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REFRACTIVE SURGERY

Vector analysis of astigmatism before and after LASIK: a comparison of two different platforms for treatment of high astigmatism

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Abstract
Purpose To compare the outcomes of astigmatic laser in-situ keratomileusis (LASIK) procedures between two different platforms using J_0 and J_{45} vector analysis.
Methods Patients were divided into four groups, depending on the type of astigmatism and laser platform on which they were treated. Astigmatism was between 2 and 7 diopters (D). One hundred and thirty-five patients with myopic astigmatism (246 eyes) and 102 patients with mixed astigmatism (172 eyes) underwent unremarkable LASIK correction on Wavelight Allegretto Eye-Q 400Hz and Schwind Amaris 750S laser platform. The preoperative and postoperative sphere, negative cylinder [C] and axis (ø) of manifest refractions were subjected to vector analysis by calculations of the standard J_0 (cos [4π(ø-90)/360]xC/2) and J_{45} (sin[4π(ø-90)/360]xC/2).
Results Reporting the key results, we found J_0 significantly reduced after LASIK in both groups ($p<0.001$) but not J_{45}. There was no significant association between individual pairs of pre and postoperative J_0 & J_{45} values. There was no significant difference between the outcomes of the two platforms.
Conclusions Wavelight Allegretto 400Hz and Schwind Amaris 750S showed excellent results for treating patients with astigmatism, regardless whether it is mixed or myopic astigmatism. The J_{45} did not reduce significantly possibly because of the low number of eyes with oblique astigmatism. There was no genuine difference post-operatively between groups treated on two different laser platforms according to the vector analyses.

Keywords LASIK · Excimer laser · Astigmatism · Vector analysis

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Introduction

Laser in-situ keratomileusis (LASIK) is probably the most popular surgical procedure used to correct refractive errors. According to Ortueta et al. [1], the goal of laser refractive surgery is to achieve predictable and stable correction of myopia, hyperopia, and astigmatism. However, it would be better if the final endpoint is emmetropia or a stable refraction which can be reliably predicted with precision. Initially, LASIK was aimed to correct spherical refractive errors, but today we have advanced algorithms aimed at correcting, if not eliminating, astigmatism in a highly predictable manner. The Wavelight Allegretto Eye-Q is a flying-spot excimer laser, with a pulse repetition rate of 400Hz, with two galvanometric scanners for positioning laser pulses. The system has an infrared high-speed camera operating at 400Hz to track the patient's eye movements that either compensates for changes in eye position or interrupts the treatment if the eye moves outside a preset predetermined range. The Schwind Amaris 750 S is a

flying-spot excimer laser with a pulse repetition rate of 750S that features a five-dimensional 1050Hz infrared eye tracker with simultaneous limbus, pupil, iris recognition, and cyclotorsion tracking integrated in the laser delivery process. This was covered in our previous publication [2]. Therefore, it is possible that different platforms featuring different algorithms may produce dissimilar end results. Predicting a change in spherical refractive error is relatively simple involving just two numbers and a subtraction. However, predicting the outcome of treating astigmatism is more complex because astigmatism involves two figures: power and axis. Thus, astigmatism can be treated as a vector because it has a magnitude and directional quality. Thibos et al. [3] and Alpins [4] proposed mechanisms to simplify the procedure for the analysis of astigmatism. The Thibos procedure involves calculation of three figures, namely J_0, J_{45}, and S. These were defined as follows:

$$J_0 = \left(\frac{cylinder}{2}\right).cos\left[\frac{4\pi(\phi - 90)}{360}\right]$$

$$J_{45} = \left(\frac{cylinder}{2}\right).sin\left[\frac{4\pi(\phi - 90)}{360}\right]$$

$$S = Sphere + \left(\frac{cylinder}{2}\right)$$

J_0refers to a cylinder power set at orthogonally 90° and 180° meridians, representing Cartesian astigmatism. Positive values of J_0 indicate "with the rule" astigmatism, and negative values of J_0 indicate "against the rule" astigmatism. J_{45} refers to a cross-cylinder set at 45° and 135°, representing oblique astigmatism. S describes the numerical value of the cylinder and sphere. It does not consider the axis of astigmatism. These figures eloquently describe any sphero-astigmatic, or plano-astigmatic, corrections rendering them amenable to statistical scrutiny. Therefore, it is possible to compare the outcome of different procedures aimed to correct astigmatism in a more useful way. The J_0 and J_{45} vectors consider just the cylinder value and axis. Thus the J_0 and J_{45} vectors provide more meaningful relatively simple uncomplicated descriptions of change in astigmatic power and axis. The Alpins procedure has been used to analyse the refractive inconsistencies that can occur after implanting toric IOLs [5, 6]. The Thibos et al. procedure has been used for the analysis of astigmatism in myopia and keratoconus [7]

A recent search in PubMed using the key words 'vector analysis astigmatism LASIK' led to 61 citations. Only one of these publications revealed that the method described by Thibos et al. had been used for vector analysis of astigmatism before and after LASIK [8]. The Alpins procedure has been more recently used to analyse persistent unpredicted refractive errors after toric IOL implantation [5, 6]. To the best of our knowledge, the Thibos et al. technique has not been used for IOLs, and only once for LASIK treatment where a single platform was used.

The purpose of this study was to investigate two quite different laser delivery platforms aimed to correct astigmatism by subjecting the pre and postoperative astigmatic values to vector analysis as proposed by Thibos et al., and to determine if there is any significance in the outcomes between the two procedures.

Materials and methods

Patient selection

Prior to embarking on this study, the proposed investigation was approved by the Ethics Committee at 'Svjetlost' Specialty Eye Hospital. The Tenets of the Helsinki Agreement were followed throughout.

Between January 2010 and December 2011, 470 eyes (274 patients) with astigmatism more than 2 diopters (D) were operated in 'Svjetlost' Specialty Eye Hospital in Zagreb, Croatia. Four hundred and eighteen eyes (237 patients) completed 1 year of follow-up. Only the eyes that completed 1 year of follow-up were included in this study.

The inclusion criteria were: patients over 18 years of age with a refractive error stable for at least 1 year, astigmatism≥ minus 2.0D, corneal thickness≥500 μm, mesopic pupil≤ 7.5 mm, and unremarkable corneal topography. Exclusion criteria were topographic patterns that were suggesting any form of ectatic disease, and systemic or ocular diseases that could interfere with the healing process of the cornea. Patients with previous ocular surgery were also excluded. Patients were separated into two groups according to the laser platform on which they were treated — Wavelight Allegretto Eye-Q 400Hz and Schwind Amaris 750S. Within each group, the treated eyes were further subdivided according to the type of astigmatism, myopic astigmatism or mixed astigmatism. A total of 188 eyes (110 patients) were included in the Allegretto group. There were 127 eyes (71 patients) with myopic astigmatism and 61 eyes (39 patients) with mixed astigmatism. A total of 230 eyes (127 patients) were included in the Amaris group. There were 119 eyes (64 patients) with myopic astigmatism and 111 eyes (63 patients) with mixed astigmatism. These data are also provided in our previous publication [2].

Preoperative examinations

Every patient had complete preoperative ophthalmologic examination prior to deciding if the patient met the criteria for surgery.

Examination included uncorrected and best-corrected distant visual acuity (UDVA, CDVA), manifest and cycloplegic refraction, corneal topography (Pentacam HR, Oculus Optikgeräte GmbH, Wetzlar, Germany), aberrometry (L 80

wave+, Luneau SAS, Prunay-le-Gillon, France), tonometry (Auto Non-Contact Tonometer, Reichert Inc., Buffalo, NY, USA), slit-lamp and dilated funduscopic examination. Visual acuity was measured using a standard Snellen acuity chart at 6 m, and presented in decimal format. The patients were asked to discontinue use of contact lenses for up to 4 weeks prior to this examination, depending on the type of lenses they were using.

Laser platforms

Two laser platforms for correction of astigmatism were investigated, namely Schwind Amaris 750S (Schwind eye-tech-solutions, Kleinostheim, Germany) and Wavelight Allegretto Eye-Q 400Hz excimer laser (Alcon, Forth Worth, TX, USA). The main differences between the two platforms are shown in Table 1.

Surgical procedure

Two hundred and thirty-seven patients (418 eyes) underwent LASIK procedure. After topical anesthesia (two drops of Novesin, OmniVision GmbH, Puchheim, Germany) that was instilled at 2-min intervals, the eye was cleaned with 2.5 % povidone iodine. A corneal flap with superior hinge was created using the Moria M2 mechanical microkeratome with 90 μm head (Moria, Antony, France), lifted, and folded onto superior conjunctiva. The stromal bed was dried with a Merocel sponge (Alcon, Forth Worth, TX, USA) and excimer laser ablation was applied with either Wavelight Allegretto Eye-Q 400Hz or Schwind Amaris 750S. Excimer laser ablation algorithms, optical and tranzition zones chosen, and nomograms applied were described in our previous publication [2]. After the photoablation, the stromal bed was irrigated with Balanced Salt Solution (BSS) to remove any debris, and the flap was carefully repositioned in place. All patients received postoperative therapy; a combination of topical antibiotic and steroid drops (Tobradex, Alcon, Forth Worth, TX, USA) was given 4 times daily for 14 days, and artificial tears (Blink, Abbott Medical Optics, Santa Ana, CA, USA) were given 6–8 times daily for at least 1 month.

Patient allocation

Patients were assigned to a particular laser platform depending upon the availability of technical staff, scheduling, and other administrative factors. The surgeon performing the treatment did not influence patient allocation, and the staff performing pre- and postoperative refractions were kept unaware of the laser platform used to correct each patient's refractive error.

Postoperative evaluation

All patients were examined at 1 day, 1 week, 1 month, 3 months, and 1 year after the surgery. Manifest refraction was performed each time, together with slit-lamp examination, tonometry, corneal topography, and visual acuity. Results at 1 year after the surgery were used to perform the vector analysis and statistical evaluation.

Analysis of collected data

All data were entered on a Microsoft Office Excel 2007 spreadsheet for statistical analysis.

For this report, the J_0 and J_{45} vectors were calculated for the refractive data collected preop and at 1 year postoperative. Cases were separated into four groups as follows:

Group 1, myopic astigmatism treated with Allegretto (n=127 eyes)
Group 2, myopic astigmatism treated with Amaris (n=119 eyes)
Group 3, mixed astigmatism treated with Allegretto (n=61 eyes)
Group 4, mixed astigmatism treated with Amaris (n=111 eyes)

Table 1 The main differences between the two laser platforms

	Schwind Amaris 750S	Wavelight Allegretto 400Hz
Ablation type	Scanning spot	Scanning spot
Beam profile	Super Gaussian	Gaussian
Beam size (mm)	0.54	0.95
Avarage fluence (mj/cm^2)	Automatic (faster–slower)	200
Pulse frequency (Hz)	750	400
Eye tracker sampling rate (Hz)	1050	400
Cyclotorsion compensation	Yes	No
Optical zone	Static and dynamic Adjustable	Conditional fixed 6.5 mm

The data were analyzed to determine the significance of any:

i) Difference in the means between the two groups of myopic astigmatic cases both before and after treatment according to the two astigmatic vectors J_0, and J_{45} (*t* test).
ii) Difference in the means between the two groups of mixed astigmatic cases both before and after treatment according to the two astigmatic vectors J_0, and J_{45} (*t* test).
iii) Correlation between the change (Δ) in each astigmatic vector (J_0 and J_{45}) and pretreatment astigmatic vector value within each of the four groups (Pearson correlation) and apparent difference between the two correlation coefficients, for each of the two platforms, within four groups (Fisher's '*r*' to 'z' transformation [9]).
iv) Association between J_0 and J_{45} vectors before and after treatment within each of the 4 groups (Pearson correlation).

The null hypothesis was rejected when *p* exceeded 0.01.

Results

The main results of this investigation are shown in Tables 2 and 3, and Figs. 1, 2, 3, 4, 5, 6, 7, and 8. Results with regard to visual acuity, refraction, and aberrometry were described in our previous publication [2].

Myopic astigmatism

Comparison of platforms for the J_0 vector

In the Allegretto group, mean (±SD) preop J_0 vector was +1.369 (±0.776), and in the Amaris group it was +1.221 (±0.832). The difference was not statistically significant (p=0.150). Postoperatively, the mean J_0 vector was +0.092 (±0.276) for the Allegretto group and +0.065 (±0.202) for the Amaris group. The difference was not statistically significant (p=0.380). These data are shown in Table 2.

Comparing mean pre- with mean postop J_0 values for each platform

There was a statistically significant difference between J_0 preop and J_0 postop for both platforms (p<0.001).

Comparison of platforms for the J_{45} vector

In the Allegretto group, mean (±SD) preop J_{45} vector was +0.076 (±0.695), and in the Amaris group it was −0.023 (±0.769). The difference was not statistically significant (p=0.289). Postoperatively, the mean J_{45} vector for Allegretto group was −0.058 (±0.204) and +0.005(±0.184) for the Amaris group. The difference was not statistically significant (p=0.012). These data are shown in Table 2.

Comparing mean pre- with mean postop J_{45} values for each platform

There was no statistically significant difference between J_{45} preop and J_{45} postop for either platform (p=0.042 and 0.685 for the Allegretto and Amaris groups respectively).

Correlation between ΔJ_0 and preop J_0 values

The least squares regression lines equating ΔJ_0 and preop J_0 were as follows:

$$\text{Allegretto group } \Delta J_0 = 0.924\ J_0 + 0.190 (r = 0.936, n = 127, p < 0.001)$$
$$\text{Amaris group } \Delta J_0 = 1.019\ J_0 + 0.041 (r = 0.971, n = 119, p < 0.001)$$

The difference between these two correlation coefficients was significant (z=−3.086, p=0.002).

Correlation between ΔJ_{45} and preop J_{45} values

The least squares regression lines equating ΔJ_{45} and preop J_{45} were as follows:

$$\text{Allegretto group } \Delta J_{45} = 0.905 J_{45} + 0.046 (r = 0.961, n = 127, p < 0.001)$$
$$\text{Amaris group } \Delta J_{45} = 1.009 J_{45} + 0.009 (r = 0.971, n = 119, p < 0.001)$$

Table 2 Myopic astigmatism, mean values for the J_0 and J_{45} vector, and significance of any differences (*p* values) according to *t*-test

	Preop J_0 mean (± SD)	Postop J_0 mean (± SD)	Preop J_{45} mean (± SD)	Postop J_{45} mean (± SD)
Wavelight Allegretto Eye-Q	+1.369±0.776	+0.092±0.276	+0.076±0.695	−0.058±0.204
Schwind Amaris 750S	+1.221±0.832	+0.065±0.202	−0.023±0.769	+0.005±0.184
Comparison of platforms	p*=0.150	p*=0.380	p*=0.289	p*=0.012

* paired *t*-test assuming unequal variances

Table 3 Mixed astigmatism, mean values for the J_0 and J_{45} vector and significance of any differences (p values) according to t-test

	Preop J_0 mean (± SD)	Postop J_0 mean (± SD)	Preop J_{45} mean (± SD)	Postop J_{45} mean (± SD)
Wavelight Allegretto Eye-Q	+1.417±1.198	+0.108±0.359	−0.120±0.782	−0.039±0.285
Schwind Amaris 750S	+0.609±1.581	+0.064±0.268	−0.036±0.916	−0.031±0.209
Comparison of platforms	p*<0.001	p*=0.402	p*=0.528	p*=0.863

* paired t-test assuming unequal variances

The difference between these two correlation coefficients was not significant (z=−1.13, p=0.259).

Association between pre- and postop values of J_0 and J_{45}

In the Allegretto group, preop r=−0.158 (p=0.076) and postop r =−0.197 (p=0.026).

In the Amaris group, preop r=0.126 (p=0.172) and postop r=0.0904 (p=0.328).

Mixed astigmatism

Comparison of platforms for the J_0 vector

In the Allegretto group, mean (±SD) preop J_0 vector was + 1.417 (±1.198), and in the Amaris group it was +0.609 (±1.581). The difference was statistically significant (p<0.001). Postoperatively, the mean J_0 vector was +0.108 (±0.359) for the Allegretto group and −0.064 (±0.268) for the Amaris group. The difference was not statistically significant (p=0.402). These data are shown in Table 3.

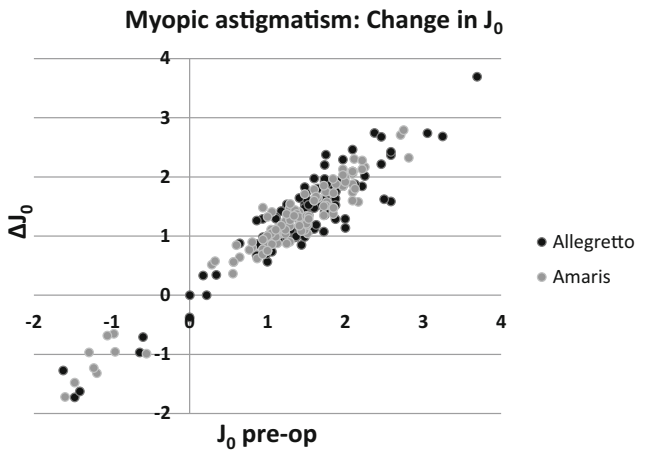

Fig. 1 Myopic astigmatism comparing the difference (Δ) between the pre- and postop J_0 vector values with pre-op J_0 values. Equations for the least squares regression lines are, for the Allegretto group, ΔJ_0=0.924 ΔJ_0+0.1895 (r=0.936, n=127, p<0.001) and ΔJ_0=1.019 ΔJ_0+0.041 (r =0.971, n=119, p<0.001) for the Amaris group

Comparing the mean pre- with mean postop J_0 values for each platform

There was a statistically significant difference between J_0 preop and J_0 postop for both platforms (p<0001).

Comparison of platforms for the J_{45} vector

In the Allegretto group, mean (±SD) preop J_{45} vector was −0.120(±0.782), and in the Amaris group it was −0.036 (±0.916). The difference was not statistically significant (p= 0.528). Postoperatively, the mean J_{45} vector was −0.039 (±0.285) for the Allegretto group and −0.031 (±0.209) for the Amaris group. The difference was not statistically significant (p=0.863). These data are shown in Table 3.

Comparing the mean pre- with mean postop J_{45} values for each platform

In the Allegretto group, preop r=−0.158 (p=0.077) and postop r=−0.197 (p=0.027).

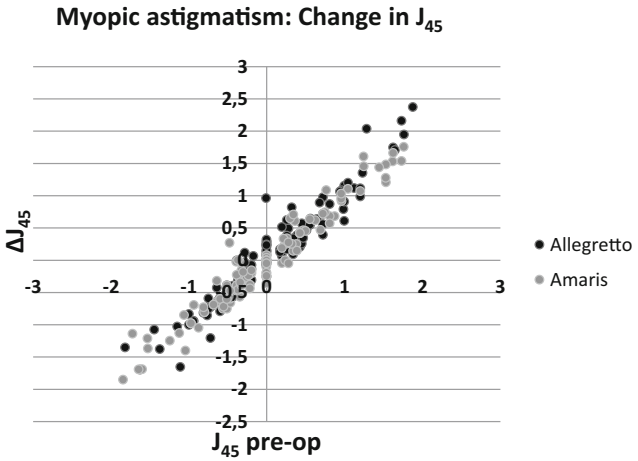

Fig. 2 Myopic astigmatism comparing the difference (Δ) between the pre- and postop J_{45} vector values with pre-op J_{45} values. Equations for the least squares regression lines are, for the Allegretto group, ΔJ_{45}=0.905 ΔJ_{45} -0.046 (r=0.961, n=127, p<0.001) and ΔJ_{45}=1.009 ΔJ_{45}+0.009 (r=0.971, n=119, p<0.001) for the Amaris group

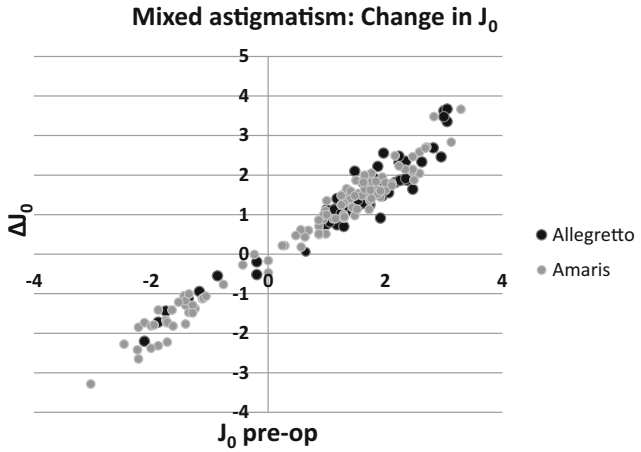

Fig. 3 Mixed astigmatism comparing the difference (Δ) between the pre- and postop J_0 vector values with pre-op J_0 values. Equations for the least squares regression lines are, for the Allegretto group, $\Delta J_0 = 0.955\Delta J_0 + 0.168$ ($r = 0.956$, $n = 61$, $p < 0.001$) and $\Delta J_0 = 0.999\Delta J_0 + 0.065$ ($r = 0.986$, $n = 111$, $p < 0.001$) for the Amaris group

In the Amaris group, preop $r = 0.103$ ($p = 0.265$) and postop $r = 0.104$ ($p = 0.259$).

There was no statistically significant difference between J_{45} preop and J_{45} postop for either platform ($p = 0.424$ and 0.955 for the Allegretto and Amaris groups respectively).

Correlation between ΔJ_0 and preop J_0 values

The least squares regression lines equating ΔJ_0 and preop J_0 were as follows:

$$\text{Allegretto group } \Delta J_0 = 0.955\,J_0 + 0.168 (r = 0.955, n = 61, p < 0.001)$$
$$\text{Amaris group } \Delta J_0 = 0.999\,J_0 + 0.065 (r = 0.986, n = 111, p < 0.001)$$

The difference between these two correlation coefficients was significant ($z = -3.533$, $p = 0.0004$).

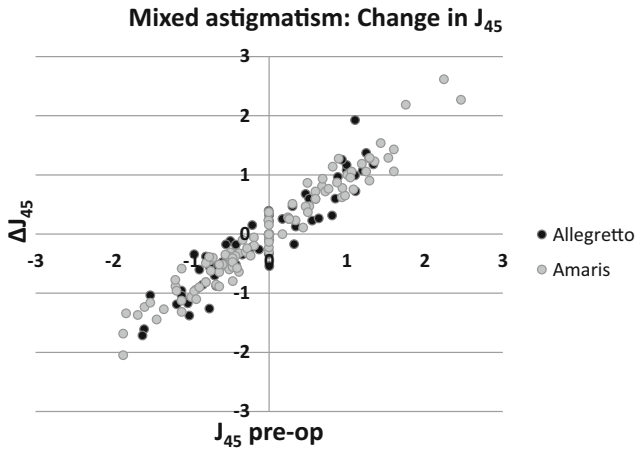

Fig. 4 Mixed astigmatism comparing the difference (Δ) between the pre- and postop J_{45} vector values with pre-op J_{45} values. Equations for the least squares regression lines are, for the Allegretto group, $\Delta J_{45} = 0.926\ \Delta J_{45} - 0.045$ ($r = 0.934$, $n = 61$, $p < 0.001$) and $\Delta J_{45} = 1.020\Delta J_{45} + 0.032$ ($r = 0.974$, $n = 111$, $p < 0.001$) for the Amaris group

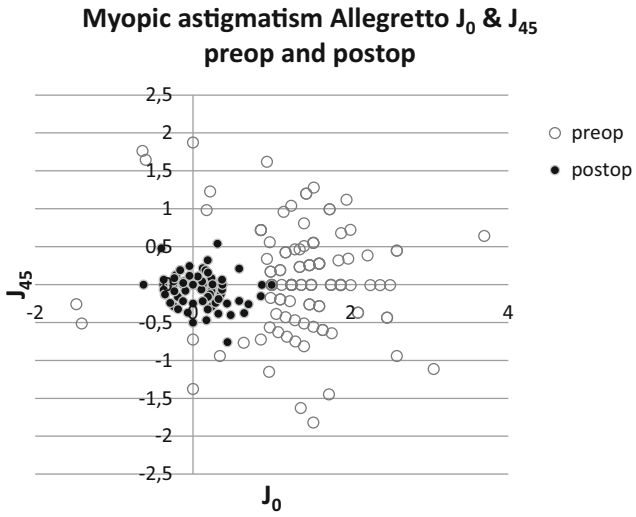

Fig. 5 Myopic astigmatism, the association between J_0 and J_{45} values before and after treatment with the Allegretto platform

Correlation between ΔJ_{45} and preop J_{45} values

The least squares regression lines equating ΔJ_{45} and preop J_{45} were as follows:

$$\text{Allegretto group } \Delta J_{45} = 0.926\,J_{45} + 0.045 (r = 0.934, n = 61, p < 0.001)$$
$$\text{Amaris group } \Delta J_{45} = 1.020\,J_{45} + 0.032 (r = 0.974, n = 111, p < 0.001)$$

The difference between these two correlation coefficients was significant ($z = -2.886$, $p = 0.004$).

Association between pre- and postop values of J_0 and J_{45}

In the Allegretto group, preop $r = 0.238$ ($p = 0.065$) and postop $r = -0.028$ ($p = 0.833$).

In the Amaris group, preop $r = 0.104$ ($p = 0.277$) and postop $r = 0.030$ ($p = 0.754$).

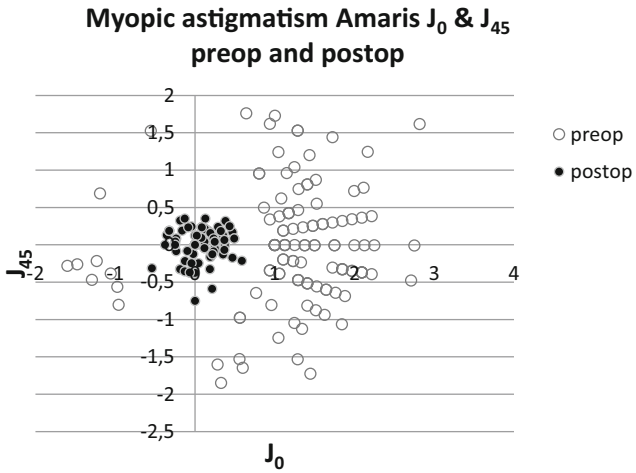

Fig. 6 Myopic astigmatism, the association between J_0 and J_{45} values before and after treatment with the Amaris platform

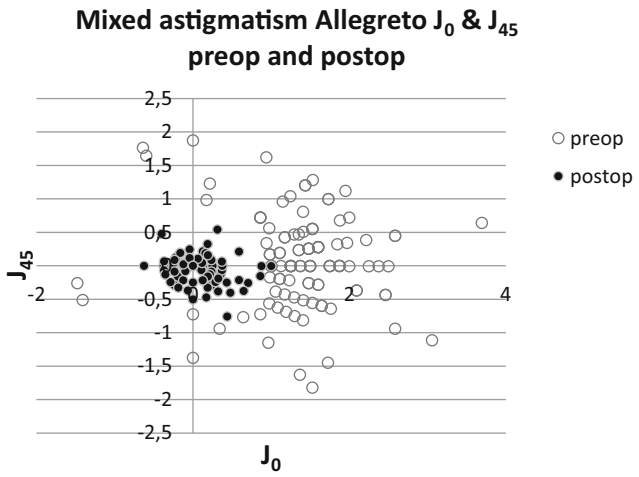

Fig. 7 Mixed astigmatism, the association between J_0 and J_{45} values before and after treatment with the Allegretto platform

Discussion

Myopic astigmatism

There was no significant difference of mean J_0 values between the two groups before surgery. Therefore, the two sets of cases can be considered as being drawn from the same population. After treatment, the two groups still remained mutually indistinguishable, but clearly the surgical treatment reduced the value of J_0 vector, showing that both platforms reduced astigmatism as expected. The percentage change in the J_0 vector was 93 % and 95 % for the Allegretto and Amaris platforms respectively. Using the Nidek 500 platform, Abolhassani et al. [8] reported a 103 % shift in J_0 vector. Such a change can only occur if the sign of the J_0 vector changed from plus to minus or vice versa. In our cases, the mean J_0 vector fell in value but still remained positive.

Turning to the J_{45} vector, there was no significant difference between the two groups preop and postop. However, we

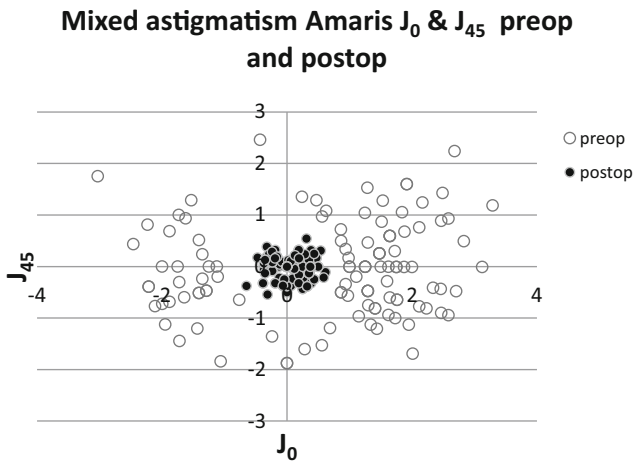

Fig. 8 Mixed astigmatism, the association between J_0 and J_{45} values before and after treatment with the Amaris platform

did detect a slight difference postop at the p=0.012 level, and the variance in the data is responsible for masking the true significance in the difference between the +0.0051 and −0.0581 mean J_{45} values. According to the vector, the two laser platforms are not producing totally identical results. The J_{45} vector describes the astigmatism in the oblique meridia, in contrast to the J_0 vector, which describes astigmatism in the vertical and horizontal meridia. This suggests that one platform is tending to produce a more precise correction, or offering a better treatment, along the oblique meridian compared with the other. In a perfect scenario, the treatment should reduce the J_0 and J_{45} vectors to near zero. Referring to Table 2, the Amaris platform reduced the J_{45} vector to a mean of 0.0051, and the Allegretto reduced it to −0.0581. Thus, it appears that for myopic astigmatism the Amaris platform is preferred when the presenting axis of astigmatism is predominantly oblique. In cases when the myopic astigmatic axis is either with or against the rule, there is no detectable difference in performance between the two platforms. Abolhassani et al. [8] reported a 76.4 % fall in the average value for the J_{45} vector. We found J_{45} vector to change by 176 % and 102 % for the Allegretto and Amaris platforms respectively. Table 2 shows the signs of the mean values shifted from plus to minus for the Allegretto cases, but the opposite was found in the Amaris cases. This indicates that besides reducing astigmatism, the two platforms are not producing identical endpoint results as noted earlier.

Mixed astigmatism

The two groups were mutually distinguishable before treatment. After treatment, the two groups were mutually indistinguishable, but clearly the treatment reduced the value of the J_0 vector, showing that the two platforms reduced astigmatism as expected. On a percentage basis, the changes in both vectors are similar to those reported by Abolhassani et al. [8].

Postop, the J_{45} vector showed that there was no difference between the two groups before and after treatment. Furthermore, it appears neither of the platforms significantly reduced the values of J_{45} vectors. This suggests that treatment had no real effect on J_{45} vectors. This may be a statistical anomaly, because the J_0 vector certainly did reduce very significantly. This unforeseen result may be due to the fact that in most cases the astigmatism was predominantly either with or against the rule. Very few cases presented with oblique astigmatism.

The question remains as to why the J_0 vector was different between the two groups preop but not postop. Referring to the formulae used to calculate J_0 and J_{45}, the preop J_0 values between the two groups could differ either because the cylinder power in one group was higher than the other or because the mean and range of axes in one group was weighted differently. By process of elimination, the two groups differed

because in one group the axis of astigmatism was predominantly with the rule, and against the rule in the other one. Nevertheless, postoperatively the two populations converged to become mutually indistinguishable.

The correlations between changes in vector compared with pre-op values and J_0 and J_{45} before and after treatment

Glancing at Figs. 1, 2, 3 and 4, the strong correlations between changes in the vector values with preop values were expected. In both myopic and mixed astigmatism, the slope values for the cases treated using the Allegretto platform are less than one. The nomogram for the Allegretto procedure advises the surgeon to intentionally under-correct the astigmatism by 25 %. Based on our previous experience, we adjusted the nomogram, under-correcting by 15 %. Therefore, encountering slope values <1.00 was to be expected. However, the slope values revealed using the Amaris platform were ≥1.00, and the corresponding correlation coefficients were consistently higher compared with the Allegretto cases. The significant differences between the platforms lead us to conclude that the outcome of the Amaris procedure can be predicted with more reliability compared with the Allegretto procedure. The refractive surgeon is more likely to reach the desired endpoint refraction using the Amaris procedure when attempting to correct moderate to high myopic or mixed astigmatism.

Glancing at Figs. 5, 6, 7 and 8, we would expect the vector values to converge towards the 0.0 point after the treatment. A lack of convergence towards the 0.0 coordinate would be counter-intuitive, suggesting that the treatment was of no clinical value. The postop data show the vector values collapsing towards a cluster about the 0.0 point. The cluster, as opposed to a single point, demonstrates that the treatments are working to nullify astigmatism but not completely cancel it out. In other words, some residual astigmatism is still present after sophisticated surgery. Even to this day, a small but significant amount of residual astigmatism is not unexpected [10]. The area covered by the Amaris-treated cases is lower than the area covered by the Allegretto-treated cases, indicating that the former is more accurate than the latter.

There was no significant correlation when we compared J_0 with J_{45} either pre or postop for each of the two platforms. This is not surprising when we consider that the majority of cases presented in this study were either with or against the rule astigmatism. In such cases, the J_0 vector by definition will always have a much greater value compared with J_{45}. For example, when the preop astigmatism is −3.00 dcyl×180, J_0 is 1.500 and J_{45} is −0.004. For the Allegretto-treated cases, the correlation between J_0 and J_{45} for mixed astigmatism group preop was 0.238 and for a two tailed test the p value was 0.063 reducing to 0.032 for a single-tailed test. To avoid making an erroneous conclusion, we accept the result of the two-tailed test. This correlation reduced to −0.028 postop. The difference between these two correlation coefficients appears to be significant, but a posthoc analysis proved otherwise (Fisher's r to z transformation z=1.47, p=0.142).

Conclusion

Both platforms significantly reduced astigmatism. However, in an ideal situation the postop J_0 and J_{45} values should be zero. They are not. The smallest value was 0.005 for the myopic astigmatic cases treated with Amaris in relation to the J_{45} vector. The highest value was 0.1085 for the mixed astigmatism cases treated with Allegretto in relation to the J_0 vector. Other methods of vector analysis of astigmatism [4–6] may yield different results, but for the current study the technique used was relatively simple, producing viable results. Emsley [11] said that Franciscus Cornelius Donders (1818–89) was the first to introduce cylindrical lenses for measurement and correction of astigmatism. To this day, we do not have a universally accepted system for assessing change in ocular astigmatic power and axis. The procedure advocated by Thibos et al. [3] can be considered as a simple and robust tool for future studies in this area.

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