EXTENDED REPORT

Influence of tilt and decentration of scleral-sutured intraocular lens on ocular higher-order wavefront aberration

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Aim: To investigate the influence of tilt and decentration of scleral-sutured intraocular lenses (IOLs) on ocular higher-order wavefront aberrations.

Methods: In 45 eyes of 36 patients who had undergone scleral suture fixation of posterior chamber IOL, tilt and decentration of IOLs were determined by Scheimpflug videophotography, and higher-order aberration for a 4-mm pupil was measured using the Hartmann–Shack aberrometer. In another 100 eyes of 100 patients after standard cataract surgery with posterior chamber IOL implantation, ocular higher-order aberration was measured.

Results: In eyes with scleral-sutured IOL, the mean (SD) tilt angle and decentration were 4.43° (3.02°) and 0.279 (0.162) mm, respectively. Ocular coma-like aberration in the sutured IOL group was 0.324 (0.170) μm, which was significantly greater than that of the standard cataract surgery group (0.169 (0.061) μm, $p<0.001$, Student's t test). No significant difference was found in ocular spherical-like aberration between the sutured IOL group (0.142 (0.065) μm) and standard surgery group (0.126 (0.033) μm; $p=0.254$). In the sutured IOL group, IOL tilt significantly correlated with ocular coma-like aberration (Pearson's correlation coefficient $r=0.628$, $p<0.001$), but no significant correlation was found between IOL tilt and ocular spherical-like aberration ($r=0.222$, $p=0.175$). The IOL tilt did not correlate with corneal coma-like ($r=0.289$, $p=0.171$) and spherical-like ($r=0.150$, $p=0.356$) aberrations. The IOL decentration did not correlate with any higher-order aberrations.

Conclusion: In eyes with scleral-sutured posterior chamber IOL, tilting of the lens induces considerable amount of ocular coma-like aberrations.

Proper positioning and on-axis alignment of an intraocular lens (IOL) are critical in obtaining satisfactory quality of vision after cataract surgery. Patients with tilted or decentred IOLs may be unhappy with the results of otherwise successful cataract surgery. In fact, malposition of an IOL is one of the leading indications for removal, exchange or repositioning of a posterior chamber IOL.[1–5]

Malposition of the IOL comprises decentration and tilt. Although it has been known that decentration of the IOL can cause unwanted optical image or dysphotopsia,[6–10] the influence of major IOL tilting on the optical quality of the eye has never been reported. With expanding indications of cataract surgery, more complicated cases will undergo cataract removal and IOL implantation procedures, which would increase the risk of IOL misalignment after surgery. Patients tend to have longer longevity after surgery, which might further increase the risk of postoperative events. The optical performance of IOLs in the presence of displacement has been an important issue even in modern cataract surgery.[11–15] We conducted the current retrospective study to assess the influence of tilting and decentration of scleral-sutured posterior chamber IOLs on ocular higher-order aberrations.

PATIENTS AND METHODS

Patients

Forty five eyes of 36 patients (16 men and 20 women) who had undergone scleral suture fixation of a posterior chamber IOL were included. Their age ranged from 46 to 87 years (mean (standard deviation, SD)) 66.3 (14.2) years). The scleral-sutured IOLs were hydrophobic acrylic foldable IOL (MA60AC, AcrySof, Alcon Laboratories, Fort Worth, Texas, USA) in 18 eyes and polymethylmethacrylate IOL in 19 eyes, but details were not available in the remaining 8 eyes. Another 100 eyes of 100 patients (41 men and 59 women) after standard cataract surgery with in-the-bag implantation of hydrophobic acrylic foldable IOL (MA60AC) served as age-matched controls, ranging in age from 48 to 88 years (64.5 (13.5) years). The research protocol had institutional review board approval, and written informed consent was obtained from each patient. The study adhered to the tenets of the Declaration of Helsinki.

Examinations

In the scleral-sutured IOL group, tilt and decentration of IOLs as well as higher-order wavefront aberration were measured. In the standard cataract surgery group, higher-order wavefront aberration of the eye was measured.

Tilt and decentration of IOLs were determined by an anterior eye segment analysis system (EAS-1000; NIDEK, Gamagori, Aichi, Japan).[16–18] The EAS-1000 system consists of a Scheimpflug CCD video camera unit and an image analysis computer. The online computer included a special software package to quantitate the length of the decentration and the degree of the tilt.[16–18] Two Scheimpflug images of the IOL after full mydriasis were taken at slit angles of 45° and 135° by the CCD camera. After geometric correction, the weakly exposed original images were then enhanced further using binarisation and curve-fitting techniques. Next, by plotting the anterior surface of the IOL as well as the corneal surface on these images, the tilt angle of the IOL optic axis relative to the cornea vertex was quantified by the image analysis computer. The length of decentration was indicated by the distance of the IOL optic axis from the corneal vertex. The data of the two different Scheimpflug images were analysed in a three-dimensional manner.

Abbreviation: IOL, intraocular lens

Corneal and ocular wavefront aberrations for a 4-mm pupil were measured using the Hartmann–Shack wavefront aberrometer (Topcon, Tokyo, Japan).[19–21] The light source of the wavefront sensor is an infrared super luminescent diode laser ($\lambda = 840$ nm; the spectral full-width at half-maximum = 14 nm; power at the cornea = 20 μW). Reflected light from the point image was led to a Hartmann–Shack wavefront sensor by a lens system. The Hartmann–Shack wavefront sensor consists of 169 small lenses (square shape, edge = 0.6 mm) aligned in a grid on a Hartmann plate and a cooled charge-coupled device (pixel size = 9 μm). All of the Hartmann images were revised to the pupil-centre images. The obtained data were expanded into the set of orthogonal Zernike polynomials. The root-mean squares of third-order Zernike components (Z_3^{-3} to Z_3^{3}) were used to represent coma-like aberration and root-mean squares of fourth-order Zernike components (Z_4^{-4} to Z_4^{4}) were used to represent spherical-like aberrations.[22–24]

RESULTS

The average mean (SD) tilt angle and decentration of scleral-sutured IOLs were 4.43° (3.02°) and 0.279 (0.162) mm, respectively. The amounts of ocular coma-like and spherical-like aberrations in the eyes with sutured IOL were 0.324 (0.170) and 0.142 (0.065) μm, respectively. The ocular coma-like aberration in the sutured IOL group was significantly greater than that of the standard cataract surgery group (0.169 (0.061) μm, $p<0.001$, Student's t test). No significant difference was observed in the ocular spherical-like aberration between the sutured IOL group and the standard cataract surgery group (0.126 (0.033) μm; $p = 0.254$).

The amounts of corneal coma-like and spherical-like aberrations in the eyes with sutured IOL were 0.192 (0.116) and 0.097 (0.096) μm, respectively. The amounts of corneal coma-like and spherical-like aberrations in the standard cataract surgery group were 0.153 (0.095) μm and 0.072 (0.054) μm, respectively. Corneal aberrations did not differ considerably between the sutured IOL and standard cataract surgery groups.

Among the sutured IOL group, there was no significant difference in the amount of tilt, decentration, and ocular and corneal aberrations between the hydrophobic acrylic foldable and polymethylmethacrylate IOL groups.

In the sutured IOL group, there was a significant positive correlation between the IOL tilt and ocular coma-like aberration (Pearson's correlation coefficient $r = 0.628$, $p<0.001$; fig 1), but no significant correlation was found between the IOL tilt and ocular spherical-like aberration ($r = 0.222$, $p = 0.175$; fig 2). The IOL tilt did not correlate with corneal coma-like ($r = 0.289$, $p = 0.171$; fig 3) and spherical-like ($r = 0.150$, $p = 0.356$; fig 4) aberrations.

The IOL decentration did not correlate with ocular coma-like ($r = 0.123$, $p = 0.457$), ocular spherical-like ($r = -0.067$, $p = 0.685$), corneal coma-like ($r = 0.121$, $p = 0.456$) and corneal spherical-like ($r = -0.187$, $p = 0.249$) aberrations.

DISCUSSION

There have been several studies on the tilt and decentration of IOLs.[9 25–31] In general, modern cataract surgery yields smaller amount of tilt and decentration than the previous surgical procedures. On the other hand, a significant amount of tilt and decentration can sometimes be induced after trans-scleral suture fixation of IOLs in the absence of capsular support.[32 33] Hayashi *et al*[34] reported mean (SD) tilt angle of 6.35° (3.09°) and decentration length of 0.62 (0.31) mm in eyes with scleral suture-fixed IOLs, which were significantly greater than the values obtained in eyes with in-the-bag IOLs, tilt angle of 3.18° (1.66°) and decentration length of 0.29 (0.21) mm. Durak *et al*[35] reported that mean (SD) tilt and decentration of trans-sclerally sutured posterior chamber IOLs were 6.09° (3.80°) and 0.67 (0.43) mm, respectively. In the current study, we obtained a mean (SD) tilt angle of 4.43° (3.02°) and decentration length of 0.28 (0.16) mm in eyes with sutured IOL, which are favourably compared with the previous data.

In the present study, we found that major tilting of an IOL caused a substantial amount of ocular coma-like aberration. There was a significant positive correlation between IOL tilt and ocular coma-like aberration. Ocular spherical-like aberration, and corneal coma-like and spherical aberrations did not correlate with the amount of IOL tilt. Similarly, IOL decentration showed no correlation with any ocular or corneal higher-order aberrations. Recently, there has been a case report of a significant amount of ocular coma-like aberration caused by major tilting of an IOL, 28.87°, which was successfully treated by IOL repositioning surgery.[36] Taketani *et al*[30] reported that IOL tilt of even a small amount, 3.43° (4.55°), significantly correlated with ocular coma-like aberration.[30]

As shown in the results, the ocular coma-like aberration in the sutured IOL group (0.324 (0.170) μm) was significantly greater than that of the standard cataract surgery group (0.169 (0.061) μm). On the other hand, there was no significant difference in the ocular spherical-like aberration between the

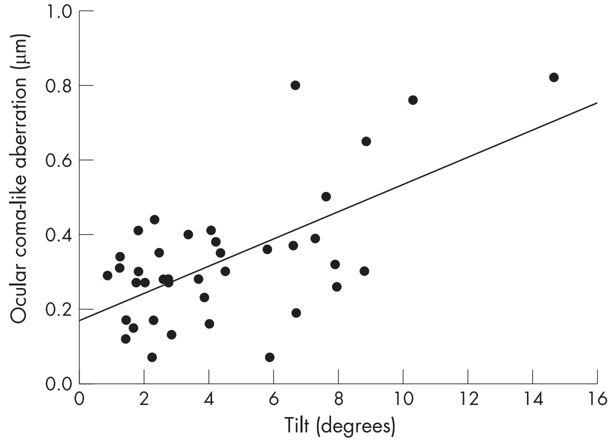

Figure 1 A significant positive correlation was found between the intraocular lens tilt and ocular coma-like aberration (Pearson's correlation coefficient $r = 0.628$, $p<0.001$).

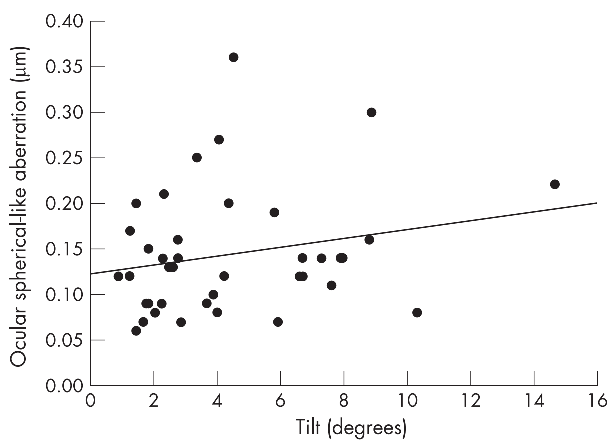

Figure 2 No significant correlation was found between the intraocular lens tilt and ocular spherical-like aberration (Pearson's correlation coefficient $r = 0.222$, $p = 0.175$).

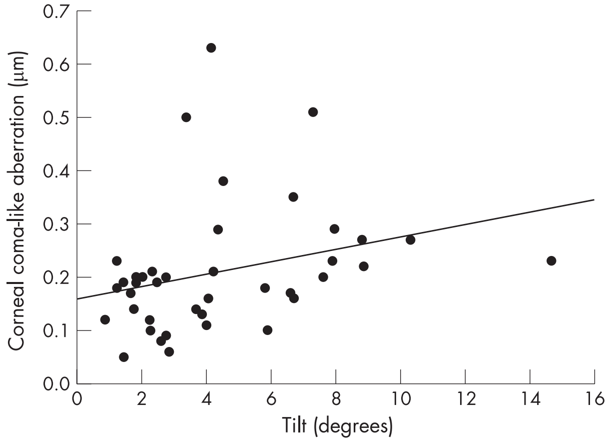

Figure 3 No significant correlation was found between the intraocular lens tilt and corneal coma-like aberration (Pearson's correlation coefficient r = 0.289, p = 0.171).

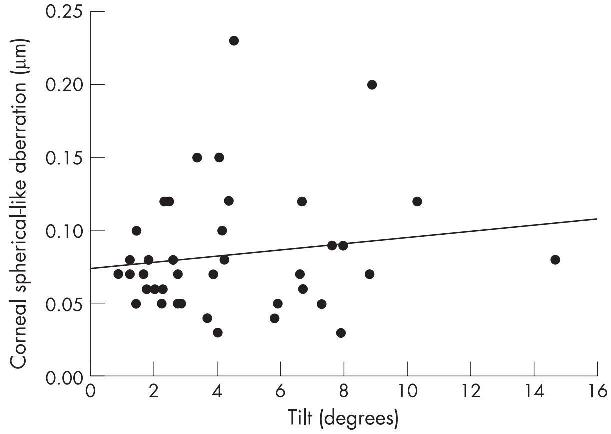

Figure 4 No significant correlation was found between the intraocular lens tilt and corneal spherical-like aberration (Pearson's correlation coefficient r = 0.150, p = 0.356).

sutured IOL group (0.142 (0.065) µm) and the standard cataract surgery group (0.126 (0.033) µm). In eyes after standard cataract surgery with foldable acrylic IOL implantation, the mean (SD) ocular coma-like and spherical-like aberrations for 4.0-mm aperture diameter were reported to be 0.194 (0.081) and 0.144 (0.07) µm, respectively.[30] In pseudophakic eyes with acrylic IOLs, ocular coma-like aberration for a 4-mm pupil was 0.125–0.15 µm and ocular spherical-like aberration for a 4-mm pupil was 0.075–0.082 µm.[37] Similar values have been reported for 4-mm to 5-mm aperture diameter in eyes after standard cataract surgery with implantation of spherical IOLs,[38 39] indicating that coma-like aberration was remarkably increased in eyes after scleral suture fixation of the IOL.

It would be interesting to know the influence of IOL tilt and coma-like aberration on visual quality of patients after scleral suture fixation of IOLs. These patients, however, had undergone complicated surgical procedures, which included primary or secondary scleral suture fixation of the IOL, and many of them have other ocular pathologies that affect visual functions. Thus, such evaluation is difficult in this study population. There have been several simulation studies on the visual impairment caused by IOL misalignment.[11–13] These studies, however, did not consider higher-order aberrations of human corneas, and therefore exact simulation of situations in living human eyes was rather difficult. In a case report, retinal image simulation of a Landolt ring was conducted using the wavefront aberration profile.[36] It was found that major tilt of the IOL resulted in remarkably skewed and blurred Landolt images, which were significantly improved by IOL repositioning surgery.[36] Compared with that report, the amount of IOL tilt in the current study was small, but still induced coma-like aberration may have induced skewed distortion of the object image. The present study alone cannot determine the extent of these changes in human eyes. Future studies are needed to elucidate these points.

Another weakness of this retrospective study is that various types of IOLs were used in the sutured IOL group. This was because of the retrospective nature of the current study. Moreover, surgical details including the type of IOL were not available in several patients, because they had been operated on at different surgical sites. There is a possibility that the differences in IOL design and material resulted in different amount and pattern of ocular wavefront aberrations. Bellucci *et al*[39] have reported, however, that ocular coma-like aberrations did not differ significantly among various types of IOLs, whereas ocular spherical-like aberrations were largely affected by the style of IOLs. Thus, we believe that there was little, if any, influence of the type of IOLs on the results of the current study.

Scleral suture fixation of a posterior chamber IOL is one of the surgical procedures used to implant an IOL in eyes with inadequate capsular support.[40 41] Other options to correct aphakic eyes in the absence of capsular support include anterior chamber IOL, iris-sutured posterior chamber IOL and contact lens correction of aphakia. Until now, these alternatives have been compared in terms of safety, efficiency and feasibility. The data obtained in the current study suggest that the influence of these procedures on optical quality of the eye should also be evaluated, making these comparisons more comprehensive and elaborate.

Although the current study was conducted in eyes with scleral suture fixation of IOLs, the findings obtained may have clinical implications in regular cataract surgery. The advent and widespread use of continuous curvilinear capsulorhexis greatly contributed to long-term centration of IOLs. However, perfect centration of IOLs is rare for many reasons including in–out-of-the-bag placement, incongruence between bag diameter and overall IOL diameter, a large capsulorhexis, asymmetrical capsule coverage, IOL placement in the sulcus, capsule fibrosis, capsule phimosis and radial bag tears.[13 42] Even if the IOL is perfectly centred, the other optical components of a human eye are rarely, if ever, centred on the visual axis or on any common axis. A new class of IOLs designed to offset corneal spherical aberration has been recently introduced,[43–46] making the relative alignments of IOLs and other optical components of the eye more important. Further studies in these fields are warranted.

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