ORIGINAL ARTICLE

Analysis of cataract surgery induced astigmatism: Two polar methods comparison

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KEYWORDS
Surgical induced astigmatism (SIA); Polar value analysis; Toric IOL; Corneal incision

Abstract

Purpose: Surgically induced astigmatism (SIA) caused by the incision after cataract surgery may be calculated to improve IOL toric power calculation and achieve better visual outcome. SIA could be determined as the difference between preoperative and postoperative keratometry expressed in polar values using different equations. The objective of this study is to compare the SIA calculated with two different polar value analysis methods [Method #1: KP (90)/KP (135) developed to be used with incisions placed at 90° and Method #2: AKP/AKP (+45) developed to be used independently of the incision location].

Methods: Preoperative and one month postoperative data of 210 cataractous eyes (131 patients) undergoing uncomplicated cataract surgery were assessed. All incisions were performed at 11 o’clock (120°). No sutures were used in any patient. IOLMaster (Carl Zeiss Meditec, Dublin, Ireland) keratometry was used to polar calculation.

Results: The average age was 66.25 ± 12.33 years (range 22-89). SIA polar value data calculated with Method #1 were KP (90) = -0.06 ± 0.52D and KP (135) = +0.05 ± 0.91D and calculated with Method #2 were AKP = -0.10 ± 0.87D and AKP (+45) = +0.02 ± 0.02D. However, SIA value represented in traditional notation (diopters/axis in degrees) was the same value independently of the method used to calculate; +0.65@110.70°.

Conclusion: SIA value is independent of the polar method used to its calculation and slight variations in the incision position could be accepted without clinical relevant impact in SIA magnitude. Both methods [Method #1: KP (90)/KP (135) and Method #2: AKP/AKP (+45)] are useful to calculate SIA with superior incisions at 120°.

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Análisis del astigmatismo inducido en la cirugía de cataratas: comparación de dos métodos polares

Resumen

Objetivo: El astigmatismo quirúrgicamente inducido (SIA) causado por la incisión tras la cirugía de cataratas se puede calcular para mejorar el cálculo de la potencia de las lentes intraocular en tóricas y lograr un mejor resultado visual postquirúrgico. El SIA puede determinarse como la diferencia entre la queratometría preoperatoria y postoperatoria expresada en valores polares, utilizando diferentes ecuaciones. El objetivo de este estudio fue comparar el SIA calculado mediante dos métodos de análisis de valores polares [Método 1: KP (90)/KP (135) desarrollado para ser utilizado con incisiones situadas a 90 grados, y Método 2: AKP/AKP (+45) desarrollado para ser utilizado independientemente del lugar de la incisión].

Métodos: Se analizaron los datos preoperatorios y postoperatorios tras un mes de cirugía de catarata no complicada, de 210 ojos (131 pacientes). Todas las incisiones se realizaron a las 11 en punto (120 grados). No se realizaron suturas en ningún paciente. Se utilizó la queratometría proporcionada por el sistema IOLMaster (Carl Zeiss Meditec, Dublin, Irlanda) se empleó para realizar el cálculo polar.

Resultados: La edad media fue de 66,25 ± 12,33 años (rango de 22 a 89). Los datos de los valores polares del SIA calculados con el Método 1 fueron KP(90) -0,06 ± 0,52D y KP(135) ± 0,05 ± 0,91D, y los calculados con el Método 2 fueron AKP -0,10 ± 0,87D y AKP (+45) -0,02 ± 0,02D. Sin embargo, valor SIA representado en la notación tradicional (dioptrias@ejes en grados) fue el mismo, independientemente del método de cálculo utilizado: -0,65@110,70°.

Conclusion: El valor SIA es independiente del método polar utilizado para su cálculo, pudiendo aceptarse ligeras variaciones en el lugar de incisión, sin impacto clínico relevante en cuanto a la magnitud del SIA. Ambos métodos [Método 1: KP (90)/KP (135) y Método 2: AKP/AKP (+45)] son útiles para calcular el SIA con incisiones superiores localizadas a 120 grados.

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Introduction

Nowadays, cataract surgery with implantation of an intraocular lens (IOL) is the most common ophthalmic surgical procedure.1 Over the past years, surgical technique has evolved from standard extracapsular to micro incision without suture. Also, the formulas and devices that calculate the IOL power have experimented an important advance. These progresses have allowed cataract surgery to be a less invasive procedure, with better and more predictable refractive results. So that, most patients have increased expectations about cataract surgery result.2,3

For this reason, toric IOLs have been developed to improve the refractive outcome in patients with astigmatism. To accurate toric IOL power calculation is necessary to know not only the preoperative astigmatism, axial length, etc. as standard IOL calculations, but also the surgically induced astigmatism (SIA) caused by the incision. SIA must be added to the preoperative measured corneal astigmatism using vector analysis.4-6 Thus, it would be possible to elucidate the total astigmatism that is necessary to correct with the IOL7 and improve visual outcome of the surgery. SIA could be calculated as the change in corneal astigmatism using keratometry values.

The objective of this study was to compare induced astigmatism as the change in the keratometry (measured with IOLMaster) pre and post cataract surgery, with two different ways to conduct the polar value analysis [Method #1: KP (90)/KP (135) proposed to be used with incisions placed at 90° and Method #2: AKP/AKP (+45) proposed to be used independently of the incision location]. These results will be of great utility to clarify the controversy about what method to choose to calculate SIA.

Patients and methods

This prospective and comparative study included two visits: the baseline visit, before cataract surgery, and one month postsurgery.

Subjects

This study included 210 cataractous eyes of 131 patients (54.96% female) attending the IOBA-Eye Institute, University of Valladolid, Spain, scheduled to undergo phacoemulsification to remove cataract.

Exclusion criteria included patients with significant pathology that could influence the refraction such as diabetic retinopathy, corneal dystrophy, past or present keratitis, corneal leucomas affecting the visual axis, corneal degenerations, corneal ectasias, or uveitis. Subjects with a history of eye surgery and those having combined procedures at the time of cataract surgery, and cases requiring surgical suturing or developing inflammation that did not
correspond to the natural course of postoperative healing were also excluded.

After explaining the details of the study, written informed consent was obtained from all patients before enrolment. The study was approved by the Human Sciences Ethics Committee of the University of Valladolid and was carried out in accordance with the Declaration of Helsinki.

Study visits

Preoperative and one month postoperative complete eye examination were conducted; including uncorrected and corrected distance visual acuity assessment, autorefraction, biometry, slit lamp biomicroscopy, Goldman tonometry and indirect ophthalmoscopy with pupil mydriasis.

Cataract surgery was performed by the same experienced surgeon, making a 2.75 mm clear corneal incision at 11 o’clock position (around 120°), and clear corneal paracentesis was performed at 1 o’clock position. An aspheric acrylic posterior chamber IOL Acrysof natural IQ SN60WF (Alcon Cusi S.A. El Masnou, Barcelona, Spain) was implanted. When the IOL power was lower than 6.50D, Acrysof Multipiece MA60MA (Alcon Cusi S.A. El Masnou, Barcelona, Spain) was implanted. The corneal wound was hydrated and no sutures were used in any patient.

Instrumentation

Pre and post autorefraction were measured with ARK-30 autorefractor (Nidek Co. LTD, Aichi, Japan). Keratometry was conducted with the IOLMaster (Carl Zeiss Meditec, Dublin, Ireland). IOLMaster uses six light reflections projected on the anterior corneal surface in an area of approximately 2.5 mm of diameter, depending on the corneal curvature, to measure main meridians keratometry. Three measurements were performed by the same experienced operator and mean value was taken like final value. A difference of 0.25 D or less between three readings in both main meridians was used as validation criteria.

Statistical analysis

Statistical analysis was performed using the SPSS 14.0 (SPSS Chicago, IL, EEUU) statistical package for Windows. A descriptive analysis of keratometry and polar values calculated with two different approaches [Method #1: KP (90)/KP (135) and Method #2: AKP/AKP (+45)] have been conducted. Pre and postoperative corneal astigmatism has been represented in a polar graph.

Polar value analysis

Polar value analysis was performed to calculate the SIA. The general expressions\(^5,6,7,8\) for the polar value method are:

**Meridional or on – axis KP**

\[
KP = M \sin^2[\alpha + 90] - \cos^2[\alpha + 90]
\]

**Oblique or torqued KP**

\[
KP = M \sin^2[\alpha + 45] - \cos^2[\alpha + 45]
\]

where \(\alpha\) symbolize the plane analyzed, \(M\) is the magnitude of the net astigmatism reported in diopters (D) and \(\alpha\) the meridian of net astigmatism in degrees (°)\(^9\).

To calculate the polar values, it is possible to use different equations by changing \(\alpha\) in expression (1) and (2). The following equations are the most frequently employed.

**Method #1:**

\[
KP (90) = M \sin^2[\alpha + 90] - \cos^2[\alpha]
\]

\[
KP (135) = M \sin^2[\alpha + 45] - \cos^2[\alpha + 45]
\]

This equation, among other applications, is used for incisions located around the 90° meridian\(^3\). As incision in all our patients was placed at 11 o’clock (120°) we have chosen these equations due to the incision is close to 90°.

**Method #2:**

\[
AKP = M \sin^2[\alpha + 90] - \cos^2[\alpha + 90]
\]

\[
AKP (+45) = M \sin^2[\alpha + 45] - \cos^2[\alpha + 45]
\]

Replacing \(\alpha\) by the incision meridian orientation (120°), the AKP and AKP (+45) were calculated with these expressions:

\[
AKP = M \sin^2[\alpha + 90] - \cos^2[\alpha + 90]
\]

\[
AKP (+45) = M \sin^2[\alpha + 45] - \cos^2[\alpha + 45]
\]

This variation is recommended for any procedure\(^5\) independently of the incision location. So, these equations may be suitable to use in our patients.

Finally, SIA expressed as polar values was calculated with the difference between the postoperative and preoperative polar values calculated with both methods. SIA calculated with each method has been represented in a polar graph.

The meridional polar values, KP (90) or AKP, indicate the flattening or steepening of the surgical meridian.\(^3\) A positive polar value expresses a steepening of the surgical meridian, a with-the-rule (WTR) change, while a negative result a flattening or against-the-rule (ATR) change. The polar values of the oblique meridian, KP (135) or AKP (+45), expresses the surgically induced torque of the cylinder. A positive polar value signifies an anticlockwise torque and a negative result a clockwise torque.

It is possible to transform the polar values to conventional astigmatism notation (diopters@axis in degrees) by using the following equations\(^3,9\):

With **Method #1:**

\[
M = \pm \sqrt{KP (90)^2 + KP (135)^2}
\]

\[
\alpha = \arctan \left( \frac{M - KP (90)}{KP (135)} \right) + p180 - 90
\]

where \(p\) is an integer.
Cataract surgery induced astigmatism: Polar methods comparison

The average age was of 66.25 ± 12.33 years (range 22–89). Mean preoperative spherical equivalent was −3.38 ± 6.52D (sphere −2.97 ± 6.35D and cylinder −1.40 ± 1.07D) and keratometry was 43.55 ± 1.64D in flatter meridian and 44.66 ± 1.76D in steeper corneal meridian with 1.11 ± 0.38D of preoperative corneal astigmatism. After surgery mean spherical equivalent was −0.47 ± 0.85D (sphere −0.04 ± 0.93D and cylinder −0.85 ± 0.59D) and keratometry was 43.56 ± 1.62D in flatter meridian and 44.76 ± 1.76D in steeper corneal meridian with 1.20 ± 1.11D of postoperative corneal astigmatism. Fig. 1 shows vector representation of corneal astigmatism pre and post cataract surgery. The polar value data calculated with both polar methods and SIA are summarized in Table 1. Using Method #1 and Method #2 the same SIA (expressed in conventional notation diopeters@axis in degrees) value was achieved; ±0.65@110.70° (Fig. 2).

Discussion

The classical spherocylinder format written as sphere, cylinder and axis is useful for a single analysis but is not appropriate for mathematical and statistical analysis of aggregate data. The cylindrical component is characterized by a magnitude expressed in diopters and a direction in degrees. Thus, it is necessary to use a method able

And with Method #2 values:

\[ M = \pm \sqrt{AKP^2 + AKP (+45)^2} \]  \hspace{1cm} (11)

\[ \alpha = \arctan\left(\frac{M - AKP}{AKP (+45)}\right) - 90 \]  \hspace{1cm} (12)

Results

The average age was of 66.25 ± 12.33 years (range 22–89). Mean preoperative spherical equivalent was −3.38 ± 6.52D (sphere −2.97 ± 6.35D and cylinder −1.40 ± 1.07D) and keratometry was 43.55 ± 1.64D in flatter meridian and 44.66 ± 1.76D in steeper corneal meridian with 1.11 ± 0.38D of preoperative corneal astigmatism. After surgery mean spherical equivalent was −0.47 ± 0.85D (sphere −0.04 ± 0.93D and cylinder −0.85 ± 0.59D) and keratometry was 43.56 ± 1.62D in flatter meridian and 44.76 ± 1.76D in steeper corneal meridian with 1.20 ± 1.11D of postoperative corneal astigmatism. Fig. 1 shows vector representation of corneal astigmatism pre and post cataract surgery. The polar value data calculated with both polar methods and SIA are summarized in Table 1. Using Method #1 and Method #2 the same SIA (expressed in conventional notation diopeters@axis in degrees) value was achieved; ±0.65@110.70° (Fig. 2).

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Discussion

The classical spherocylinder format written as sphere, cylinder and axis is useful for a single analysis but is not appropriate for mathematical and statistical analysis of aggregate data. The cylindrical component is characterized by a magnitude expressed in diopters and a direction in degrees. Thus, it is necessary to use a method able
to manage this type of data, such as the polar value analysis.5,7,10

The astigmatism is represented by two polar values. One possible application of this calculation is to describe the astigmatic change following cataract surgery. Naeser et al.9 have developed and described the equations required to calculate the polar values mentioned. In another study they
described the uses of the different polar values. Varying $\Omega$
in Eqs. (1) and (2) it is possible to obtain the different polar values,
of which the most commonly used are those already
tioned in Eqs. (3)–(6).

The KP (90) and KP (135) are used for superior incisions,
located around the 90° meridian, and also for the analysis
of refractive data population and spectacle prescriptions.7 The
AKP and AKP (+45) are usually used for analysis of an incision
disposed in the preoperative steeper meridian, or indeed
any procedure with the objective of reducing the steep
meridian.5 So, it is expected no difference between both meth-
ods in the same patients undergoing cataract surgery with
the incision at vertical meridian, as we enrolled in this study.

Nae
er9 reported not significant difference in the flattening
change in KP (90) of 0.52D induced by two different
surgical techniques in 24 eyes after uncomplicated cataract
surgery with corneal or scleral incision; however torque
value change in KP (135) of 0.77D showed statistical sig-
nificant differences.

SIA polar calculation is useful to assess the effect of
corneal incision length. Large incisions induce high SIA
than small incisions. Naeser9 reported near of 1.00D vertical
flattening [KP (90)] and 0.50D of counterclockwise torque [KP
(135)] with 9.0-mm superior incision ($p < 0.05$) against of
a vertical flattening of 0.71D with 5.5-mm and 0.64 with
4.0-mm incisions and close to zero torque.

It is well known that SIA value vary between surgeons
and patients because it is highlight influenced by location
and size of the incision and by the individual biological
response of each patient’s cornea.4 Moreover, some authors
recommend develop customized equations taking into
consideration the exact incision location11 to obtain a
precise result. However, our results suggests that slight vari-
atations in the incision location (around 120° instead 90°
that Method #1 proposes) does not induce different SIA as achieve
the same value expressed in conventional notation (diopt-
tries $\odot$ degrees). To the best of our knowledge this is the
first report that compares the differences between two dif-
ferent polar methods to calculate SIA in the same sample of
patients. These results could be useful to surgeons, eye care
practitioners and researchers, helping to choose the method
to calculate SIA and improve visual outcome after toric IOL
surgery.

In our study we do not get the same polar SIA value with
both methods analyzed. We noted that different flattening
[KP (90) −0.06D or AKP −0.10D values] and different anti-
clockwise torque astigmatism [KP (135) +0.11D or AKP (+45)
+0.59D] with either Method #1 or #2 (Table 1). These slight
differences are related with the difference in the vector cal-
culation because it is simply a projection onto two different
meridians with each calculation method. These differences
disappear to represent SIA with the conventional notation
(astigmatism $\odot$ degree) (Fig. 2). These "apparent differ-
ences" in polar vectors results should be taken in account
to make a correct data interpretation, because results of
different studies that use different vector projection to cal-
culate SIA could be non-interchangeable.

It should be noted that differences in keratometry data
achieved with difference devices (IOLMaster, topographers
or auto-keratometers) could induce any effect in SIA cal-
culation and just devices with high repeatability and minimum
operator dependency should be recommended to achieve
sound data and improve toric IOL power calculation.6

Using anterior corneal keratometry to SIA calculation
could be criticized after cataract surgery because these
measurements do not take in account posterior corneal
surface. However, on the posterior surface changes below of
0.1D has been described12 so the effect of posterior corneal
surface after cataract surgery in SIA calculation is of negli-
gible clinical relevance.12

Other limitation of our study is the short follow-up period
(one month after surgery), because other reports,7,12 sug-
gest a change in the polar value data during the visits.
However, refraction after uncomplicated cataract surgery
is stable one week after surgery12 and corneal swelling after
two weeks, so the follow up of our study has a minimum
impact in our results and conclusions. Because all surgeries
were performed by the same experienced surgeon lower SIA
value than less-experienced surgeon, could be expected.

In conclusion, SIA value is independent of the polar
method used to its calculation and slight variations in the
incision position could be accepted without clinical rele-
vant impact in SIA magnitude. Both methods [Method #1:
KP (90)/KP (135) and Method #2: AKP/AKP (+45)] are useful
to calculate SIA with superior incisions at 120°.

Conflicts of interest

None of the authors has a financial or proprietary interest in
any material or method mentioned.
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