ORIGINAL PAPER

Treatment of High Astigmatism with WaveLight Allegretto Eye-Q Excimer Laser Platform

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ABSTRACT

Introduction: 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. **Aim:** The purpose of this study was to investigate WaveLight Allegretto Eye-Q 400Hz laser delivery platform aimed to correct astigmatism by subjecting the pre and postoperative astigmatic values to vector analysis. **Methods:** Patients were divided into two groups, depending on the type of astigmatism. Astigmatism was between 2 and 7 diopters (D). A total of 188 eyes (110 patients), 127 eyes (71 patients) with myopic astigmatism and 61 eyes (39 patients) with mixed astigmatism underwent unremarkable LASIK correction on WaveLight Allegretto Eye-Q 400Hz. 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 that J_0 significantly reduced after LASIK (p<0.001) but not J_{45}. There was no significant association between individual pairs of pre and postoperative J_0 &J_{45} values. **Conclusion:** WaveLight Allegretto 400Hz showed excellent results for treating patients with high 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 postoperatively between groups treated on WaveLight Allegretto platform according to the vector analyses.

Keywords: Laser In Situ Keratomileusis, Excimer Laser, Refractive Surgery, Astigmatism.

1. INTRODUCTION

Laser in-situ keratomileusis (LASIK) is probably the most popular surgical procedure used to correct refractive errors. LASIK is a highly successful keratorefractive procedure for the treatment of myopia and low degrees of hyperopia. However, treatment of astigmatism, especially hyperopic astigmatism, is still a therapeutic challenge, and often results in significant refractive misscorrections. (1, 2) 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.

Predicting the outcome of treating astigmatism is more complex because astigmatism involves two figures: power and axis. Because of that, 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:

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

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

$$M = sphere + \left(\frac{cylinder}{2}\right)$$

J_0 refers to a cylinder power set at orthogonally 90° and180° 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.

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.

2. AIM

The purpose of this study was to investigate WaveLight Allegretto Eye-Q 400Hz laser delivery platform aimed to correct astigmatism by subjecting the pre and postoperative astigmatic values to vector analysis as proposed by Thibos et al., and to determine the outcomes of the procedure.

3. METHODS

Patient selection

Prior to embarking on this study, the proposed investigation was approved by the Ethics Committee at University Eye Hospital ‘Svjetlost’. The Tenets of the Helsinki Agreement were followed throughout. Between January 2014 and December 2018 a total of 188 eyes (110 patients), with astigmatism more than 2 diopters (D) were operated in University Eye Hospital ‘Svjetlost’ and completed 1 year of follow-up. The inclusion criteria were: patients over 18 years of age with a refractive error stable for at least 1 year, astigmatism ≥–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 the type of astigmatism, myopic astigmatism or mixed astigmatism. There were 127 eyes (71 patients) with myopic astigmatism and 61 eyes (39 patients) with mixed astigmatism.

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 80wave+, Luneau SAS, Prunay-le-Gillon, France), tonometry (Auto Non-Contact Tonometer, Reichert Inc., Buffalo, NY, USA), slit-lamp and dilated fundus examination. Visual acuity was measured using a standard Snellen acuity chart at 6m, 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.

Surgical procedure

One hundred and ten patients (188 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 WaveLight Allegretto Eye-Q 400Hz. After the photo-ablation, 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 10 days, and artificial tears (Blink, Abbott Medical Optics, Santa Ana, CA, USA) were given 6–8 times daily for at least 1 month.

Postoperative evaluation

All patients were examined at 1 day, 1 week, 1 month, 3 months, and 1 year after the surgery. 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 two groups as follows:

- Group 1, myopic astigmatism treated with Allegretto (n= 127 eyes)
- Group 2, mixed astigmatism treated with Allegretto (n=61 eyes)

The data were analyzed to determine the significance of any association between J_0 and J_{45} vectors before and after treatment within each of the 2 groups (Pearson correlation).

The null hypothesis was rejected when p exceeded 0.01.

4. RESULTS

Myopic astigmatism

In the myopic astigmatism group, mean (±SD) preop J_0 vector was +1.369 (±0.776), and postoperatively was + 0.092 (±0.276). There was a statistically significant difference between J_0 preop and J_0 postoperatively (p<0.001). In the same group, mean (±SD) preop J_{45} vector was +0.076 (±0.695) and postoperatively was −0.058 (±0.204). There was no statistically significant difference between J_{45} pre-op and J_{45} postoperatively (p=0.042) (Table 1).

In the group 1, preoperative r=−0.158 (p=0.076) and postoperative r=−0.197 (p=0.026). Vector values are converging towards zero, but they are not zero. Treatments are working to nullify astigmatism but they don’t cancel it out completely. Some residual astigmatism is still present

	Preop J_0 mean (± SD)	Postop J_0 mean (± SD)	P	Preop J_{45} mean (± SD)	Postop J_{45} mean (± SD)	P
Wavelight Allegretto Eye-Q	+1.369±0.776	+0.092±0.276	<0.001	+0.076±0.695	−0.058±0.204	0.042

Table 1. Myopic astigmatism, mean values for the J0 and J45 vector, and significance of any differences (p values) according to t-test

	Preop J_0 mean (± SD)	Postop J_0 mean (± SD)	P	Preop J_{45} mean (± SD)	Postop J_{45} mean (± SD)	P
Wavelight Allegretto Eye-Q	+1.417±1.198	+0.108±0.359	<0.001	−0.120±0.782	−0.039±0.285	0.424

Table 2. Mixed astigmatism, mean values for the J0 and J45 vector, and significance of any differences (p values) according to t-test

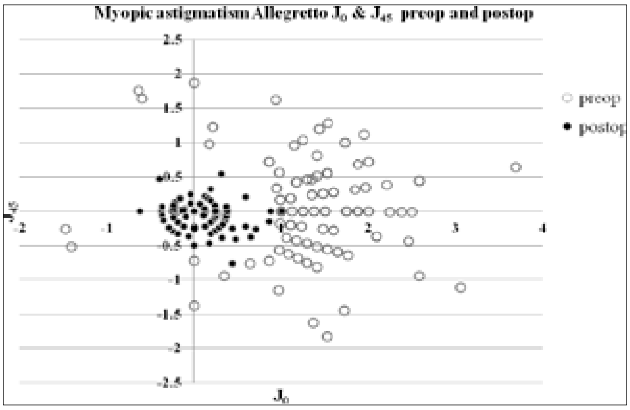

Figure 1. Association between pre- and postoperative values of J0 and J45 for myopic astigmatism

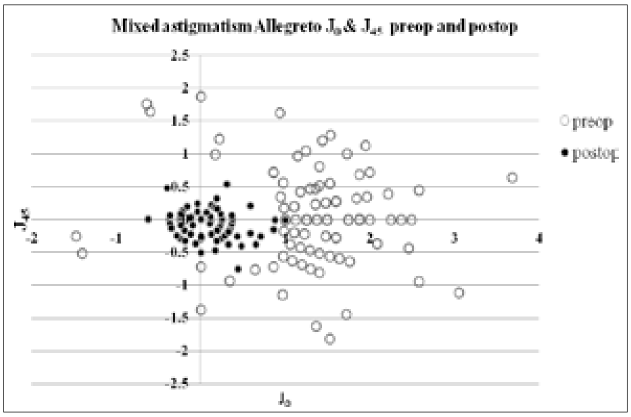

Figure 2. Association between pre- and postoperative values of J0 and J45 for mixed astigmatism

after the surgery.

Mixed astigmatism

In the mixed astigmatism group, mean (±SD) pre-op J_0 vector was + 1.417 (±1.198) and postoperatively was +0.108 (±0.359). There was a statistically significant difference between J_0 pre-op and J_0 postoperatively (p<0.001). In this group, mean (±SD) pre-op J_{45} vector was −0.120 (±0.782) and postoperatively was −0.039 (±0.285). There was no statistically significant difference between J_{45} pre-op and J_{45} postoperatively (p=0.424) (Table 2).

In the group 2, preoperative r=0.238 (p=0.065) and postoperative r=−0.028 (p=0.833). Treatments are working to nullify astigmatism (vector values are converging towards zero) but they don't achieve it completely (Figure1 and 2).

5. DISCUSSION

Laser in situ keratomileusis (LASIK) is regarded as the most performed elective procedure in medicine. It is estimated that almost 1,000,000 people per year have a LASIK procedure in the USA (5,6). Causes of LASIK popularity are based on various factors – no postoperative pain, fast recovery of visual acuity, refractive predictability and accuracy, and minimal incidence of intraoperative and postoperative complications (7-11). LASIK is a highly successful surgical treatment for correcting myopia and low levels of hyperopia. However, treatment of astigmatism, especially hyperopic astigmatism, is still a therapeutic challenge and often results in significant refractive miss-corrections (2,12). Methods to calculate differences between, and changes of, astigmatic powers and axes have been previously developed (13,14). The individual algorithms and equations may appear different from each other, but the computed results are almost the same. The company that manufactures the WaveLight Allegretto platform advises surgeons to use the Wellington nomogram before photoablation. This nomogram advises the surgeon to reduce the astigmatic correction by 25%. In our series, we elected to reduce the correction by 15% as noted in our previous study (15). The WaveLight Allegretto platform feature sophisticated built-in mechanisms to ensure any astigmatic correction remains on target and along the inputted axis. The Allegretto platform has a high-speed camera operating at 400 Hz to track the patient's eye movements and compensates for shifts in eye position or interrupts the treatment if the eye moves outside a preset range during treatment. For myopic astigmatism the surgical treatment reduced the value of J_0 vector, showing that platform reduced astigmatism as expected. The surgical treatment reduced the value of J_0 vector, showing that platform reduced astigmatism as expected. The percentage change in the J_0 vector was 93 %. Using the Nidek 500 platform, Abolhassani et al. (16) 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, it describes the astigmatism in the oblique meridian, in contrast to the J_0 vector, which describes astigmatism in the vertical and horizontal meridian. In a perfect scenario, the treatment should reduce the J_0 and J_{45} vectors to near zero. Referring to Table 1, the Allegretto platform reduced the J_{45} vector to a mean of −0.0581. Abolhassani et al. (16) reported a 76.4 % fall in the average value for the J_{45} vector. We found J_{45} vector to change by 176 % for the Allegretto platform. Table 1 shows the signs of the mean values shifted from plus to minus. There was no surgical complications in any of these cases. For mixed astigmatism, the treatment reduced the value of the J_0 vector, showing that the platform reduced astigmatism as expected. On a percentage basis, the changes in both vectors are similar to those reported by Abolhassani et al. (16) It appears that the platforms did not significantly reduce 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 and very few cases presented with oblique astigmatism. We did not encounter any surgical complications in any of these cases.

6. CONCLUSION

In this study, LASIK showed comparable safety, efficacy, and predictability for laser correction of high astigmatism (greater than 2 D) in myopic eyes. WaveLight Allegreto Eye-Q laser platform showed excellent results in treating high astigmatism with LASIK procedure. Predictability of the correction of the cylindrical component was lower than that for the SE. WaveLight Allegretto laser produced acceptable results tending to preserve optical performances of the eye without significant induction of high-order aberrations. In myopic astigmatism there was a statistically significant difference between J_0 pre-op and J_0 postop for this platform ($p<0.001$). There was no statistically significant difference between J_{45} pre-op and J_{45} postop for this platform ($p=0.042$). This laser platform significantly reduced astigmatism. In an ideal situation the postoperative J_0 and J_{45} values should be zero. They were not. The highest value was 0.1085 for the mixed astigmatism cases in relation to the J_0 vector. 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 this purpose.

- **Author's contribution**: M.A.P, M.B. and S.G gave substantial contributions to the conception or design of the work in acquisition, analysis, or interpretation of data for the work. A.B and S.P. had a part in article preparing for drafting or revising it critically for important intellectual content, and A.P gave final approval of the version to be published and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part.
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