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Refractive outcomes following cataract surgery in patients who have had myopic laser vision correction

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ABSTRACT

Objective Prediction errors are increased among patients presenting for cataract surgery post laser vision correction (LVC) as biometric relationships are altered. We investigated the prediction errors of five formulae among these patients.

Methods and analysis The intended refractive error was calculated as a sphero-cylinder and as a spherical equivalent for analysis. For determining the difference between the intended and postoperative refractive error, data were transformed into components of Long's formalism, before changing into sphero-cylinder notation. These differences in refractive errors were compared between the five formulae and to that of a control group using a Kruskal-Wallis test. An F-test was used to compare the variances of the difference distributions.

Results 22 eyes post LVC and 19 control eyes were included for analysis. Comparing both groups, there were significant differences in the postoperative refractive error (p=0.038). The differences between the intended and postoperative refractive error were greater in post LVC eyes than control eyes (p=0.012), irrespective of the calculation method for the intended refractive error (p<0.01). The mean difference between the intended and postoperative refractive error was relatively small, but its variance was significantly greater among post LVC eyes than control eyes (p<0.01). Among post LVC eyes, there were no significant differences between the mean intended target refraction and between the intended and postoperative refractive error using five biometry formulae (p=0.76).

Conclusion Biometry calculations were less precise for patients who had LVC than patients without LVC. No particular biometry formula appears to be superior among patients post LVC.

Key messages

What is already known about this subject?

- Biometry calculations were less precise among patients post laser vision correction (LVC) presenting for cataract surgery. No particular biometry formula was superior among these patients in previous studies which used spherical equivalent to compare the intended and postoperative refractive outcomes.

What are the new findings?

- Using a sphero-cylindrical analysis, we found that cataract surgery refractive outcomes among patients who had previously undergone LVC showed greater variation than control patients, with no significant difference found between currently used biometry formulae.

How might these results change the focus of research or clinical practice?

- Presenting refractive data as spherical equivalent and treating components of refractive power independently introduce errors in analysis of refractive outcomes. When determining the differences between the intended and actual postoperative refractive error, refractive data should be transformed into components of Long's formalism, before changing back into sphero-cylindrical notation.

INTRODUCTION

Cataract surgery is the most common operation performed in the National Health Service (NHS), with around 330 000 procedures carried out each year in England.[1] Phacoemulsification and removal of cataract with implantation of a synthetic intraocular lens (IOL) provides significant patient benefit.[2] Benchmark standards for refractive outcomes after cataract surgery have been put forward by The Royal College of Ophthalmologists. It is recommended that the postoperative spherical equivalent should be within 1 dioptre of that aimed for in 85% of operations, and within 0.5 dioptres in 55% of operations.[1 3] Refractive outcomes have generally improved with time as a result of refinements in operative techniques, acquisition of increasingly accurate biometric data and the refinement of biometric formulae used to calculate the IOL power.[4–6] Although these have led to a progressive reduction in spherical equivalent prediction errors, it is not a good predictor of spectacle independence.[7] The analogy is that spectacle prescriptions are not prescribed or dispensed as a spherical equivalent but as a sphero-cylinder.

Laser vision correction (LVC) has become increasingly popular for the correction of refractive errors, commonly laser in-situ keratomileusis (LASIK), laser epithelial keratomileusis (LASEK) or photorefractive keratectomy (PRK). Many patients who have previously undergone LVC are now developing cataract and presenting for surgery.[8] The formulae which are commonly used for IOL power calculation, such as the SRK-T and Hoffer Q formulae, are prone to error in patients who have had LVC for a number of reasons.[9–14] Standard formulae assume a fixed relation between the anterior and posterior corneal surface curvatures. This assumption does not hold for eyes which have undergone myopic LVC as the anterior corneal curvature is reduced, so that the ratio between the anterior and the posterior curvature is altered, along with the total corneal power and index of refraction.[15 16] In addition, keratometers measure the central corneal zone and assume a sphero-cylindrical shape to the cornea, which is no longer true after LVC.[17] All third and fourth generation IOL calculation formulae also use the central corneal power to help predict the effective lens position (ELP). In patients with myopic ablation patterns, however, the central cornea has been flattened, and these formulae predict a falsely shallow ELP, thereby recommending insufficient IOL power, causing postoperative hyperopic surprise.[16 18 19] Higher order aberrations induced by LVC are also not taken into account in standard practice.

All of these factors can lead to inaccuracies in biometric calculations using standard formulae and a large deviation from the expected refractive outcome for the IOL power selected. These 'refractive surprises' can lead to very unhappy patients with the need for further risk-prone procedures such as IOL exchange or further LVC. A number of methods have been introduced to measure or estimate the true corneal power after LVC. The Clinical History Method (CHM), introduced by Holladay in 1989, calculates the corneal power by subtracting the change in manifest refraction at the corneal plane induced by the refractive surgical procedure from the corneal power obtained before refractive surgery.[20] There are however, a number of limitations to the CHM. The relevant historical information may be unavailable and of questionable reliability. There may also have been changes in the corneal curvature since the initial LVC procedure. A number of alternative methods have since been proposed for calculating the IOL power required.[12 21–23] Recent work has suggested that the Masket Method, the Haigis-L, the Shammas post-Lasik (Shammas-PL) and the Barrett True-K formulae give some of the most reliable predictions for choosing IOL power.[24–28]

An important issue when considering IOL power calculations and refractive outcomes which has often been overlooked is the effect of uncorrected residual sphero-cylindrical refractive error, even though these appear to have a marked adverse effect on unaided vision.[7] This means that the advantages and disadvantages of different approaches to improve refractive outcomes in patients undergoing cataract surgery who have had refractive laser surgery may not be readily apparent.

Other approaches have been applied to treat the components of the refractive error as independent terms, that is, separation of the sphere and cylinder. They are not, however, independent variables and a change in one is invariably associated with a change in the other.[29–31] Attempts to treat the components of a refractive power independently, regardless of whether the cylinder is treated as a vector or a scalar number, will introduce errors and potentially lead to statistically erroneous conclusions.[32–35]

There are now informative and established methods to treat the analysis of refractive errors appropriately and which are easily applicable to assess refractive outcomes following cataract surgery.[36–39] The purpose of this study was to compare the differences between the intended and actual postoperative refractive outcomes using the CHM, Masket, Shammas-L, Haigis-L and the Barrett True-K formula methods following cataract surgery in patients who had undergone previous LVC. Outcomes in LVC patients were also compared with a group of control patients who had not undergone LVC. We used an innovative analytical technique using the sphero-cylindrical error with refractive outcome data being transformed into components of Long's formalism before transformation back into sphero-cylindrical notation. Analysis using the spherical equivalent error was also presented for reference.

PATIENTS AND METHODS

Consecutive patients undergoing uneventful cataract surgery at The Royal Liverpool University Hospital, who had previously undergone LVC were included, together with a control group of patients who had not undergone LVC. This was approved as an audit project by the hospital audit department.

Inclusion criteria were patients who were identified as having previously undergone LASIK, LASEK or PRK for myopia and then underwent phacoemulsification cataract surgery and in whom the patient notes could be located. We only included patients who had undergone uneventful standard phacoemulsification cataract surgery with IOL implantation in the capsular bag. Patients who had other ocular diseases, or suffered postoperative complications, so that the best corrected visual acuity (BCVA) postoperatively was worse than logMAR 0.6, were excluded. Exclusion criteria also included patients undergoing any additional surgical procedure at the time of cataract surgery.

Partial coherence interferometry (Zeiss IOL Master 500, Carl Zeiss Meditic) was used for biometry measurements of axial length, keratometry and anterior chamber depth. In one patient in the post LVC group, the axial length was measured by immersion ultrasound biometry (Aviso A/B, Quantel Medical). IOL Master optimised lens constants from the User Group for Laser Interference Biometry were used. The IOL model used for patients in the post LVC group included the Alcon MA 30AC, Alcon SN60 WF, Alcon Acrysof MA60AC and

Rayner C-flex 970C, whereas the Alcon SN60 WF was the only IOL model used in the control group. A standard 2.8 mm corneal incision located at 110° was used in all cases. No additional refractive procedures such as limbal relaxing or opposite clear corneal incisions were made. Postoperative subjective refraction was performed by an optometrist in the department at 6 weeks after surgery. The predicted outcomes for the IOL used were calculated using the CHM and the Masket Method when historical data were available. Predicted outcomes using the Haigis-L, the Shammas-PL and the Barrett True-K were calculated using the ASCRS online calculator.[40] No account was made for surgically induced refractive effects including surgically induced astigmatism.

The average keratometry and the differences between the steep (K2) and flat (K1) meridia were added to the intended error to give the intended refractive error as a sphero-cylinder, and also as a spherical equivalent.[33–35] To determine the difference between the intended and postoperative refractive error, the data were transformed into the components of Long's formalism before changing back into sphero-cylinder notation.[38] Descriptive statistics were computed to give the mean, SD, 95% CI, mean+/-3 SD, minimum and maximum.[36] The methods of Harris and Kaye were used to test the differences between the intended and actual postoperative refractive error.[32 33] A Kruskal Wallis test was used to compare the five groups (SPSS version 22) and controls whereas an F test was used to compare the variances of the difference distributions. A general univariate linear model was used with the difference between the intended and postoperative refractive error as the dependent variable, the intended as a covariate and the method used to calculate the intended outcome as a factor. The proportions of patients within 0.5 dioptres, 1 dioptre and 2 dioptres of the intended refractive error as a spherical equivalent were also calculated.

RESULTS

Twenty-two eyes of 17 patients who had cataract surgery post LVC were included. Of the 22 eyes, 16 (72.7%) were female, and the mean age was 64 years (range 50–77 years). Nineteen eyes of 19 consecutive patients undergoing routing cataract surgery were included in the control group, of whom 10 (52.6%) were female, and the mean age was 76 years (range 59–86).

In the post LVC group, 15 eyes (68 %) had undergone LASIK; 5 (23 %) had undergone PRK; 1 (4.5 %) had undergone LASEK; and the previous type of laser was unknown in 1 (4.5%) eye. Historical patient information could be obtained before the LVC in 19 (86%) eyes and was used for the CHM and Masket formulae. The Haigis-L, Shammas-PL and Barrett True-K formulae could be used for all 22 eyes. Individual patient details of the post LVC and control groups, including refractive findings, were shown in online supplementary tables 1 and 2. The left eye was operated on 10 (45%) of the post LVC eyes with no significant intraoperative complications. Mean BCVA postoperatively was 0.03 (range −0.18 to 0.48). The majority of patients (21 eyes) achieved a BCVA of 0.3 or better.

The descriptive statistics for the intended and postoperative refractive error and the difference between the two, using the different formulae for post LVC eyes were presented in table 1. Similar data for control eyes using the SRK-T formula were also shown.

The differences between the intended and postoperative refractive error were greater in post LVC eyes than the control eyes (p=0.012), irrespective of which method was used to calculate the intended refractive error (p<0.01). In particular, although the mean difference between the intended and postoperative refractive error was relatively small, the variance of the difference between intended and postoperative refractive error was significantly greater among post LVC patients, as compared with the control group (p<0.01). There were no significant differences between the mean intended target refraction and between the intended and postoperative refractive errors using the five biometry calculation methods (p=0.76). Comparing the post LVC group to the control group, there were significant differences in the postoperative refractive errors (p=0.038).

Absolute errors using spherical equivalents and percentages of patients who were within 0.5, 1 and 2 dioptres of the intended outcome as a spherical equivalent, using the different biometry formulae, were shown in table 2.

DISCUSSION

The number of patients having LVC worldwide is substantial, with an estimated 1 million patients having had the procedure in the USA.[41] For these individuals who subsequently undergo cataract surgery, IOL power calculation is more challenging than in those who have not had previous LVC, as it gives increased risk of refractive surprises. These patients also often have very high expectations of being spectacle independent.[42]

Several strategies have been proposed to overcome the errors in IOL power calculations, with the aim of improving refractive outcomes after cataract surgery in such patients. These strategies can be grouped into five categories: (1) methods that require prerefractive surgery data; (2) methods that calculate corneal power from postrefractive measurements; (3) using current corneal measurements with adjustment of IOL power; (4) direct measurements of anterior and posterior cornea after refractive surgery; (5) intraoperative IOL power determination.[27] Methods using the first two categories are often limited in a real-life setting as historical data is often difficult or impossible to obtain. Methods using OCT to measure the posterior corneal curvature (fourth category), and technologies using intraoperative measurements (fifth category) show potential promise, however, they require further studies and are currently not available in most units.[23]

Table 1 Intended (target) and postoperative refractive errors, and the differences between the two, using the five different formulae for post LVC eyes. Similar data shown for control eyes using the SRK-T formula

		Intended (target)	Difference between Intended and post-op	Post-op
		Sphere/cylinder × axis	Sphere/Cylinder × axis	Sphere/Ccylinder × Aaxis
CHM	Mean	−0.58/+0.76×89	−0.90/+0.68×0	−0.58/+0.1×27
	Upper 95% CI	+2.74/−1.34×28	+1.14/+1.73×150	+1.11/+1.43×146
	Lower 95% CI	−1.76/−1.42×151	−3.92/+1.59×36	−2.12/−1.54×143
Masket	Mean	−0.81/+0.61×83	−0.42/+0.65×178	−0.58/+0.10×27
	Upper 95% CI	+2.74/−1.34×28	+1.14/+1.73×150	+1.11/+1.43×146
	Lower 95% CI	−1.76/−1.42×151	−3.92/+1.59×36	−2.12/−1.54×143
Haigis-L	Mean	−0.37/+0.61×84	−0.79/+0.65×178	−0.58/+0.10×27
	Upper 95% CI	+1.29/+1.19×138	+0.95/+1.74×151	+1.11/+1.43×146
	Lower 95% CI	−1.05/−1.95×156	−3.47/+1.45×37	−2.12/−1.54×143
Shammas-PL	Mean	−0.42/+0.61×84	−0.74/+0.65×178	−0.58/+0.10×27
	Upper 95% CI	+1.53/+1.10×136	+1.01/+1.78×152	+1.11/+1.43×146
	Lower 95% CI	−1.42/−1.88×155	−3.44/+1.43×39	−2.12/−1.54×143
Barrett True-K	Mean	−0.71/+0.61×84	−0.45/+0.65×178	−0.58/+0.10×27
	Upper 95% CI	+0.94/+1.20×139	+1.12/+1.82×153	+1.11/+1.43×146
	Lower 95% CI	−1.36/−1.97×157	−2.99/+1.41×40	−2.12/−1.54×143
Controls	Mean	−0.51/+0.33×11	−0.29/+0.56×164	−0.75/+0.80×174
	Upper 95% CI	−0.16/+1.38×139	+0.39/+1.68×146	+0.10/+1.81×154
	Lower 95% CI	−2.04/+1.67×38	−1.75/+1.01×36	−2.30/+1.19×34

CHM, clinical history method; Shammas-PL, Shammas post-Lasik.

A relatively large study of 173 eyes in patients who had previously undergone myopic laser refractive surgery compared a number methods of relying on historical information and the Haigis-L and Shammas-PL formulae.[28] This study suggested that the five most accurate methods to minimise a hyperopic surprise were the Masket with the Hoffer Q, Shammas-PL, Haigis-L, CHM with the Hoffer Q and the Latkany Flat-K with the SRK-T. The variance was still however, a significant issue, with a notable proportion of patients having unacceptable postoperative refractive errors. A more recent meta-analysis, also on postmyopic laser surgery patients, found that the CHM, the corneal bypass method and the Feiz-Mannis methods were less accurate than the Haigis-L.[25] The meta-analysis concluded that the Masket method and the Shammas-PL performed better than the Haigis-L.

Table 2 Absolute spherical equivalent refractive errors for the five different formulae. Similar data shown for control eyes using the SRK-T formula

	Mean AE, in D (95% CI)	AE range (D)	AE within 0.5D (%)	AE within 1D (%)	AE within 2D (%)
CHM	1.15 (0.52 to 1.78)	0.08–5.30	31.6	68.4	79.0
Masket	0.78 (0.43 to 1.13)	0.02–2.83	42.1	73.7	94.7
Haigis-L	0.84 (0.52 to 1.16)	0.00–2.93	40.9	68.2	90.9
Shammas-PL	0.71 (0.46 to 0.96)	0.03–2.24	50.0	77.3	100.0
Barrett True-K	0.69 (0.43 to 0.91)	0.13–2.43	40.9	86.4	95.5
Control patients	0.49 (0.32 to 0.66)	0.06–1.25	55.6	88.9	100.0

AE, Absolute error (absolute value of the difference between the Intended and postoperative spherical equivalent refractive error); CHM, clinical history method; D, dioptres; Shammas-PL, Shammas post-Lasik.

The Barrett True-K formula is one of the more recently developed methods, and it can be used without historical data.[26 27 43 44] Studies comparing it with other formulae after previous myopic LASIK or PRK suggested that it was at least equal to, and often better than, the other methods.

Previous studies comparing the accuracy of IOL power calculation for cataract surgery among post LVC patients have generally been limited by using spherical equivalent to compare the intended and postoperative outcome, or in some cases treating the cylinder as an independent variable.[45] Using the spherical equivalent is analogous to prescribing spectacles as a spherical equivalent rather than as a sphero-cylinder. This raises the question of why intended outcomes following cataract surgery are based on spherical equivalent rather than the sphero-cylinder. Presenting data as spherical equivalent loses specificity and sensitivity of refractive error calculation.[46] Treating the components of refractive power independently will also introduce errors.[30–32] To overcome these issues, we analysed the differences between the intended and actual postoperative refractive error as a sphero-cylinder as previously described.[32 33 39]

One of the limitations of our study was the heterogeneity of our small patient sample with patients who had previously undergone different types of LVC (LASIK/LASEK/PRK), although this does reflect the real-world situation. Also, we only included eyes which were previously myopic in our analyses. We relied on postoperative subjective refraction for our analyses, rather than keratometry, with possible inaccuracies in measuring true changes in the shape of the eye after surgery. Despite these limitations, it would appear that at present, regardless of the strategies used to predict the intended refractive outcomes, the measurement precision among post LVC patients is significantly less than that of patients who have not had LVC, and no particular biometry formula calculation method appears to be superior. As a result, any of the current five biometry formulae can be used, depending on what data are available before and following LVC. It is important to caution our patients that all these methods have limited precision and may lead to a refractive surprises.

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