Abstract

Purpose: To analyze the post operative results of targeting zero spherical aberration by selecting the best-fit aspheric intraocular lens (IOL), based on preoperative corneal spherical aberration of patients with phacoemulsification surgery.

Setting: AlHokama Eye Specialist Center, Riyadh, Saudi Arabia.

Period: From the 1st of October 2012 until the 10th of April 2013.

Methods: Fifty-three eyes, were subjected to phacoemulsification cataract surgery and divided into two groups, 34 eyes were implanted with aspheric IOLs based on their corneal spherical aberration targeting post operative zero total spherical aberration, whereas 19 eyes were implanted with neutral aspheric IOLs regardless of their corneal spherical aberrations (CSAs). As a pre and post routine examination, patients underwent: slit lamp testing, intraocular pressure (IOP) measuring, fundus examination, best spectacle corrected visual acuity (BSCVA), manifest refraction, pupillometry, axial length, contrast sensitivity, and corneal aberration measurement using Pentacam HR (OCULUS, Germany) at the 6-mm optical zone. Post operatively, visual function questionnaire (VF-14) was asked to all patients.

Results: Fifty-three eyes of 45 patients, whose age ranged from 45 to 90 years old, were available for analysis, the selected group was implanted with: Tecnis ZA9003 or ZCB00 (Abbott Medical Optics) IOLs in 17 eyes with corneal spherical aberration of more than 0.27 μm, AcrySof IQ SN60WF (Alcon Laboratories Inc.) IOLs were implanted in 4 eyes with CSA = (0.2–0.27) μm, and Rayner 970C, 920H or 620H IOLs with spherical aberration (SA) = 0 in 13 eyes with CSA less than 0.20 μm. The other group of 19 eyes was implanted with aspheric IOLs that have zero spherical aberration (Rayner 970C or 920H) regardless of their CSA. Root mean square (RMS) of total corneal aberration positively correlates to the pupil diameter ($P = 0.0031$, $r = 0.3989$). A low negative correlation was found between the corneal spherical aberration of the fourth ordered ($Z_{40}$) and the axial length ($r = -0.2009$, $P = 0.1492$). There was no significant difference between the selected and non-selected group in contrast sensitivity, best spectacle corrected visual acuity, and visual satisfaction ($P = 0.5316$, $P = 0.3919$, $P = 0.7667$).

Conclusion: Customized selection of aspheric IOLs based on the eyes’ corneal spherical aberration has no significant importance comparing their results with the non-selected group.

Keywords: Spherical aberration, $Z(4,0)$, $Z(6,0)$, IOL, Cataract, Corneal aberration, Higher order aberration, Intraocular lens

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Introduction

Optical degradation with age is caused by the increase of the opacification of the crystalline lens that will result in visual impairment, loss of contrast, and an increase in the spherical aberration of the optical system. In young healthy crystalline lens, the lens compensates for the cornea positive spherical aberration. With age, the crystalline lens becomes less negative (or even more positive), and the angle of refraction of the peripheral rays will be larger comparing to the paracentral rays, resulting in increasing the total optical spherical aberration of the eye.

With the advancement of cataract eye surgery and wavefront sensors, the unquantifiable refractive measurements have been identified and the high ordered aberrations have shown their effect on high resolution imaging.

Therefore, the conventional spherical intraocular lenses (IOLs) have been replaced with aspheric intraocular lenses (IOLs) that have no or negative spherical aberration to overcome the naturally occurring positive spherical aberration of the corneal surface and then achieve better results.

Thus, this study was designed to determine whether patients with selected IOLs have better visual acuity, contrast sensitivity, and visual satisfaction outcomes than comparable patients who had no specific target of postoperative spherical aberration.

Patients and methods

Fifty-three eyes of forty-five Saudi subjects (25 men and 20 women), whose age ranged from 45 to 90 years old, with comparable spherical equivalent of their refractive errors, were subjected to routine pre cataract surgery examination of: slit lamp testing, intraocular pressure (IOP) measuring, fundus examination, best spectacle corrected visual acuity (BSCVA), manifest refraction, pupillometry, axial length, contrast sensitivity, and corneal aberration measurement using Pentacam HR (OCULUS, Germany) at the 6-mm optical zone.

34 eyes were implanted with IOLs according to their spherical aberration

1- Tecnis IOLs with spherical aberration (SA) of 0.27 μm were implanted in 17 eyes with corneal spherical aberration (CSA) of more than 0.27 μm.

2- IQ IOLs (SA = 0.2 μm) were implanted in 4 eyes with CSA (0.2–0.27) μm.

3- Rayner IOLs (SA = 0) were implanted in 13 eyes with CSA less than 0.20 μm.

Whereas 19 eyes were applied with non selected IOLs (Rayner IOLs (SA = 0)) (Table.1).

<table>
<thead>
<tr>
<th>IOL type</th>
<th>Tecnis</th>
<th>AcrySof IQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturer</td>
<td>Rayner</td>
<td>Advanced Medical Optics</td>
</tr>
<tr>
<td>Code number</td>
<td>920H, 970C, 620H</td>
<td>ZA9003, ZCB00</td>
</tr>
<tr>
<td>Optic diameter (mm)</td>
<td>(5.75–6.25) mm</td>
<td>6.00 mm</td>
</tr>
<tr>
<td>Optic material</td>
<td>Hydrophilic acrylic</td>
<td>Hydrophobic acrylic (ZA9003)</td>
</tr>
<tr>
<td>Spherical aberration</td>
<td>Zero</td>
<td>−0.27 μm</td>
</tr>
<tr>
<td>Design</td>
<td>Single-piece</td>
<td>3-piece (ZA9003), single-piece (ZCB00)</td>
</tr>
<tr>
<td>Refractive index</td>
<td>1.46</td>
<td>1.47</td>
</tr>
<tr>
<td>Overall length (mm)</td>
<td>(12.00–12.50) mm</td>
<td>13.00 mm</td>
</tr>
</tbody>
</table>

One month postoperatively, patients returned to measure: the best spectacle corrected visual acuity (BSCVA), manifest refraction, contrast sensitivity, visual function questionnaire (VF-14), and corneal aberration measurement using Pentacam HR (OCULUS, Germany) at the 6-mm optical zone.

Patients with a history of contact lens wear, keratorefractive surgery, existing ocular or systemic pathologies were excluded. Otherwise, all patients with clear cornea, no scarring nor pigmentation were included in the study. Corneal spherical aberration root mean square (RMS), total and high order aberrations (RMS) up to 6th order of all eyes were obtained without dilatation in the dark at 6 mm optical zone.

The study was conducted according to the tenets of declarations of Helsinki in a central anterior segment referral clinic and received the approval of the institute. All the subjects signed a comprehensive written consent prior to participation in the study.

Statistical analysis

Statistical analysis of the results was done by Microsoft Excel, Graphpad prism, and Instat.

Results

Fifty-three eyes of forty-five patients underwent uneventful phacoemulsification and IOL implantation by one surgeon (Al-Saleh A.). Thirty-four eyes were implanted with IOLs based on their corneal spherical aberrations, Rayner for the eyes with a CSA less than 0.2 μm, AcrySof IQ for the CSA of [0.2–0.27] μm, and the Tecnis IOLs were implanted in the eyes with a CSA of >0.27 μm. The rest nineteen eyes have been implanted with Rayner IOLs that have zero spherical aberration, regardless of their CSA.

The mean corneal spherical aberration of the fourth order (Z4) of the entire eyes was $0.3354 \pm 0.1965 \mu m$, RMS of the 6th order spherical aberration was $0.0059 \pm 0.0738 \mu m$, whereas the mean total corneal aberration was $2.867 \pm 1.174 \mu m$, while the RMS of high order aberration (HOA) $= 0.8164 \pm 0.3524 \mu m$. The P value for the four was <0.0001, considered extremely significant (Fig. 1).

The total CSA of the fourth and sixth order ranged from $-0.254$ to $0.817 \mu m$, with a mean RMS of $0.3413 \pm 0.1814 \mu m$.

The pupil diameter under mesopic condition was found to slightly positively correlate to the fourth order corneal spherical aberration and RMS of HOA ($P = 0.4677$, $r = 0.1019$) ($P = 0.2813$, $r = 0.1507$), respectively, whereas RMS of the total corneal aberration moderately to highly positively correlates to the pupil diameter ($P = 0.0031$, $r = 0.3989$) (Fig.2).
By measuring the axial length (AL), we found that there is a low negative relationship between the corneal spherical aber-
ration ($Z_4$) and the axial length ($r = -0.2009$) ($P = 0.1492$). The mean value of AL of all candidates was $23.655 \pm 1.514$, ($P < 0.0001$). Also there was no correlation between the axial length and the age group in this study ($r = -0.04994$, $P = 0.7225$).

Postoperative BSCVA measured 20/16 in 11 eyes, 20/20 in 37 of 53 eyes, and 20/25 in five eyes. There was no statistical significant difference between the selected and non-selected groups in the best spectacle corrected visual acuity ($P = 0.3919$).

Mean spherical equivalent refraction measured postopera-

tively $-0.4104 \pm 0.8043$ D. No significant tilt or decentra-
tion of any IOL was found. The mean residual refractive error after the surgery for the selected and non-selected groups was $(-0.5588 \pm 0.8213)$ D and $(-0.1447 \pm 0.7184)$ D, respectively, suggesting no quite significant difference ($P = 0.0719$).

Examination of the difference between the preoperative corneal spherical aberration and the measured corneal spherical aberration postoperatively for both groups shows no significant difference between the mean values ($P$ value = 0.6458).

Contrast sensitivity was measured with Pelli-Robson in the two groups postoperatively under photopic conditions, the mean value of the contrast sensitivity in the selected group was higher than in the non-selected group but there was no significant difference between the two groups ($P = 0.5316$).

Questionnaire for visual satisfaction and visual function (VF-14) was asked to the entire patients after one month post-
operatively, there were no significant differences in visual sat-
isfaction between the selected and non-selected groups ($P$ value = 0.7667).

The questionnaire (VF-14) was focused on function related to spherical aberration, such as glare, which was found to be not statistically different between the two groups ($P = 0.6880$) with the appreciation to the no glare by the selected one (Fig.3).

Daily activities and night vision were also compared between the two groups, there are no significant differences between the selected and non-selected groups in driving at night and good vision in dim light ($P = 0.2443$, $P = 0.5208$, respectively) (Fig.4).

Residual calculated spherical aberration of the two groups was measured, and there was an extremely significant difference ($P$ value is <0.0001) between the selected & non-selected groups (Fig.5). Note that, there was a significant difference between the two groups preoperatively ($P = 0.0275$) (Fig.6).

**Discussion**

Targeting plano post-operative refraction is not the only aim that refractive/cataract surgeons are looking for, furthermore adjustment of higher order aberrations and their effect on visual performance are well appreciated. This study was intended to determine the change of corneal spherical aberration pre and post operatively in Saudi population and the effect of managing spherical aberration by coupling preoperative corneal spherical aberration with the suitable aspheric IOL to achieve a reproducible reduction in total ocular spherical aberration.

Data from 30 eyes were available for analysis in Packer, the mean preoperative corneal spherical aberration measured at the 6-mm optical zone for the entire population was $0.26 \pm 0.089 \mu m$ for patients ranging from 62 to 86 years old.

In the current study, the corneal spherical aberration of the fourth order ranged from $-0.31$ to $0.799 \mu m$. Wang et al. and Shimozono, also found individual variability in corneal spherical aberration, that ranged from $+0.069$ to $+0.511 \mu m$ and $-0.103$ to $+0.497 \mu m$, respectively, with a mean value of $+0.204 \pm 0.10 \mu m$ in Shimozono’s study.

In our study, the mean RMS of CSA of the fourth order for the whole groups was $0.33543 \pm 0.1965 \mu m$. This agrees strongly with the preoperative corneal spherical aberration reported previously in many studies, like Holladay et al., who found that the mean corneal spherical aberration, derived from measurements with the Orbscan unit, was $+0.27 \pm 0.02 \mu m$ and, Beiko et al. who evaluated the corneal spherical aberration in 708 patients aged 39–92 years, with the Easygraph, and found a mean RMS of $+0.274 \pm 0.095 \mu m$. Another study by the same authors Beiko et al. revealed a preoperative corneal spherical aberration ($Z_4$) of thirty-three cataract patients, age from 50 to 90 years, of $+0.32 \pm 0.075 \mu m$. Preoperative corneal spherical aberration measured at a 6.0-mm pupil was $+0.260 \pm 0.084 \mu m$ for the entire study group in the Solomon’s study, of forty eyes of patients aged from 67 to 82 years old. In a recent study by Li, there was a linear positive correlation between the mean preoperative CSA ($Z_4$) of age, in their 93 patients aged from 50 to 89 years ($r = 0.203$, $P < 0.003$).

Shimozono study reported, a low negative correlation between axial length and corneal spherical aberration ($r = -0.135$, $P = 0.036$), which support our findings of the kind of relation between the ($Z_4$) cornea spherical aberration and the axial length ($r = -0.2009$).

As all the patients underwent phacoemulsification surgery, they were divided into 2 groups, the first one is implanted with aspheric IOLs based on their corneal spherical aberrations, and the other group has been implanted with neutral aspheric IOLs, regardless of their CSA. Postoperative comparisons were made by means of visual acuity, residual refractive error, contrast sensitivity, and subjectively by questionnaire of visual satisfaction VF-14.

In evaluating the results, the accepted value for the surgically induced spherical aberration is $0.03 \pm 0.17 \mu m$. That was the same in our study, as there was no significant differ-
Figure 2. Correlation of the pupil diameter under mesopic condition with SA, HOA, and total corneal aberration.

Figure 3. Postoperative no glare results in the selected and non-selected groups.
ence between the mean pre and post operative corneal spherical aberration of the fourth order ($P = 0.6458$), which means there was no surgically induced spherical aberration. In agreement with Solomon,\textsuperscript{14} measurements of corneal spherical aberration after the surgery as compared to their preoperative values, detected no statistical difference ($P = 0.48$).

Many studies suggest super vision in individuals with slightly positive ocular spherical aberration\textsuperscript{17} like Beiko\textsuperscript{13} who found improved contrast sensitivity with a targeted residual ocular $Z(4,0)$ of $+0.10 \, \mu m$.

In Packer study,\textsuperscript{18} the selected patient group demonstrated significantly better contrast sensitivity than the unselected group of control patients under photopic condition. The Pelli-Robson contrast sensitivity test is a reliable and easy to apply method.\textsuperscript{19–21} Mäntyjärvi and Laitinen\textsuperscript{19} published normal values for Pelli-Robson test in phakic individuals from 60 to 75 years old and found a mean value of log $1.72 \pm 0.08$, while Elliot and Whitaker\textsuperscript{22} showed a mean value of log $1.50$ in phakic people above 50 years old. Contrast sensitivity with Pelli-Robson chart under photopic condition was measured in the two groups and there were no significant differences between the selected and non-selected groups ($P$ value = 0.5316) with mean values of logs in the selected and non-selected groups: $1.7338 \pm 0.153$, $1.7052 \pm 0.167$, respectively. This agrees with munõz,\textsuperscript{23} who found no statistical significant difference in contrast sensitivity between the eyes that were implanted with the Tecnis Z9000 IOL and the eyes implanted with AR40e or Stabibag IOLs. Rocha,\textsuperscript{24} also reported that there were no statistically significant differences
in photopic conditions in pseudophakic patients that were randomized to receive three IOL types, monofocal aspheric intraocular lens (AcrySof IQ) and spherical IOLs (AcrySof Natural, and AMO Sensar), (1.61 ± 0.08, 1.60 ± 0.10, and 1.61 ± 0.08, respectively) using the Pelli-Robson contrast sensitivity test and FACT (Optec 6500). While in Beiko et al., there was no significant difference between the Tecnis-selected group and the Tecnis-non selected group and there was a statistically significant difference in the spatial frequencies of 6.0 cpd and 12 cpd under photopic and mesopic conditions.

In agreement with Beiko et al., Munoz et al., there was no significant difference between the residual refractive error in the selected and non-selected groups (P = 0.0719).

Furthermore, there was no statistical significant difference between the selected and non-selected groups in the best spectacle corrected visual acuity (P = 0.3919), as in Beiko et al., Munoz, and Rocha.

In the current study, the pupil diameter has a low positive correlation with the (Z4) spherical aberration (r = 0.1019) (P value = 0.4677). In the matter of fact in some other studies, the aspheric IOLs have shown little or no benefit with smaller pupils because small pupils produce a little amount of spherical aberration. Subjective visual satisfaction of both groups was tested by (VF-14) focusing on functions related to spherical aberration and the IOL selection technology as it is related to many intervening factors. Refractive errors, pupil size, axial length, residual CSA, all are shown to influence the postoperative outcomes.

Conflict of interest

The authors declared that there is no conflict of interest.

References


