Surgically induced astigmatism after cataract surgery – a vector analysis

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Title: Surgically induced astigmatism after cataract surgery – a vector analysis

Short title: SIA after cataract surgery

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Abstract

**Background:** Surgically induced astigmatism (SIA) has been widely discussed in the literature as the change in corneal astigmatism resulting from corneal incision. The purpose of this study was to investigate the change in corneal refractive power preoperative to postoperative using a vector analysis of keratometry, total keratometry, and corneal back surface data from a modern optical biometer.

**Methods:** The analysis was based on a dataset of 122 eyes of 122 patients with preoperative and 1 month postoperative measurements performed with the IOLMaster 700 biometer from 1 clinical centre and a standardised surgical technique involving a corneal 2.5 mm 45°-incision made from the superior direction. Keratometry, total keratometry and corneal back surface data were processed in 3 vector components (spherical equivalent power SEQ and astigmatism considered in 0°/90° (C₀) and in 45°/135° (C₄₅) meridian), and the changes in corneal power vectors were analysed, comparing preoperative to postoperative values.

**Results:** The mean corneal power of total keratometry reduced slightly after cataract surgery (-0.05 dpt), resulting mostly from a decrease in back surface power (-0.04 dpt). The astigmatism vector component C₀ of total keratometry reduced by -0.28 dpt, mostly due to a decrease at the corneal front surface (-0.26 dpt). With the corneal incision at 12 o’clock position this flattening in the 90° meridian refers to a SIA of around ¼ dpt. The change in C₀ and the C₄₅ astigmatic vector components for both keratometry and total keratometry show a large variation ranging between 0.24 and 0.33 dpt (standard deviations), indicating a poor predictability of the change in astigmatism due to cataract surgery.

**Conclusion:** Cataract surgery locally flattens the cornea in the incision meridian. This flattening shows a large individual variation and therefore a poor predictability. Our study indicates that SIA in modern cataract surgery with standardised corneal incision is in a range of 1/4 dpt.

**Key words:** Surgically induced astigmatism; Optical biometry, Vector analysis, Keratometry, Total keratometry, Back surface power
Background

Most lens power calculation programs for toric intraocular lenses (IOL) offer the option to consider surgically induced astigmatism (SIA) in predicting IOL power or residual refraction after cataract surgery. This SIA considers the change in corneal power vector as a result of cataract incisions [1,2]. Corneal incisions are known to induce iatrogenic flattening of the cornea. In general, the closer the incision to the corneal centre or the larger the incision, the more the cornea flattens in the area surrounding area [3-5]. Therefore, as a rule of thumb, corneal surgeons aim to locate corneal incisions in the steep corneal meridian so as to diminish corneal astigmatism, provided that the situation allows for such an incision in the steep meridian (e.g. temporally or superiorly).

Such an effect of corneal flattening resulting from corneal incisions is well known from arcuate or transverse keratotomies, where deep stromal incisions are placed mostly symmetrically to the cornea to reduce corneal astigmatism [6-8], e.g. following penetrating keratoplasty. To enlarge the effect of astigmatic correction such pairs of incisions are sometimes supplemented with interrupted sutures in the orthogonal meridian.

We know from the literature that the long-term flattening effect of corneal incisions in modern cataract surgery is limited, and the predictability is rather low. Furthermore, in minimal invasive cataract surgery (MICS) techniques with corneal incisions of 2.2 mm or less, corneal flattening must be analysed carefully to deal with SIA in IOL calculation programs, especially if the incision is placed more peripherally instead of a clear cornea incision [9-11].

The SIA has to be extracted specifically for the surgical technique of each individual surgeon, as the flattening may depend not only on the incision width and location and the corneal diameter [12], but also on the tools used and the incision angle (e.g. tunnel length) [13]. For extracting the SIA, keratometry or corneal topography should be analysed before as well as after cataract surgery after stabilisation of corneal curvature. However, the curvature changes are not fully described when using standard keratometry or topography [10], and a measurement of corneal back surface curvature before and after surgery may give additional insight in the change of corneal refraction due to cataract surgery, to be considered for subsequent surgical interventions. Astigmatism of the corneal front (and back) surface is decomposed into vector components [1,2,14-16], and the change from preoperative to postoperative may be directly investigated with the astigmatic difference vector or the change of vector components [17].

However, even if corneal front and back surface astigmatism is analysed before and after cataract surgery, asymmetrical changes in the corneal curvature profile are not considered, and this may
induce optical aberration such as coma or trefoil [10,18]. Such optical aberrations might be responsible for deterioration of visual performance even when the defocus and astigmatic refraction error are fully corrected. However, it is in general very difficult to systematically describe such complex curvature changes due to cataract surgery [18].

The purpose of this study was a) to analyse corneal astigmatism in terms of keratometry, total keratometry and back surface power from biometer data (IOLMaster 700) from one clinical centre before and after cataract surgery with a standardised corneal incision at the 12 o’clock position using vector algebra, b) to investigate the change in astigmatism from preoperative to postoperative, and c) to derive the surgically induced astigmatism for use in a toric lens power calculation module for subsequent cataract surgeries.
Methods

Dataset for our study and surgical details

In total, a dataset including 498 eyes measured with the IOLMaster 700 (Zeiss, Jena, Germany) from one clinical centre (Kepler-University, Linz, Austria) was considered for this retrospective study. The data were transferred to a .csv data table using the data export and backup module of the software [19]. For all eyes, the respective preoperative (1 day to 4 weeks) and postoperative biometric measurements at follow-up stages 1 month (3 weeks to 5 weeks), 3 months (10 to 16 weeks), and 6 months (21 to 31 weeks) after cataract surgery were reorganised with all data for one eye in a single row. In cases where both eyes of a patient were included, one eye was chosen at random and the other was excluded. Data tables were reduced to the relevant parameters required for our analysis, consisting of: keratometry based on corneal front surface curvature (flat meridian R1 in mm with axis A1 in °; steep meridian R2 in mm with axis A2 in °), total keratometry based on corneal front and back surface curvature (flat meridian TR1 in mm with axis TA1 in °; steep meridian TR2 in mm with axis TA2 in °), corneal back surface curvature (flat meridian PR1 in mm with axis PA1 in °; steep meridian PR2 in mm with axis PA2 in °), preoperative axial length (AL in mm), preoperative central corneal thickness (CCT in mm), phakic anterior chamber depth (ACD in mm) measured from corneal front apex to the lens front apex, phakic lens thickness (LT in mm), and preoperative horizontal corneal diameter (W2W in mm), pupil diameter, and eye (OD / OS) [20]. Missing data, or data with a ‘Failed’ or ‘Warning’ marker in the quality check for keratometry, total keratometry, back surface curvature, or AL, CCT, ACD, LT, W2W provided by the IOLMaster 700 software, and also measurements in mydriasis (pupil size > 5.5 mm) or with changes in the pupil size from preoperative to postoperative measurement of more than 1.5 mm, were excluded. After checking for ‘Successful’ measurement, a dataset containing records of measurements from N=334 eyes with preoperative and postoperative measurements was used.

All surgeries were performed between October 2018 and October 2021 by 6 experienced surgeons under topical anaesthesia. After a clear corneal incision (CCI) in direct proximity to the limbus (Beaver Xstar Safety Slit Knife 2.5mm 45°, BVI medical, Heidelberg, Germany), the anterior chamber was filled with a dispersive OVD (Polyvisc 2.0%, Polytech Domilens GmbH, Rossdorf, Germany). Two paracenteses (Beaver Safety Sideport Knife 1.15mm 45°, BVI medical, Heidelberg, Germany) were applied perpendicularly (nasal and temporal) to the CCI. The creation of a continuous curvilinear capsulorhexis slightly smaller than the IOL optic diameter (approximately 5.5 mm) was performed in all cases. After a standard phacoemulsification procedure (OS4, Oertli Instrumente AG, Switzerland),
the IOL was inserted and the CCI and both paracenteses were hydrated. After checking the bulbus for reasonable tonisation, an ointment dressing for the first postoperative night was applied.

Only eyes with a superior location of the cataract incision (Marek et al. 2006; symmetrically to the 12 o’clock position) and with biometric measurements available before cataract surgery and at 1 month postoperatively were considered. For all remaining eyes, the intraoperative details such as surgeon, lens type and power, and incision width were recorded. The data were transferred to Matlab (Matlab 2019b, MathWorks, Natick, USA) for further processing. The study was registered with the local Ethics committee (Ärztekammer des Saarlandes, 157/21).

Preprocessing of the data

Custom software was written in Matlab to decompose the refractive power of keratometry, total keratometry and back surface power from standard notation (corneal curvature in both cardinal meridians with axis orientations) to power vector components in terms of spherical equivalent power (RSEQ, TRSEQ, and PRSEQ, respectively), power vector projected to the 0°/90° meridian (RC0°, TRC0°, and PRC0°, respectively), and power vector projected to the 45°/135° meridian (RC45°, TRC45°, and PRC45°, respectively) [1,2,14-16]:

\[
\begin{align*}
RSEQ &= 0.5 \cdot (332/R1 + 332/R2) \\
RC0° &= (332/R2 - 332/R1) \cdot \cos(2 \cdot A1) \\
RC_{45°} &= (332/R2 - 332/R1) \cdot \sin(2 \cdot A1) \\
TRSEQ &= 0.5 \cdot (332/TR1 + 332/TR2) \\
TRC0° &= (332/TR2 - 332/TR1) \cdot \cos(2 \cdot TA1) \\
TRC_{45°} &= (332/TR2 - 332/TR1) \cdot \sin(2 \cdot TA1) \\
PRSEQ &= -0.5 \cdot (40/PR1 + 40/PR2) \\
PRC0° &= (40/PR1 - 40/PR2) \cdot \cos(2 \cdot PA1) \\
PRC_{45°} &= (40/PR1 - 40/PR2) \cdot \sin(2 \cdot PA1)
\end{align*}
\]

The power vector components in 45°/135° (RC45°, TRC45° and PRC45°) for keratometry, total keratometry and back surface power were reversed in sign for all left eyes in our dataset in order to present the data in the same orientation as for right eyes.

The change in power vector from preoperative to 1 month postoperative, 1 month to 3 months postoperative, and 3 months to 6 months postoperative was derived by subtracting the respective power vector components for keratometry, total keratometry, and back surface [2,21].

For additional evaluation of the long term power vector change in addition to the entire dataset including measurements with at least the preoperative and the 1 month postoperative measurement, a subset of the complete data in which preoperative as well as 1 month, 3 months, and 6 months follow-up data of biometry were available was selected.

Double angle plots were used to display the power vector components C0° (in the horizontal direction) and C45° (in the vertical direction), as well as the changes of the power vector from...
preoperative to 1 month, from 1 month to 3 months, and from 3 months to 6 months postoperative. From the power vector components $C_{0^\circ}$ and $C_{45^\circ}$ for keratometry, total keratometry and back surface at all time stages, together with the changes in power vector components from preoperative to 1 month, from 1 month to 3 months, and from 3 months to 6 months postoperative, the 90% confidence ellipse was derived using eigenvalue decomposition [21,22]. The respective error ellipses together with the respective centroids (centres of the error ellipses) were overlaid on the double angle plots.
Results

In total, after filtering and applying inclusion/exclusion criteria to the measurements, our dataset consists of 122 eyes (53 left and 69 right eyes from 61 female and 61 male patients from one clinical centre. The mean age was $66.5 \pm 9.7$ years (median: 65 years, 90% confidence interval: 48 to 81 years). Table 1 shows the explorative data for the situation before cataract surgery: AL, CCT, ACD, LT, W2W, power vector for keratometry (RSEQ, RC0°, RC45°), total keratometry (TRSEQ, TRC0°, TRC45°), and back surface power (PRSEQ, PRC0°, PRC45°). The subset of data with complete examinations both preoperative and at all 4 postoperative time stages for analysing the time course of the power vectors includes 22 eyes.

The upper, middle and lower graph in Figure 1 display the double angle plots of power vector components $RC_{0°} / RC_{45°}$ for keratometry, $TRC_{0°} / TRC_{45°}$ for total keratometry, and $PRC_{0°} / PRC_{45°}$ for back surface. The respective starting points are marked with dots, and the vector changes between subsequent time stages are marked with lines. Blue lines indicate the vector changes from preoperative to 1 month postoperative, red lines from 1 month to 3 months postoperative, and yellow lines from 3 months to 6 months postoperative, respectively. The error ellipses indicating the 90% confidence intervals, together with the centroids for the preoperative and the 1 month postoperative data are overlaid on the graphs. The inner, middle, and outer ring plotted with dashed cyan lines refer to astigmatism below 0.5 dpt, 1.0 dpt, and 2.0 dpt for keratometry and total keratometry, and to 0.25 dpt, 0.5 dpt, and 1.0 dpt for the back surface respectively. For left eyes, the vector components $RC_{45°}$, $TRC_{45°}$, and $PRC_{45°}$ are reversed in sign in order to present the data in the same orientation as for right eyes. The inner, middle, and outer ring plotted with dashed cyan line refer to astigmatism below 0.5 dpt, 1.0 dpt, and 2.0 dpt for keratometry and total keratometry, and to 0.25 dpt, 0.5 dpt, and 1.0 dpt for the back surface respectively.

Table 2 lists the changes in power vector components for the entire dataset (with biometric measurements taken at least preoperatively and 1 month postoperatively) from preoperative to the 1 month follow-up stage for keratometry (spherical equivalent (RSEQ), and astigmatism projected to the 0°/90° meridian (RC0°) and to the 45°/135° meridian (RC45°), total keratometry (TRSEQ, TRC0°, and TRC45°), and back surface (PRSEQ, PRC0°, and PRC45°), respectively. In Table 3 the respective changes in power vector components are provided for the subset of complete data with examinations taken preoperatively and at all 3 postoperative time stages for keratometry (spherical equivalent (RSEQ), and astigmatism projected to the 0°/90° meridian (RC0°) and to the 45°/135° meridian (RC45°), total keratometry (TRSEQ, TRC0°, and TRC45°), and back surface (PRSEQ, PRC0°, and PRC45°), respectively.
Figure 2 shows the double angle plots of the change in power vector components $RC_{0°}$ / $RC_{45°}$ for keratometry (upper graphs), $TRC_{0°}$ / $TRC_{45°}$ for total keratometry (middle graphs), and $PRC_{0°}$ / $PRC_{45°}$ for back surface (lower graphs). The 3 graphs on the left side refer to the entire dataset ($N=122$) with at least preoperative and 1 month follow-up measurements, and the 3 graphs on the right side refer to the subset with complete measurement sequences taken preoperatively and 1 month, 3 months, and 6 months postoperatively ($N=30$). Blue circle markers correspond to the vector change from preoperative to the 1 month follow-up, and red and green dots refer to the vector change from 1 month to 3 months and from 3 months to 6 months postoperative. The respective error ellipses indicating the 90% confidence intervals together with the centroids (marked with ‘X’) are overlaid to the graphs. For the entire dataset (graphs on the left side) the error ellipses for the vector change from 1 month to 3 months and from 3 months to 6 months have been discarded. The inner, middle, and outer dashed cyan circles refer to astigmatism changes below 0.25 dpt, 0.5 dpt, and 1.0 dpt for keratometry and total keratometry, and to 0.125 dpt, 0.25 dpt, and 0.50 dpt for the back surface respectively.

In Figure 3 the violin plot of the change in power vector components from preoperatively to the 1 month postoperative follow-up stage is shown for the entire dataset ($N=122$) with biometric measurements taken at least preoperatively and 1 month postoperatively. The 3 graphs on the left (in blue colour) refer to the spherical equivalent power (RSEQ) and the projections of the astigmatism to $0°/90°$ ($RC_{0°}$) and $45°/135°$ ($RC_{45°}$) for keratometry, the 3 graphs in the middle (TRSEQ, $TRC_{0°}$, and $TRC_{45°}$, in red colour) and on the right (PRSEQ, $PRC_{0°}$, and $PRC_{45°}$, in green colour) refer to the respective components for total keratometry and back surface. To fit the scale of keratometry and total keratometry, the components for the back surface are scaled by x4. The violin plots show the arithmetic mean with standard deviation (small black markers and vertical black lines), the median value (horizontal blue, red or green lines, and the kernel distribution of the components of the vector changes (violin body).
Discussion

In cataract surgery, the surgically induced astigmatism (SIA) is always defined in terms of the change in corneal curvature, as indirect methods such as the change in refractive cylinder are unreliable because of the poor quality of the refraction measures prior to surgery. The change in corneal curvature can be split into a regular astigmatic component, which refers to the change in spherical equivalent power and astigmatism, and to an irregular component which is not included in the SIA, but which typically induces optical aberrations [18] and deteriorates the visual performance. Such irregular components include coma-like changes resulting from a local flattening of the cornea around the corneal incision (which is not balanced with a flattening opposite to the corneal incision [6,7,23]) as well as trefoil-like changes. As the irregular components cannot be corrected with standard techniques such as spherocylindrical spectacles or (toric) intraocular lenses, they are ignored in the derivation of the SIA. There is no common agreement as to the timepoint at which the corneal curvature should be quoted after cataract surgery to derive the SIA [17]. In most studies, the postoperative measurement is taken 1 to 3 months after cataract surgery, but there could be some minor changes or fluctuations in the corneal architecture even after 6 months, as shown in the present paper.

In many cases researchers focus on the change in the astigmatic power vector and ignore the change in overall corneal power. In the present study we decomposed the corneal power vector into 3 components [14,21], which refer to the corneal spherical equivalent power and to the 2 power components with projections to the even (0°/90°) and the odd (45°/135°) meridian, as commonly used in all power vector analysis studies. The spherical equivalent power describes the overall refraction of the cornea, whereas the two astigmatic components refer to a description of corneal astigmatism complementary to the standard notation with absolute value of astigmatism and orientation of the cylinder axis [14,15]. The benefit of the component notation is, that – in contrast to the standard notation – the respective components can be directly algebraically added (for cross cylinders) or subtracted (for the change from one time point to another [21,24]).

In general, for analysis of surgically induced astigmatism the vector analysis is performed once for a coordinate system referenced to the horizontal meridian (in a double angle representation this refers to a projection to the 0°/90° meridian and to the 45°/135 meridian) and again for a coordinate system referenced to the axis defined by the corneal incision (this refers to a projection to the meridian of corneal incision / perpendicular to the corneal incision and to the meridians 45°/135° from the corneal incision). As this dataset was restricted to superiorly located incisions, the flattening in the incision axis is directly described by the change of the power vector components $RC_0$, $TRC_0$, $RTC_0$.
and PRC\(_{0^\circ}\) for standard keratometry, total keratometry, and back surface. A separate evaluation of the vector change in the incision axis or a subdivision of the study group having different incision locations with potentially different effects of corneal incision on SIA [25] is therefore not required. Standard keratometry, total keratometry and back surface measurement were considered in order to gain insight as to whether the corneal front or back surface induces the changes in corneal power.

From Table 2 we see that the average total corneal power slightly decreases due to surgery by around 0.05 dpt. This is mostly caused by the steepening of the corneal back surface (0.04 dpt), whereas flattening of the corneal front surface is very low (0.01 dpt). In 2021 Yoon et al. studied SIA based on measurements made with an automated keratometer and a Scheimpflug tomographer [26]. They found that in their study population including 69 eyes there was a very slight statistically non-significant decrease in the power of the anterior surface (on average -0.02 dpt) and in the power of the posterior surface (on average -0.01 dpt). The corneal power vector component in the 0°/90° meridian decreases by around ¼ dpt (change of -0.26 dpt for keratometry and – 0.28 dpt for total keratometry), whereas the respective change in corneal back surface is negligible (0.01 dpt). This flattening refers directly to the surgically induced astigmatism as our dataset was restricted to corneal incisions at 12 o’clock positions. Interestingly, the flattening at the incision axis is restricted to the corneal front surface only. The corneal power vector component in the oblique meridians (45°/135°) decreases slightly by around 0.3 dpt measured with keratometry and total keratometry, whereas the corneal back surface change is very small (0.01 dpt).

Table 3 shows us, in the subset of data having measurements at all follow-up stages available, that the flattening of corneal front surface by around ¼ dpt from preoperative to the 1 month follow-up stage is not completely stable, but shows some variation from the 1 month to the 3 months (on average 0.05 dpt / 0.08 dpt for keratometry / total keratometry) as well as from the 3 months to the 6 month examination (on average -0.02 dpt for keratometry and total keratometry). This is in line with the results presented by Leen et al., who studied the vector changes in the period shortly after cataract surgery [27]. They found that, especially in the first 3 months, stabilisation of the corneal architecture is not finished and slight fluctuations of corneal astigmatism should be expected. However, the variation of the power vector components for keratometry and total keratometry from the 1 month to the 3 month (in a range of 0.10 to 0.16 dpt) or the 3 months to the 6 months examination (in a range of 0.11 to 0.19 dpt) may be even more relevant. This shows us that either the corneal curvature is not stable in a time course after 1 month postoperative or that the keratometry measurement shows some variation.

From the data scatter and the error ellipses in Figure 2 we can directly see that the change in vector components RC\(_{0^\circ}\) and TRC\(_{0^\circ}\) for keratometry and total keratometry are mostly negative from the
preoperative to the 1 month postoperative measurement. This means that the cornea is flattened in the 90° meridian. This finding is in accordance with the results of Rho et al., who found that in a study including 95 patient eyes the flattening in the steep meridian of the cornea before cataract surgery was on average 0.28 dpt [28]. The median flattening – 0.28/0.31 dpt for keratometry and 0.32/0.34 dpt for total keratometry for the entire dataset / the subset of data – refers to the surgically induced astigmatism SIA. However we also see from Figure 2 that the change in the power vector components is very inhomogeneous with a range from -0.66 to 0.23 dpt for keratometry and from -0.74 to 0.33 dpt for total keratometry (90% confidence intervals). This means that the range is much wider compared to the mean or median, and therefore correcting the mean surgically induced astigmatism with (toric) lens power calculation is only able to reduce the resulting postoperative refractive cylinder on average, and does not address the individual change in corneal curvature.

Finally, Figure 4 shows us that the average corneal power slightly decreases from the preoperative to the 1 month postoperative follow-up (total keratometry), mostly due to a steepening of the corneal back surface (reduced PRSEQ), whereas the corneal front surface remains unchanged (keratometry). These findings are in accordance with the results of Nemeth et al. who studied the surgically induced astigmatism at the posterior corneal surface using a Scheimpflug tomographer in a study population including 88 eyes. They found that in the corneal back surface the refractive power decreased following surgery due to a steepening whereas the corneal front surface power remained on average unchanged. They concluded that for SIA analysis a measurement of the corneal front surface only (e.g. using keratometry or topography) might be insufficient as potential changes of the corneal back surface geometry would be ignored. The corneal front surface significantly flattens in the incision axis (90° meridian) as documented by negative values for the power vector changes $R_{C0}$ for keratometry and $TRC_{0}$ for total keratometry, whereas the respective component for the corneal back surface power remains unchanged. The components of the power vector corresponding to the oblique meridians (45°/135°) of the astigmatism do not show a systematic change with a corneal incision at 12 o’clock position, but the individual variation is comparable to the respective variation of the power vector corresponding to the 0°/90° meridians as shown with the kernel distributions.

In conclusion, this paper shows that with a corneal incision from the superior in modern cataract surgery, the corneal power reduces by around ¼ dpt in the 90° meridian, mostly as the result of a change in corneal front surface curvature. The variations in the change of both astigmatic power vector components in 0°/90° and 45°/135° are comparable in magnitude. The reduction of corneal power in the corneal incision axis is mostly counterbalanced by a steepening in the orthogonal meridian in such a way, that on average we see only a very slight reduction of overall corneal power from preoperative to the 1 month follow-up.
References:


Declaration of Interest

The authors have no financial or proprietary interest in the material

Declaration of Funding:

This study was not funded by a public or private sponsor.

Data Availability Statement

Raw data were generated at Department of Ophthalmology, Johannes Kepler University Linz, Austria. Derived data supporting the findings of this study are available from the corresponding author (AL) on request.
Tables and Table Legends

Table 1: Preoperative measurement data from the IOLMaster 700 for the entire dataset (N=122, with biometric measurements taken at least preoperatively and 1 month postoperatively): Distance measures: axial length (AL), central corneal thickness (CCT), anterior chamber depth (ACD) from corneal front apex to lens front apex, lens thickness (LT) and horizontal corneal diameter (W2W); power vector components for keratometry (spherical equivalent power RSEQ, astigmatism projected to the 0°/90° meridian RC₀, astigmatism projected to the 45°/135° meridian RC₄₅), total keratometry (spherical equivalent power TRSEQ, astigmatism projected to the 0°/90° meridian TRC₀, astigmatism projected to the 45°/135° meridian TRC₄₅), and back surface (spherical equivalent power PRSEQ, astigmatism projected to the 0°/90° meridian PRC₀, astigmatism projected to the 45°/135° meridian PRC₄₅). MEAN, SD, MEDIAN, and 5% quantile / 95% quantile refer to the arithmetic mean, standard deviation, median, and the lower and upper bounds of the 90% confidence interval respectively.

<table>
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<th>N=122</th>
<th>Distances in mm</th>
<th>Power vector keratometry in dpt</th>
<th>Power vector total keratometry in dpt</th>
<th>Power vector back surface in dpt</th>
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<td>AL</td>
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### Table 2

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<th>N=122</th>
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</tbody>
</table>

Table 2: Change in power vector components for the entire dataset (N=122, with biometric measurements taken at least preoperatively and 1 month postoperatively) from preoperative to the 1 month follow-up stage for keratometry (spherical equivalent (RSEQ), and astigmatism projected to the 0°/90° meridian (RC0°) and to the 45°/135° meridian (RC45°), total keratometry (TRSEQ, TRC0°, and TRC45°), and back surface (PRSEQ, PRC0°, and PRC45°), respectively. MEAN, SD, MEDIAN, and 5% / 95% quantile refer to the arithmetic mean, standard deviation, median, and the lower and upper bounds of the 90% confidence interval respectively.
Table 3: Change in power vector components for the subset of complete data with examinations made preoperatively and at all 3 postoperative time stages (N=30) for keratometry (spherical equivalent (RSEQ), and astigmatism projected to the 0°/90° meridian (RC$_{0°}$) and to the 45°/135° meridian (RC$_{45°}$), total keratometry (TRSEQ, TRC$_{0°}$, and TRC$_{45°}$), and back surface (PRSEQ, PRC$_{0°}$, and PRC$_{45°}$), respectively. MEAN, SD, MEDIAN, and 5% / 95% quantile refer to the arithmetic mean, standard deviation, median, and the lower and upper bounds of the 90% confidence interval respectively.
Figures and Figure Legends
**Figure 1** Double angle plots of power vector components $RC_{0°}/RC_{45°}$ for keratometry (upper graph), $TRC_{0°}/TRC_{45°}$ for total keratometry (middle graph), and $PRC_{0°}/PRC_{45°}$ for back surface (lower graph) for the entire dataset (N=122, with biometric measurements taken at least preoperatively and 1 month postoperatively). The respective starting points are marked with dots, and the vector changes between subsequent time stages are marked with lines. Blue lines indicate the vector changes from preoperative to 1 month postoperative, red lines from 1 month to 3 months postoperative, and yellow lines from 3 months to 6 months postoperative, respectively. The error ellipses indicating the 90% confidence intervals together with the centroids for the preoperative and the 1 month postoperative data are overlaid on the graphs. The 3 months and 6 months follow-up measurement data are incomplete. The inner, middle, and outer ring plotted with dashed cyan lines refer to astigmatism below 0.5 dpt, 1.0 dpt, and 2.0 dpt for keratometry and total keratometry, and to 0.25 dpt, 0.5 dpt, and 1.0 dpt for the back surface respectively. For left eyes, the vector components $RC_{45°}$, $TRC_{45°}$, and $PRC_{45°}$ are reversed in sign in order to present the data in the same orientation as for right eyes.
**Figure 2**: Double angle plots of the change in power vector components $RC_{0^\circ} / RC_{45^\circ}$ for keratometry (upper graphs), $TRC_{0^\circ} / TRC_{45^\circ}$ for total keratometry (middle graphs), and $PRC_{0^\circ} / PRC_{45^\circ}$ for back surface (lower graphs). On the left side the graphs for the entire dataset ($N=122$, with at least preoperative and 1 month follow-up measurements) are displayed, and on the right side the graphs for the subset with complete measurement sequences taken preoperatively and 1 month, 3 months, and 6 months postoperatively ($N=30$) are shown. Blue circle markers correspond to the vector change from preoperatively to the 1 month follow-up, and red and green dots refer to the vector change from 1 month to 3 months and from 3 months to 6 months postoperative. The respective error ellipses indicating the 90% confidence intervals together with the centroids are overlaid on the graphs. For the entire dataset the error ellipses for the vector change from 1 month to 3 months and from 3 months to 6 months are not shown. The inner, middle, and outer ring plotted with dashed cyan lines refer to astigmatism changes below 0.25 dpt, 0.5 dpt, and 1.0 dpt for keratometry and total keratometry, and to 0.125 dpt, 0.25 dpt, and 0.50 dpt for the back surface respectively.
Figure 3: Violin plot of the change in power vector components from preoperative to the 1 month postoperative follow-up stage for keratometry (in blue), total keratometry (in red), and back surface (in green) for the entire dataset (N=122, with biometric measurements taken at least preoperatively and 1 month postoperatively). Please note that the respective values for the back surface components are scaled by x4. The violin plots show the mean with standard deviation (small circle marker and black lines), the median (blue, red, and green horizontal lines) as well as the kernel distribution of the parameters (violin body).