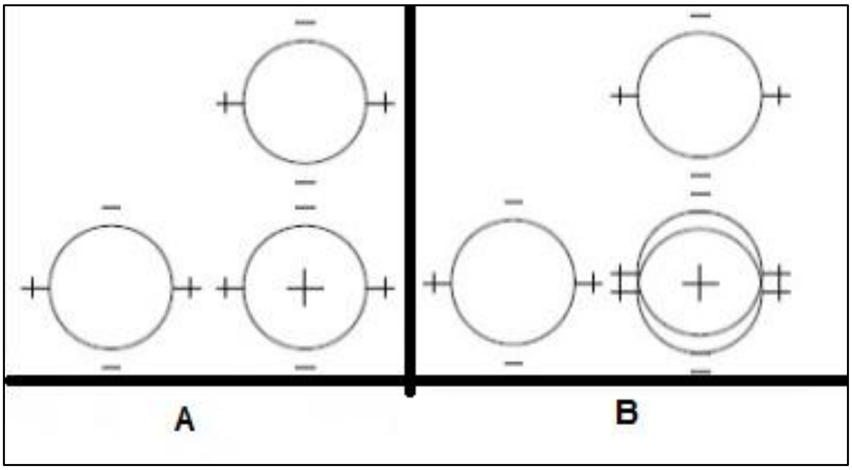

Figure (3): The mires of Bausch and Lomb keratometer.

The vertical misalignment of the plus signs indicates astigmatism as shown in **Figure 4 A**, when the horizontal lines of the plus signs appears continuous it indicates correct axis alignment is shown in **Figure 4 B**, and the measurement of horizontal meridian the horizontal measuring drum in the device should be turned to superimpose the plus signs, and when they are superimposed the drum should be left, as shown in **Figure 4 C**.

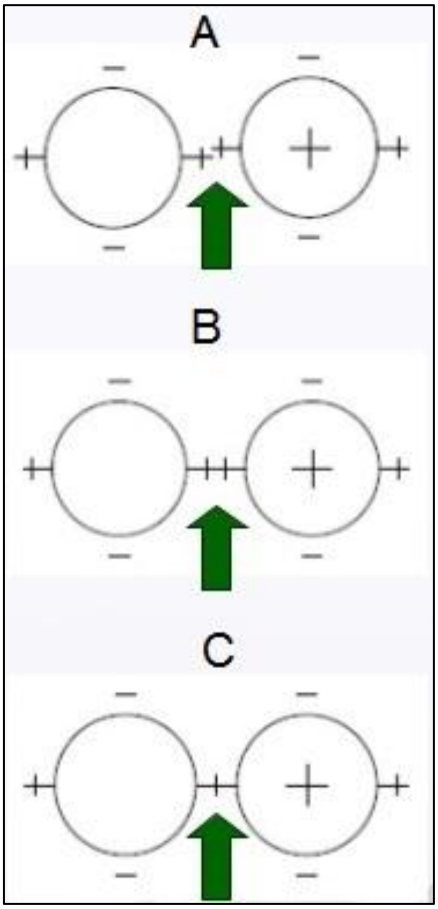

Figure (4): The horizontal meridian of astigmatism measurements.

And for vertical meridian astigmatism measurement the vertical measuring drum is turned until the minus signs are superimposed as shown in **Figure 5**, and if corneal astigmatism is present it is impossible to get both principal meridians in focus at one time.

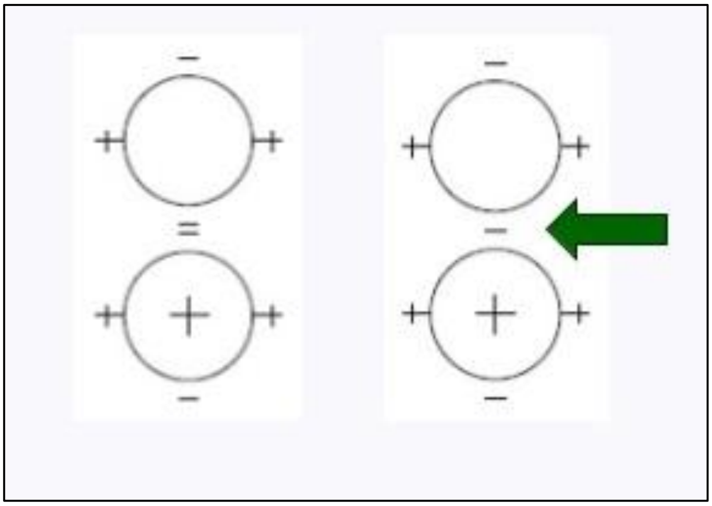

Figure (5): The vertical meridian astigmatism measurements.

Finally to interpret, the horizontal measuring drum measures the power established for the cornea in the meridians nearest to 0-180 degrees, and the vertical measuring drum measures the power established for the cornea in the meridian nearest to 90 degrees, and the difference between these two readings is the amount of corneal astigmatism, and if they are the same, there’s no measurable astigmatism ***(Eikenberry et al., 2010).***

2. Automated Keratometer:

It measures corneal curvature by projecting 3 beams of near infrared light on the cornea in a triangular pattern and that would be within an area of about 3 mm in diameter. After reflection, these beams are received by directional photo sensors that effectively isolate rays making an angle that is predetermined with the instruments optical axis. From the information provided by those 3 beams, the principal radii and meridians of the cornea can be calculated ***(Rabbets, 1998) (Eikenberry et al, 2010).*** It is usually combined with auto-refactor.

Computerized corneal Topography

There are two broad categories for the corneal topography: reflection based and projection based, which measures the corneal power from the center to about 5 mm from the center.

Reflection based methods:

Videokeratoscopy project a target that is illuminated, more complex than that of the keratometers, to generate an image that is reflected by the corneal surface which allows the investigators to quantitate the corneal shape information available in the keratoscope images.