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Corneal astigmatism in eyes undergoing phacoemulsification

Reda A. Mahdy, Zeiad M. Ali*, Basem Mohamed Ibrahim, Tamer Gamal Elsayed Mostafa

Ophthalmology Department, Faculty of medicine, Zagazig university hospitals, Zagazig, Egypt

Corresponding author: Zeiad Mohamed Ali

Email: Zeiad.moh.95@gmail.com

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Abstract:

Astigmatism is a refractive condition encountered commonly in clinical practice. This review presents an overview of research that has been carried out examining various aspects of this refractive error. We examine the components of astigmatism and the research into the prevalence and natural course of astigmatic refractive errors throughout life. The prevalence of astigmatism in various ethnic groups and diseases and syndromes is also discussed. We highlight the extensive investigations that have been conducted into the possible aetiology of astigmatism, however, no single model or theory of the development of astigmatism has been proven conclusively. Theories of the development of astigmatism based on genetics, extraocular muscle tension, visual feedback and eyelid pressure are considered. Observations and evidence from the literature supporting and contradicting these hypotheses are presented. Recent advances in technology such as wavefront sensors and videokeratoscopes have led to an increased understanding of ocular astigmatism and with continued improvements in technology, our knowledge of astigmatism and its genesis should continue to grow.

Introduction:

Astigmatism is a condition that exists when the surface of the cornea or crystalline lens is irregularly shaped. It is a form of refractive error that can be present alone or in combination with myopia and hyperopia. Its correction requires the use of cylinder lens power. **(1)**

The eye's total refractive astigmatism is a combination of corneal and lenticular astigmatism. Most astigmatism comes from the cornea. The average lenticular astigmatism is 0.5 diopters against-the-rule (ATR). The amount of lenticular astigmatism can be calculated by subtracting corneal astigmatism from the total astigmatism found by refraction. Since lenticular astigmatism is eliminated with extraction of the cataract only the corneal astigmatism is considered when planning cataract surgery. **(1)**

In a meta-analysis that looked at studies around the world from 1990-2016, the prevalence of astigmatism greater than 0.5 D in the world is estimated to be 40.4% (95% CI: 34.3%-46.6%) in adults over 30 years old and 14.9% (95% CI: 12.7-17.1%) in children under 20 years old. (**2)**

This makes astigmatism the most common refractive error in the world. Specifically for patients undergoing cataract surgery, a systematic review from 1996-2015 found there was preexisting astigmatism greater than 1.0 D in 47% of eyes[3]. In this review the prevalence of mild astigmatism (<1.5 D) ranged from 74.6-89.6%, moderate astigmatism (>1.5- <2.5 D) ranged from 8.1-14.9%, and significant astigmatism (>2.5 D) ranged from 2-6.8% in various countries around the world. (**3)**

Patients with 1.0 D or more of astigmatism are shown to benefit from correction during or after cataract surgery, as visual acuity can decline to 20/25 with 0.75 D and 20/40 with 1.5 D of astigmatism. (**4)**

In general, the goal when correcting astigmatism during cataract surgery should be a post-operative residual astigmatism of 0.5 D or less. **(4)** . Another metric that has been used to evaluate the success of astigmatism correction is independence from spectacles after cataract surgery, as the use of spectacles is correlated with a higher financial burden for the patient. **(3)**

Classifications of Astigmatism

In a spherical cornea or lens the curvature is the same in all meridians. When astigmatism is present there are two principal meridians. One with greatest curvature (steepest) the other with least curvature (flattest)

Regular astigmatism

Regular astigmatism exists when the two principal meridians are 90 degrees apart. Regular astigmatism can be fully corrected with a cylindrical lens. (**4, 5)** The great majority of astigmatism in eyes is regular. Regular astigmatism can be further classified into three types based on which meridian is the steepest.

- With-the-rule (WTR) astigmatism: The steepest meridian is vertical or within 30 degrees of the 90-degree meridian (between 60 and 120 degrees).(**5)**
- Against-the-rule (ATR) astigmatism: The steepest meridian is horizontal or within 30 degrees of the 180-degree meridian (between 0 to 30 and 150 to 180 degrees).(**5)** This type of astigmatism is more common in older patients, due to age related changes.
- Oblique astigmatism: The steepest meridian is not within 30 degrees of the horizontal or vertical meridians (31 to 59 degrees and 121 to 149 degrees). (**5**)

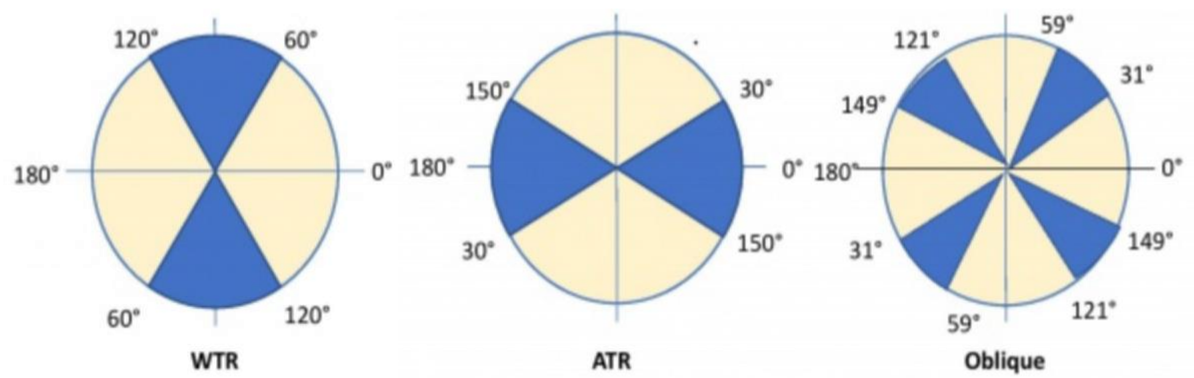

Fig. (1): Types of Astigmatism (**5**)

Irregular astigmatism

Astigmatism is termed Irregular when the two principal meridians of curvature are not 90 degrees apart or the corneal curvature is not axially symmetric. The orientation of the principal meridian, and thus, the amount of astigmatism changes from one point to another.**(5)**

Evaluation of Astigmatism

The different assessment methods available to the ophthalmologist to evaluate astigmatism are:

1) Refraction:

Refraction may be done objectively by retinoscopy, autorefractometer or it may be done subjectively. In cooperative patients, subjective refinement of refraction using a trial lens set is preferred**. (6)**

2) The Keratometry:

The keratometer, which was first described by Helmholtz in 1854 use illuminated object mires reflected from the cornea which acts as a convex mirror. Assuming a spherocylinderical cornea,the keratometer uses four reflected points (or two pairs) located at the centre of the cornea.The radius of curvature of the cornea along the meridian is determined by measuring the distance between the two points of a pair. **(7)**

There are two major clinical keratometers in use: Javal Schiotz ***(Haag-Streit)*** and Helmholtz ***(Bausch and Lomb)*** keratometers.

a- Javal Schiotz keratometer

b-Helmholtz *(Bausch and Lomb)* keratometers.

The limitations of the keratometer:

1. The keratometer measures only a small area of the cornea approximately **2.6: 3.7** mm thus; it does not give an accurate picture of the corneal periphery. **(7)**
2. The keratometer loses accuracy at high or low corneal powers**. (7)**
3. A patient's keratometer readings may depend on the instrument used, as a result of calibration differences**. (8).**

3) The Keratoscope:

Placido was the first who analyzed the corneal surface by keratoscope. In this technique a series of black and white concentric rings are projected onto the cornea. These rings are reflected by the convex mirror like corneal surface and are imaged. **(9)**

The keratoscope allows the analysis of the corneal curvature in zones both central and peripheral to those measured by the keratometer. The ring images over steeper regions of the cornea will be more closely spaced than those over flatter regions, a regular corneal surface will form uniform concentric images of the reflected surface, whereas an irregular corneal surface will produce distorted reflections.**(10)**

If corneal astigmatism is present to more than a minimal degree, it will change the reflected circles to an elliptical shape, with the steep axis of the cornea corresponding to the minor axis of the ellipse where images are closer together. Artifacts from tear film abnormalities, lid position, corneal pathology or any changes caused by the examiner's exerting pressure in an effort to keep the eyes open should be limited before the mires are inspected **(10)**

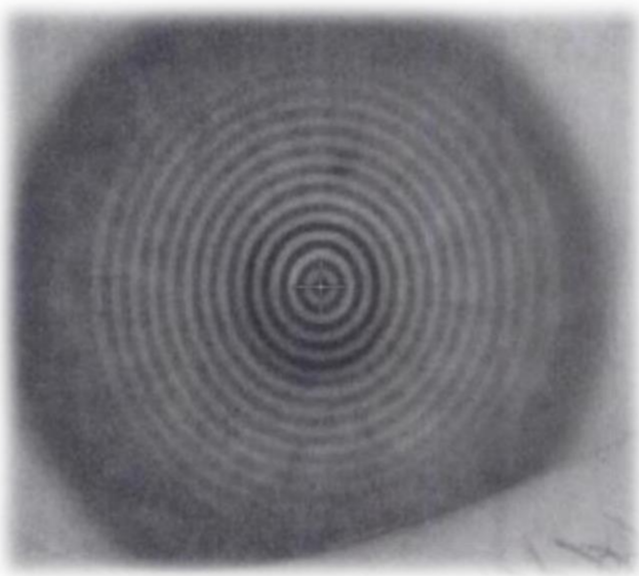

Fig. (2): Placido disc rings reflected off the cornea **(11).**

<u>4-Corneal topography:</u>

Corneal topography is a method of measuring and quantifying the shape and the curvature of the corneal surface.

The standard corneal topographer consists of three components:

1. A placido disc made up of multiple circles that can be projected onto the corneal surface.
2. A video camera capable of capturing the reflected image of these rings.
3. A computer with software to digitalize the resultant captured images.

Various topographic displays:

a- Axial (sagital) map:

To measure the refractive power of a point on the cornea, we have to draw a tangent on the surface of the cornea at this point, then we take the normal of the tangent which intersects with the anatomical axis of the cornea, this segment which pass through the point & anatomical axis is the curvature radius of the cornea at that point, and the same way refractive power of other corneal points could be measured. The computer displays these powers as a colored map utilizing colours to represent different diopteric values. Warm colours as red and orange show steeper areas whereas cold colours as blue and green represent flatter areas, the axial map gives a global view of the corneal curvature as a whole, its disadvantage is its tendency to ignore minor variations in curvature. ***(12)***.

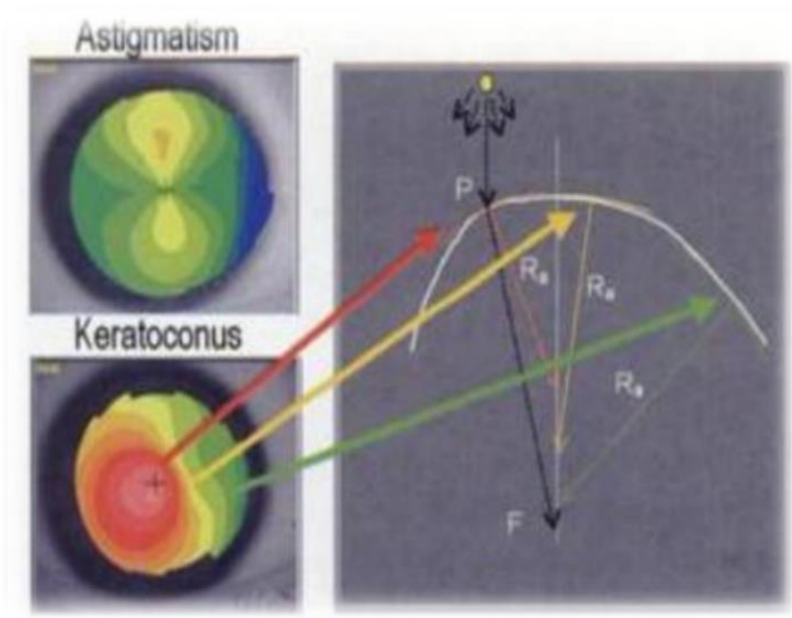

Fig. (3): The colors of each point in an axial map represent the power associated with a sphere centered on the VK axis **(12).**

b- Tangential (local or true) map:

This method uses circles tangential to the examined corneal surface at the points to be measured, The radius of the tangential circle is considered as the curvature radius, radii of circles differ according to surface changes, Geometrically, the specification of the tangent circles are more accurate than those of the tangent lines. Consequently, this method can highlight any irregularity in the cornea whatever small it is. ***(13)***.

c- Elevation map

The computer of the topography camera adjusts a reference surface for each cornea being captured; the computer considers all points above the reference surface as elevations, being displaced as positive value or warm colours, and considers all points below the reference surface as depressions, being displayed as negative values or cooler colours, the coincide points between the reference surface and the measured surface are displayed as zero. **(14)**

d- ***Refractive map***

It utilizes the measured diopteric power and applies Snell's law to describe the cornea's actual power. A refractive map compensates for spherical aberrations, as well as the aspheric contour of the cornea, the central portion of the refractive map is most important as this area overlies the pupil, so aberrations here almost invariably impact visual performance. **(15)**

e-Scaling

i-Normalized (relative) scales

This strategy subdivides the cornea into diopteric intervals based on its actual curvature range (usually 6 D range), actual colours are not specific to a diopteric value when using the normalized scale, but rather are relative to that particular patient's eye. **(16)**

ii- Absolute (standard) scales

Assigns a specific colour to each diopteric value, this strategy helps to directly compare images from different eyes. Clinically, it is probably best to use normalized (relative) maps when evaluating one particular eye, and use standard maps when comparing two different eyes or comparing the same eye over time**. (16)**

F-*Simulated keratometry display (sim K)*

Simulated keratometry measurements characterize corneal curvature in the central 3 mm area. The steep simulated K - reading is the steepest meridian of the cornea, using only the points along the central pupillary area within 3mm diameter. The flat simulated K-reading is the flattest meridian of the cornea and is by definition 90 degrees apart. These readings give an idea about the central corneal curvature which is visually most significant. **(17)**

g-Index of asphericity:

The index of asphericity indicates how much the curvature changes upon movement from the centre to the periphery of the cornea**,** normal cornea is prolate i.e becomes flatter towards the periphery with asphericity Q of – 0.26. **(18)**

Orbscan corneal topography system

Orbscan corneal topography system was based on the principle of measuring the dimensions of a slit-scanning beam projected on the cornea. The high-resolution video camera captures 40 light slits, 20 anterior and 20 posterior light slits, projected through the cornea similarly as seen during slit lamp examination. The instrument's software analyses 240 data points per slit and calculates the corneal thickness and posterior surface of the entire cornea. The anterior surface of the cornea initially was calculated in this manner.**(19)**

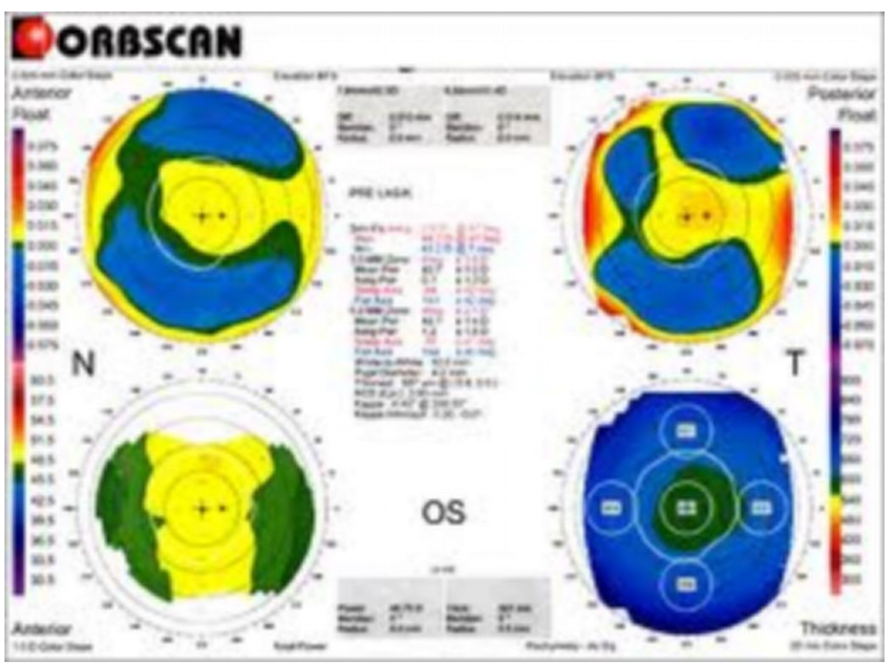

Fig. (4): Orbscan printout **(19)**

In clinical practice, Orbscan results are affected by the following factors (20).

- Eye movement.
- The presence of corneal abnormalities.
- Inability to detect interfaces as after LASIK.
- Longer time of image acquisition and processing.

The Pentacam Corneal topography System

It is the most recent, topography apparatus which provides a three-dimensional topographic map for the cornea by a rotating "Scheimpflug" camera performing series of slit photographs. This rotating process generates picture in three dimensions. The pentacam process takes less than two seconds; minute eye movements are captured and corrected simultaneously (20).

Scheimpflug principle

In 1904, Theodor Scheimpflug discovered that the depth of focus is generated when the planes within a camera intersect rather than be placed in parallel. **(21)**

In a typical camera, three imaginary parallel planes are present: the film plane, lens plane and focus plane. The image of the object placed in the plane of sharp focus will pass through the lens plane perpendicular to the lens axis, and fall on to the film plane. The depth of focus is limited in such a camera. In a Scheimpflug camera, the three planes are not parallel but intersect in a line, called the “Scheimpflug line”. The lens is tilted such that it intersects the film plane. Also, the plane of sharp focus passes through the Scheimpflug line. This will produce higher depth of focus and sharp, but distorted picture, which is then corrected by the device software. **(21)**

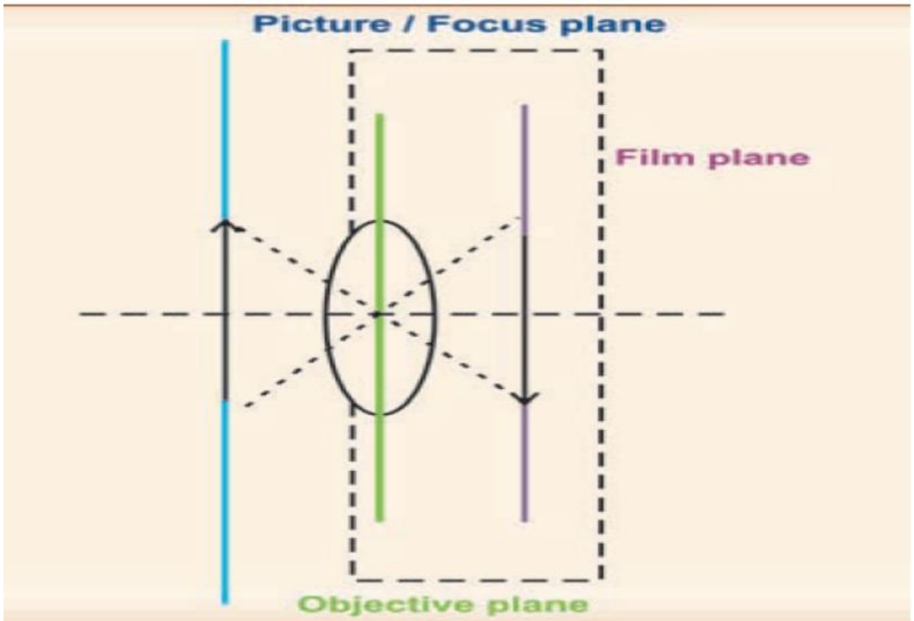

Figure (5): illustrates the image in the normal camera; the three planes (The picture plane, the objective plane and the film plane) are parallel. **(5)**

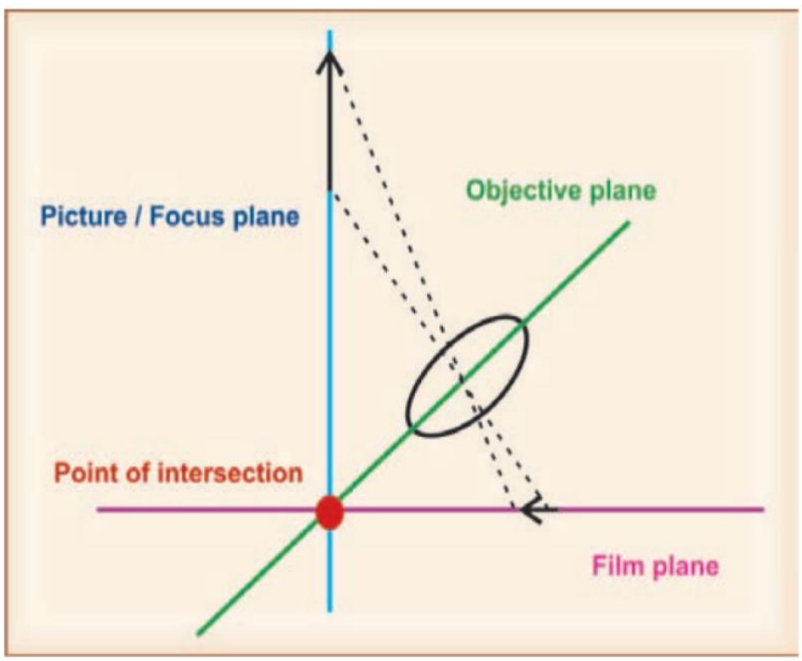

Figure (6): illustrates the Scheimpflug camera. The Scheimpflug law says: To get a higher depth of focus, move the three planes, provided that the picture plane, the objective plane and the film plane have to cut each other in one line or one point of intersection. The advantages of the Scheimpflug Camera are: higher depth of focus and sharp, but distorted picture. **(5)**

Scheimpflug cameras provide focused images from the anterior corneal surface to the posterior lens and transform them into a 3D model with their rotation capability. **(22)**

Types of Scheimpflug camera

The first Scheimpflug camera in ophthalmology practice was the Pentacam (Oculus Optikgerate GmbH). After Pentacam, a combination of Scheimpflug camera and Placido-disk topography system was introduced by Galilei (Ziemer Group). Recently 2 other devices containing a Scheimpflug camera and a Placido-disk topography system, the Sirius (Costruzione Strumenti Oftalmici) and the TMS-5 (Tomey Corp.), were developed. The Sirius acquires 25 Scheimpflug images and a Placido-disk image with 22 rings in a scanning process. Anterior surface data are calculated by merging Scheimpflug and Placido-disk images. Data for the internal structures (posterior cornea surface, anterior lens surface, and iris) are derived only from the Scheimpflug camera. **(23)**

A short-wavelength slit light (475 nm, blue light-emitting diode laser) is used by Scheimpflug camera. In short duration of two seconds, The camera is able to take 25 slit images of the anterior segment of the eye. Anterior segment 3D model can therefore be built providing valuable data. These data are corneal thickness, corneal topographic parameters, ACD, ACV, ACA, and other parameters. **(24)**

Sirius Scheimpflug-Camera is a combination of a placido disc topographer and 3D rotating Scheimpflug camera. It gives valuable data about the anterior eye segment such as ACA, ACD, ACV, CCT and corneal volume. Twenty-five Scheimpflug images are obtained in less than one second. These images are analyzed by the device software. **(25)**

Cataract incisions & surgically induced astigmatism

At present, cataract extraction offers great improvement for uncorrected visual acuity (UCVA) and best corrected visual acuity (BCVA). Postoperative astigmatism has remained an important obstacle to the achievement of the highest possible UCVA after cataract surgery. Postoperative astigmatism is a very complex clinical problem. The main determinants of its appearance are preoperative astigmatism as well as shape and length of AC opening, suturing technique and wound healing. **(26)**

Numerous factors are involved in surgically induced astigmatism (SIA). These factors include:

The site of the incision:

One of the important factors affecting the SIA is the site of the wound. It is agreed that the more posterior the incision is placed, the less is the SIA. This can be explained by the fact that the compressive vectors that are transmitted to the central cornea proceed anteriorly from the cataract incision site. **(27)**

The size of the incision:

Another factor that has a profound effect on the amount of SIA is the size of the incision. It is known that the more the cord length of the incision, the more is the wound gaping and subsequently flattening of the wound meridian. If such a long wound is secured by tight sutures, numerous enough to seal it, they will produce a good amount of plus-power astigmatism in the axis of the tight sutures.**(28)**

Decreasing incision size from 3.2 mm to 2.2 mm or 1.8 mm reduces astigmatic effects, but further reduction from 2.2 mm to 1.8 mm has limited benefit. **(29)**

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