INTRODUCTION

Postoperative refractive surprises are usually due to placement of an incorrect power intraocular lens (IOL) as result of a preoperative error in axial length (AL) measurement or keratometry[1].

Although ultrasound biometry is a well-established method for measuring AL, optical coherence biometry has been shown to be significantly more accurate and reproducible[2].

In the 1980s, IOL power prediction regression formulas (e.g., Sanders, Retzlaff, and Kraff [SRK] formulas I and II) were popular because they were simple to use. However, the use of these formulas often led to power errors that subsequently became the major reason IOLs were explanted. In the 1990s, regression formulas were largely replaced by more accurate, newer theoretical formulas. These are termed theoretical because they are based on theoretical optics, the basis of which is the Gullstrand eye[3].

The choice of these formulas was based on previous studies showing that the Hoffer Q provides the best results in short eyes, the Holladay 1 in medium-long eyes, and the SRK/T in long eyes and that all formulas provide similar results in medium eyes[4].

In 1999, Wolfgang Haigis proposed using three constants to predict the Position of the IOL based on the characteristics of the eye and the IOL to be used. The formula replaces the use of the keratometric (K) reading with using the preoperative anterior chamber depth (ACD) measurement to calculate the predicted postoperative effective lens position (ELP) [5].

Postoperative variability in the pseudophakic ACD may account for approximately (20 to 40%) of the total refractive prediction error. In particular, change in axial IOL position contributes to unexpected postoperative refractive errors. A change in ACD of approximately "720 micrometer" results in a "1.0 diopter" (D) change in refraction. Forward IOL movement away from the retina produces myopia and movement toward the retina, hyperopia [6].

Although toric IOLs have improved the refractive outcomes of patients with significant preexisting astigmatism who have cataract surgery, the residual astigmatism is not always predictable. The underlying reasons for this are a matter of some controversy. However ELP can be a factor [7].

Part of the variability in IOL position is due to the design and mechanical properties of the haptics. Attention to haptic design could therefore improve the predictability of IOL position, hence of refractive outcomes. Accuracy in IOL power labeling is sufficient. Some improvement in obtaining exactly the desired outcome could be achieved by customization of IOL power and asphericity [8].

AIM OF THE STUDY

Is to study the correlation between the effective lens position and the post-operative refraction.

Intraocular Lens Power Calculation

The postoperative refraction depends on the refractive power of the cornea, the power and position of the IOL, and the AL. [9]

Accurate assessment of these variables is essential in achieving optimal postoperative refractive results. If these biometric measurements and calculations are inaccurate, the patients may be left with a significant refractive error. [10]

Axial length, based on ultrasound (US) or optical biometry; corneal power, using manual/automated keratometry or corneal topography; and ACD, using the A-scan US, partial coherence interferometry (PCI), slit-scanning videokeratography, Scheimpflug imaging or anterior segment optical coherence tomography (OCT). These values are used collectively in theoretic or regression formulas to determine an IOL power for a desired refractive status. Axial length measurements have been the source of most refractive surprises, although refinements in biometry techniques and instruments have decreased these errors. [11]

I- Axial length:

Measurement of AL can be done by using either ultrasound biometry or optical biometry.

1- Ultrasound biometry:

The sound waves encounter an interface of differing densities, a fraction of the signal echoes return back. Greater differences in density produce a greater echo. By measuring the time required for a portion of the sound beam to return to the ultrasound probe, the distance can be calculated (d = v x t) /2 where d=axial length, v=converted sound speed, t = measured time. Because the human eye is composed of structures of varying densities (cornea, aqueous, lens, vitreous, retina, choroid, sclera, and orbital fat), the AL of each structure can be indirectly measured using ultrasound. Clinically, applanation and immersion techniques have been most commonly used. [2]

Axial length measurement can be done with the following techniques:

a- With the applanation technique, the ultrasound probe is placed in direct contact with the cornea. After the sound waves exit the transducer, they encounter each acoustic interface within the eye and produce a series of echoes that are received by the probe. Based on the timing of the echo and the assumed speed of the sound wave through the various structures of the eye, the biometer software is able to construct a corresponding echogram. In the phakic eye, the echogram has six peaks (**Fig. l**).[12]

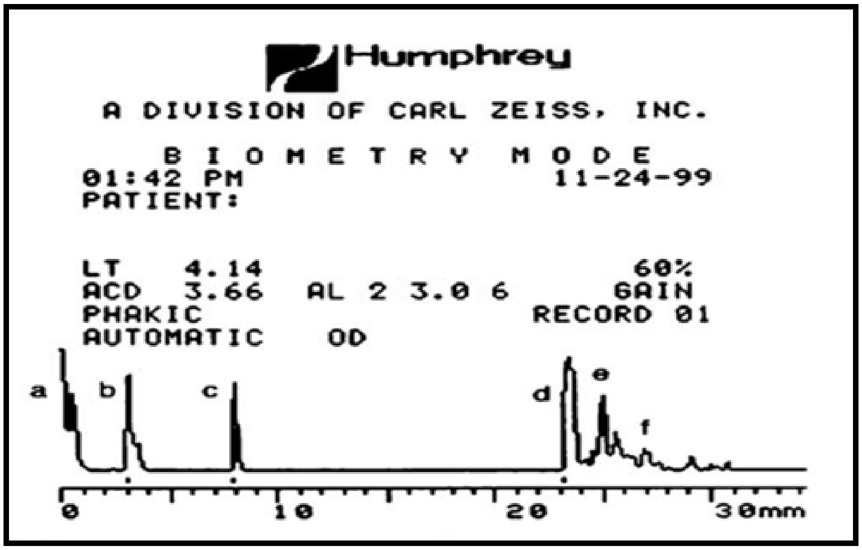

Figure (1): Phakic axial length measurement using the applanation technique, a Initial spike (probe tip and cornea), b anterior lens capsule, c posterior lens capsule, d retina, e sclera, f orbital fat. [2]

The magnitude or height of each peak depends on two factors. The first is the difference in densities at the acoustic interface; greater differences produce higher echoes. The second is the angle of incidence at this interface. The height of a spike will be at its maximum when the ultrasound beam is perpendicular to the acoustic interface it strikes. Because the applanation technique requires direct contact with the cornea, compression will typically cause the AL to be falsely shortened. At normal ALs, compression by 0.1 mm results in a postoperative refractive error toward myopia of roughly 0.25 D.[12]

b- with the immersion technique:

It is most accurate A-scan method, which, if properly performed, eliminates compression of the globe. The patient lies supine with a clear plastic scleral shell placed over the cornea and between the eyelids. The shell is filled with coupling fluid through which the probe emits sound waves. The immersion technique produces an additional spike corresponding to the probe tip **(Fig.2)**.[13]

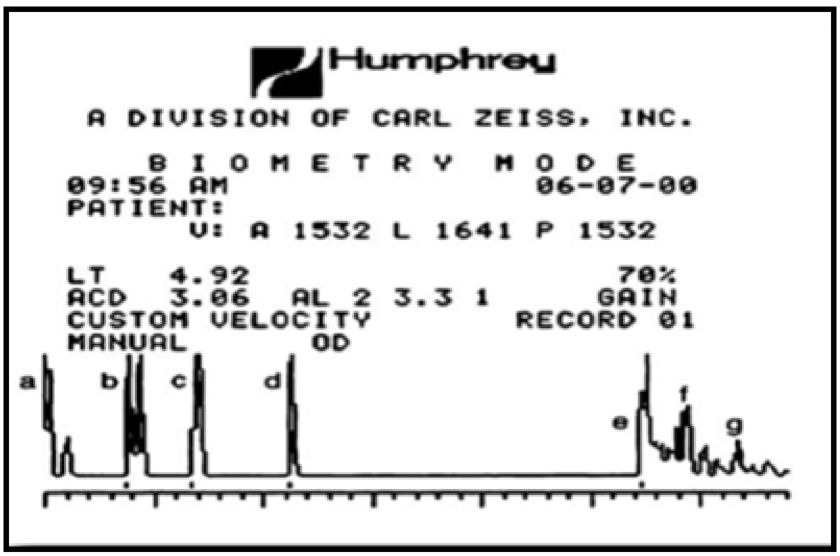

Figure (2): Phakic axial length measurements using the immersion technique.

a Probe tip-echo from tip of probe, has now moved away from the cornea and becomes visible; **b** cornea-double-peaked echo will show both the anterior and posterior surfaces; **c** anterior lens capsule; **d** posterior lens capsule; **e** retina; **f** sclera; **g** orbital fat.[2]

Another source of AL error is that the ultrasound beam has a larger diameter than the fovea. If most of the beam reflects off a raised parafoveal area and not the fovea itself, this will result in an erroneously. Short AL reading. The parafoveal area may be 0.10-0.16 mm thicker than the fovea. In addition to compression and beam width, an off-axis reading may also result in a falsely shortened axial length. If the last two spikes are not present (sclera and orbital fat), the beam may be directed to the optic nerve instead of the fovea.[2]

2- <u>Optical biometry (IOLMaster):</u>

The IOLMaster by Carl Zeiss Meditec **(Fig.3)**, introduced in 1999, is a device allowing all measurements necessary for the calculation of IOL powers to be performed with one instrument. It includes an automatic keratometer to determine central corneal curvatures as well as a slit-image-based setup to measure ACD. The technology of IOLMaster is based on laser interferometry with partial coherent light, often termed as PCI. It is a non-contact, measurement with higher speed and higher accuracy with a resolution going up to 0.01 mm. The measurement results are operator independent, the reproducibility is high. Axial length can be measured in phakic, pseudophakic and aphakic eyes. So IOL calculations using the Zeiss IOLMaster are easy to perform and result in excellent refractive outcomes and the measurement requires minimal cooperativeness and fixation capability of the patient.[14]

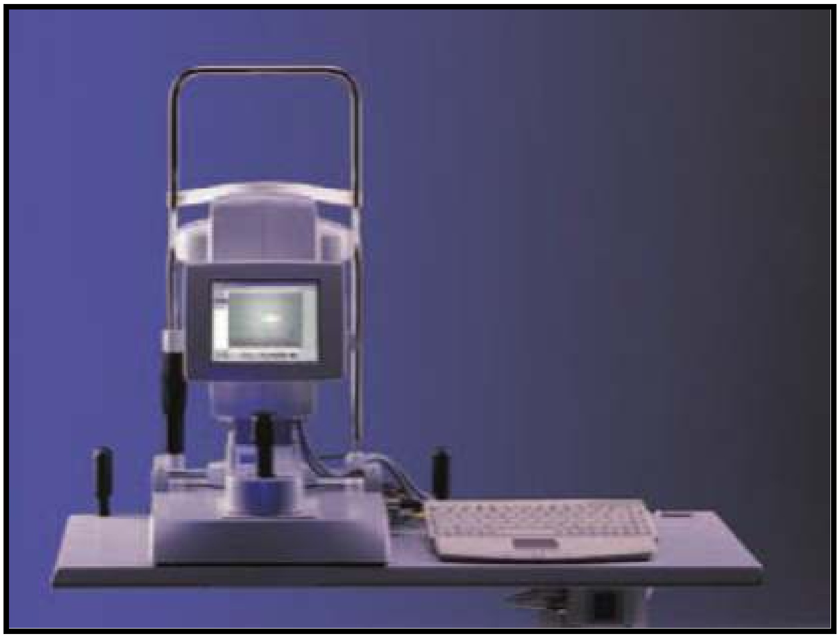

Figure (3): Zeiss IOLMaster.[14]

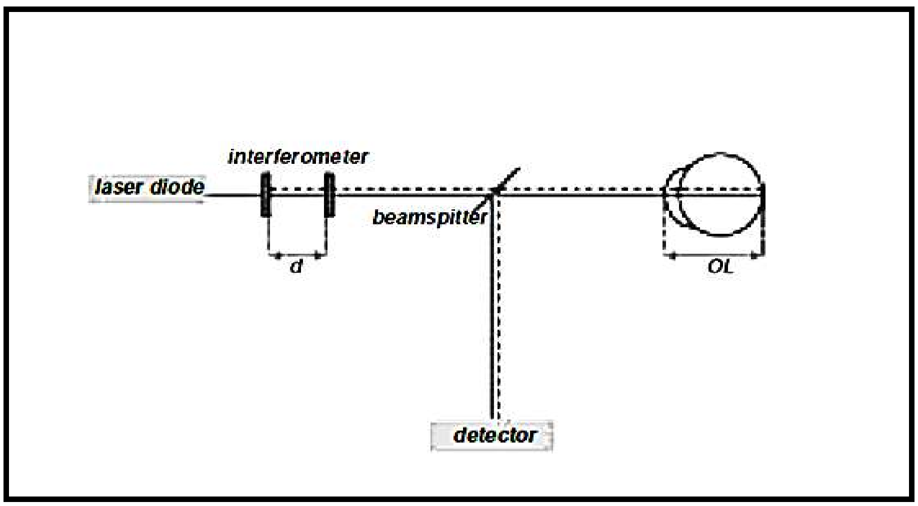

Figure (4): Diagram of the laser interferometer for measuring the AL of the eye.d: plate spacing of the interferometerOL: optical length of the eye.[15]

Light from a laser diode **(Fig.4)** passes an interferometer that splits the beams into two parallel beams: a direct beam and a second beam that is reflected once at both interferometer plates and hence is retarded by a path difference of twice the plate spacing d. Both beams illuminate the eye through a beam splitter. They serve as measuring beams as well as a fixation target. The two coaxial beams are reflected at both the cornea and the retina yielding four reflected beams. This introduces an additional path difference of twice the optical length (OL) of the eye between the two beams reflected at the cornea and the two beams reflected at the retina, respectively. If the coherence length of the laser is shorter than 2 OL, the wave fronts from the retina and the cornea do not interfere. However, if the two path differences 2d and 2 OL equal each other, two of the four reflected beams will interfere. The interference pattern that results will be seen with a detector. In principle, the eye length can be measured by a shift of the interferometer plates. The diode laser emits infrared light with a wave length of 780 nm. The time needed for measurements is about 0.5 sec. The IOLMaster provides a measuring range of "14 to 39 mm". [15]

3- Optical biometry (LENSTAR):

The second optical biometry device introduced was the LENSTAR (Haag-Streit). This unit utilizes optical low coherence reflectometry (OLCR) with a superluminescent diode laser of 820 nm. Because of the spectral characteristics of this laser, a high level of resolution can be achieved and reflective structures within the cornea, anterior chamber, lens, and retina can be detected. This allows simultaneous measurements of the AL, central corneal thickness, ACD, and lens thickness.[16]

Although both the IOLMaster and the LENSTAR measure AL using optical biometry, the LENSTAR also uses this technology to measure ACD, while the IOLMaster uses slit lamp imagery, which is considered to be slightly less accurate.[16]

II- Corneal refractive power:

Measurement of corneal curvature/power can be performed with a variety of instruments, most commonly including manual keratometry, automated keratometry, corneal topography. These devices measure the radius of curvature and provide the corneal power in the form of keratometry diopters using an assumed index of refraction of 1.3375. Corneal curvature is usually used for IOL calculations and corneal refractive surgery. It is also, helpful for contact lens fitting and detecting irregular astigmatism.[17]

A- Conventional manual and automated keratometry:

Conventional manual and automated keratometry measure the size of an image reflected from 4 paracentral points on two orthogonal meridians separated" 3 to 4 mm" on the paracentral cornea. Doubling prisms in the device stabilize the image to enable more accurate focusing. The anterior corneal curvature is then derived from the convex mirror formula and cornea' power is estimated empirically based on Snell’s law of refraction with simplified optics. The keratometry measures the radius of anterior corneal curvature but uses a fudge factor in the index of refraction 1 3375 to account for the posterior corneal power and also to allow 45 D to equal 7.5 mm radius of curvature (K (diopters) = 1 337 5/r). To simplify the calculation, the cornea is assumed to be spheres finder and a thin lens with a fixed anterior to posterior corneal curvature ratio. In most normal eyes with regular astigmatism, the calculated power is easy to obtain and fairly accurate**.** [17]

Therefore, a number of limitations exist: the keratometry only measures a small region of the cornea (4 points at the 3-4 mm zone), it measures different regions for corneas of different powers, it does not provide information about the cornea central or peripheral to these points, it assumes the cornea is spherocylindrical and symmetric with a major and minor axis separated by 90 degrees, it ignores spherical aberration, it is susceptible to focusing and misalignment errors, and mire distortion prevents actuate measurement of irregular corneas and cannot be quantified. So errors in corneal power measurement can be an equally important source of IOL power calculation error, as a 0.50 D error in keratometry will result in a 0.50 D postoperative error at the spectacle plane.[18]

(Auto- keratometry):

IOLMASTER measures at 2.5mm diameter (most manual keratometers measure 3mm). 30 data points per measurement 6 spots x 5 samples, 5 images automatically captured in 0.5 sec displayed, result is average of 5 captured images**.** [19]

Plausibility Checks: There are plausibility checks of:

1. AL Measurements.
2. K values.
3. Consistency between OD (right)/OS (left) eye.

These are additional safety checks, especially helpful for problematic eyes. The system checks after AL plausibility, and will give the following message if needed:

AL <22mm-short

AL >25mm-long eye

r > 8.4mm or K < 40 D flat central cornea

r < 7.2mm or K > 47 D steep central cornea

r < 7.Omni or K > 48 D very steep central cornea consider keratoconus

r1 - r2 > 0.5mm or > 2.5 D high astigmatism. [19]

The LENSTAR makes use of 32 reference points, that are arranged on 2 concentric rings with 16 measuring points each. The outer circle is projected in a 2.3-mm diameter ring, and the inner circle is projected in a 1.65-mm diameter ring. The small diameter can provide useful data in patients who have undergone a refractive laser procedure that has altered the central corneal curvature.[16]

B- Corneal topography

1**- Keratoscopy or Photokeratoscopy**: is a qualitative reflection based instrument, the projected light is placido disk target according to the changes in the shape of the reflected rings and the spaces in between, one can take an idea about the shape of the cornea, for instance, small, narrow and closely spaced rings indicate steep regions with small radius of curvature. Some of the known deficiencies of the photokeratoscope are:

- It requires assumptions about the corneal shape.
- It misses data on the central cornea (not all topographers).
- It is only able to acquire limited data points.
- It measures slope not height.
- It measures only the anterior surface of the cornea.
- Defocusing and misalignment.
- It is severly affected by tear film disturbances.[20]

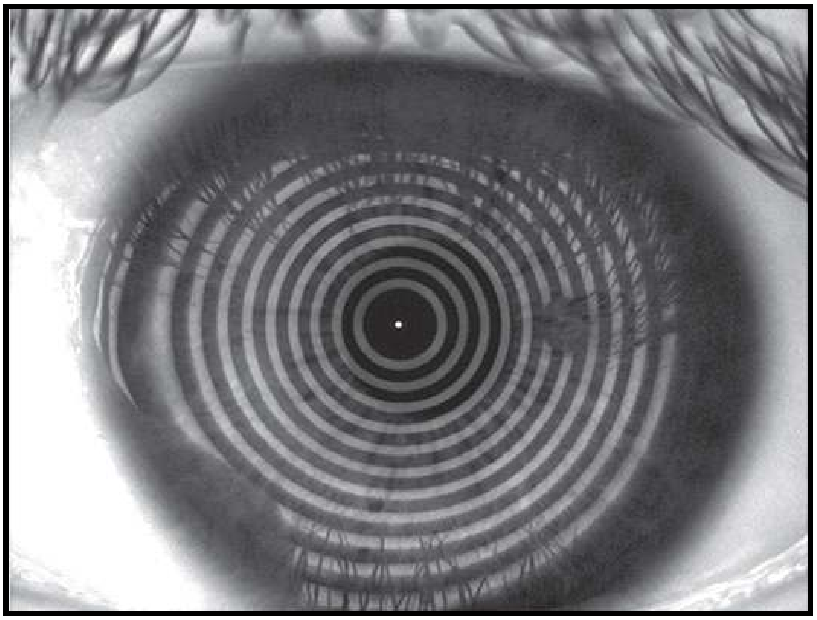

Figure (5.a): Image of Placido rings on a normal cornea**.** [21]

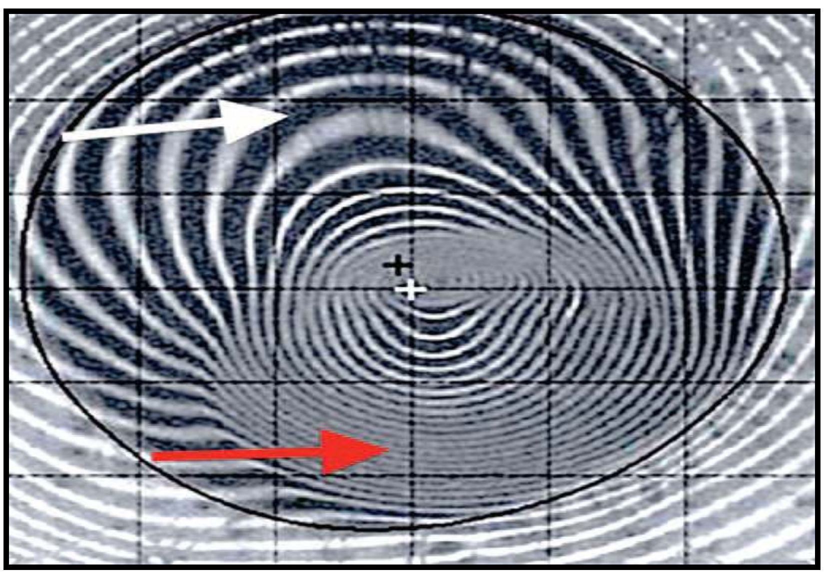

Figure (5.b): Image of Placido rings on an abnormal distorted cornea. The white arrow points at a flat area where the rings are spaced, and the red arrow points at a steep area where the rings are crowded. [21]