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BEYOND PSEUDO-ACCOMODATIVE CORNEA LASIK (PAC LASIK). A PERSONAL INSIGHT

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ABSTRACT

Laser in-situ keratomieleusis (LASIK) is a common intervention for young, active, ametropic individuals to improve their visual acuity. pseudo-accommodative cornea (PAC), a variant of LASIK, to correct ametropia among presbyopic patients is proven in maintaining good distant vision; yet, the satisfactory spectacle free reading vision is limited to the ageing progression.

However, successful treatments do not guarantee patient's satisfaction. Assesment of the objective topographic indicators, visual acuity, higher order abrasion, and contrast sensitivity; revealed the clarification of a mild headache as a personal subjective experience after the treatment.

The role of the persistent, dominant eye, the brain perception, seems to be critical factor to a patient's satisfaction. To a certain degree, the interplay amongst the optical part and it's supporting tissue, within and between the eyeballs, as well as its relationship to the neurosensory parts of the visual systems after Lasik surgery have not yet been assessed and reported elsewhere.

Keywords: Eyeballs; Lasik surgery; Neuro sensory parts; supporting tissue; topographic indicators; visual acuity

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INTRODUCTION

It is already well known, that corneal refractive surgery, either by excimer laser and/or femtosecond laser has proven to be an effective mode to improve visual acuity such that young adult ametropic patients' glasses can be spectacle-free. The impact of such an intervention is not merely on visual outcome, but also the foundation for a broader, better future and a better quality of life [1].

Such successful impact on young adults is generating demand among middle aged generations, who are burdened by their reading glasses (presbyopic patients), as well as on refractive surgeons and scientists in this field. A presbyopic state is known to be the impact the accommodative amplitudes of the natural lens in older age. The decreased of the accommodative amplitudes of the natural lens will incrementally raise the tension of the muscles within the iris-pupil diaphragm in order to prevent the progressive loss of the depth of focus [2].

Pseudo-accomodative Cornea (PAC) is a multifocal laser-assisted keratomielusis (LASIK) surgery, which shapes a new distant-dominant center cornea, and near-dominant corneal periphery in hyperopic, myopic, or emmetropic presbyopic patients.

This type of corneal refractive surgey, was introduced by Dr. Alain Telandro [3], using the NIDEK CXIII excimer laser in 2004; inspired by the use of a multifocal intra-ocular lens which has refractive power surface in the anterior side and diffractive posterior power in cataracts surgery.

I myself have had experience performing photorefractive keratectomy (PRK) since1994, and LASIK in 1997, Wavefront guided Lasik (2001) in addition to all it's variants (Lasek, Epi-Lasik, PAC), and Femtosecond Laser Assisted Lasik (2006), RelexSmile (2016) thereafter. Being a LASIK surgeon, I myself (at the age of 52 years old) was very dependent to wear presbyopic spectacles, have always been asked a cynical question, either by ametropic patients or their parents, a sinical question, "Why do you still use glasses?".

Such question triggered me to receive this mode of treatment directly by the PAC' inventor himself about 14 years ago; after witnesses that he, who has had undergone such procedures about five years earlier, never needed to use reading glasses during several days of this training period in our institution. Herewith, I would like to share my own immediate and longterm objective results, as well as my personal subjective experience; and analyze all signs and symptoms in an integrated way. To the best of my knowledge, this has not yet been done elsewhere.

CASE REPORT

At the age of 52 years old, though the far vision was fine (Right eye [RE] 1.00 S-0.25:C-0.50x40**o** = 1.25, Left eye [LE] 1.00 S-0.25 = 1.25); however, I was very dependent on reading glasses (addition S+2.25 Diopter). The LE is the dominant eye. The corneal topographic, refractive power and other diagnostic data were obtained from the Nidek OPD-ScanII**™** topographer and Aberrometer, and Nidek Dream Chart SSC 330**™**.

The PAC was carried out using an excimer laser machine Nidek EC 5000 CX III**™**, directly, after creating a 110 µm corneal flap using a Moria microkeratome on August 13, 2006, in our satelite clinic by Dr. Alain Telandro, himself. Based on the point spread function (PSF) data, higher order corneal aberasion correction was implemented to the right eye, and treated the left eye with PAC treatment only. The LASIK surgery was uneventful; and afterward, antibiotic steroid eye drops and tear substitutes were administered thereafter.

The aims of the PAC treatment are to have free

spectacles for near/reading, and subsequently to ameliorate one's far sightedness vision[3-5]. These objectives seem to be had been achieved (Table 1), reflecting the subjective distance visual acuity and spectacles-free reading capabilities.

Table 1. Far and reading distance visual acuity

	RE	LE	Reading
Pre **13.08.06**	0.9 S-0.25:C-0.50x40º **=** 1.25	1.0 S-0.25 = 1.25	S+2.25 * Jaeger 1
Post **15.08.06**	0.5 S-1.00 = 1.0 Hazy, unstable	0.5 S-100 = 1.0 Hazy, unstable	w.o. Jaeger 1
25.08.06	0.8 S-0.50:C-0.50x70o = 1.25	0.8 S-0.50:C-0.50x60o = 1.25	w.o Jaeger 1
31.08.06	1.0 S-0.25 = 1.6	0.9 S-0.50 = 1.25	w.o Jaeger 1
2014 – 2017 Using the previous spectacle			Jaeger 1
24.8.19	1.0 S+0.25 = 1.25	1.0 S+0.25 = 1.25	+2.75 Jaeger 1

* Very dependent on spectacles

Actually, the dominant, left eye's far visual acuity was slightly decreased; as compared to the sharpening of the right eye visual capability, due to the higher order abrasion correction. However, binocular far vision was practically back to within normal levelstwo weeks after the PAC proce-dures. Reading capacity was excellent within one week post surgery.

In relation to the ageing process, the visual condition was nearly stable for about 7 years. It, then began to degrade and spectacles were required for reading distant; which was fix by using the pre-PAC' spectacles untill these broke. The last refraction examination revealed that for comfortable near-sightedness required an additional 2.75 diopter positive spherical power.

Corneal topography

The basic principle of LASIK as a refractive surgery is to gain the optimal vision by reshaping the corneal' volume and thickness, subsequently changing the corneal curvature and its refractive power [1,6,7]. Safety of LASIK procedure can be defined as the number and percentage of eyes that lose two or more lines of best spectacle-corrected visual acuity. The PAC seeks to develops

the central optical cornea for far vision, while the peripheral cornea for reading distance [3-5].

• **Maintaining the good far visual acuity**

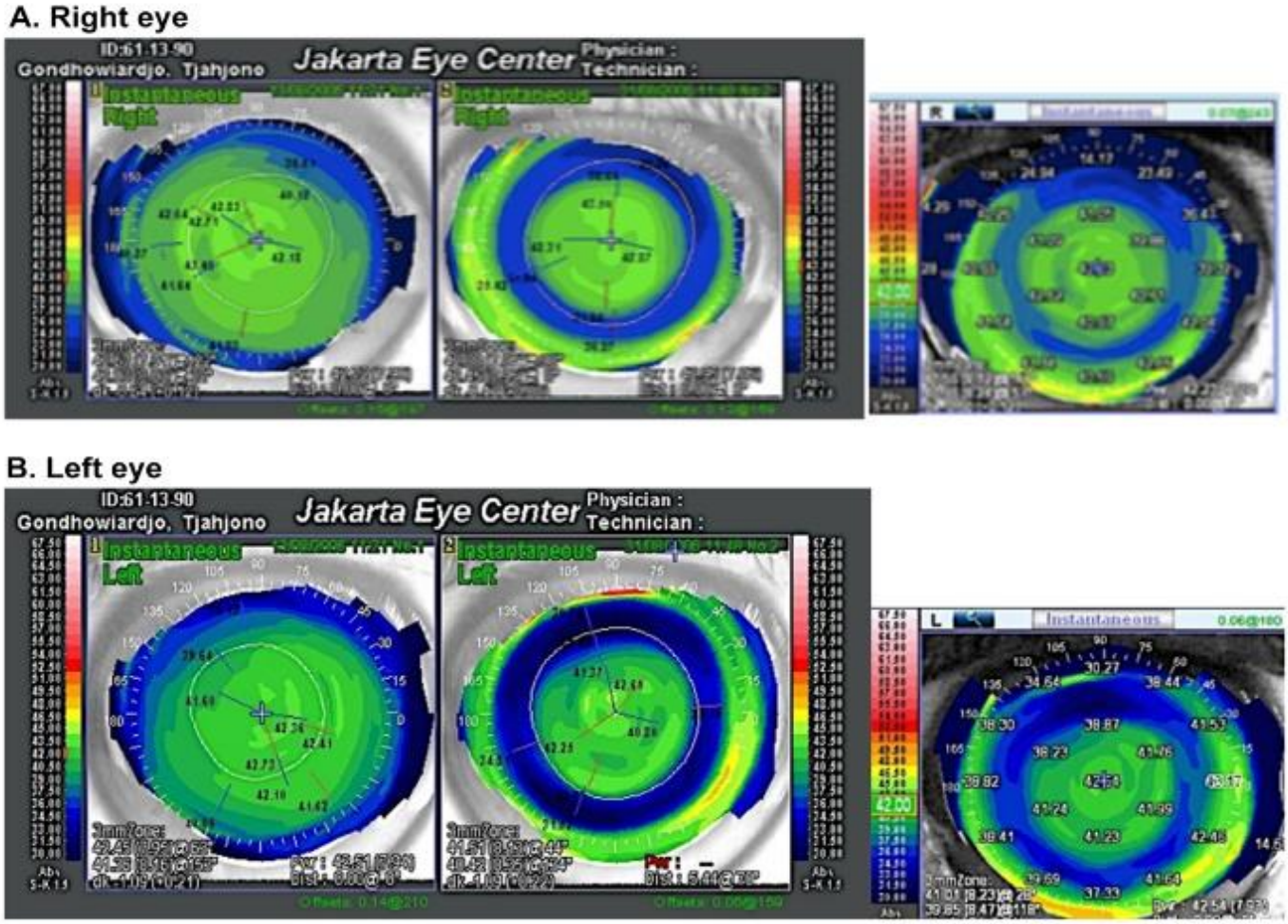

Figure 1. Corneal contour pre- and post-PAC, and 13 years afterward

Figures left to the right represent respectively, the pre surgical condition, followed by the condition two weeks after PAC, and the 13-year follow up.

The central 3-mm ring of the cornea, which are representing for the distance vision were preserved after the PAC procedures (figure 1). The results of PAC treatment could be clearly be seen as the encircling dark blue mid corneal guttering in both eyes; which resulted in peripheral corneal curvature steepening (yellowish - light green circle). The long follow up revealed that there was slight flattening in the central optical zone,and narrowing in the deep blue guttering width. The light green to red circle represented the steep curvature peripheral cornea. There is a deep dark-blue indentation area in the superior cornea, which seems to be, due to the constant upper eye-lid pressure. The LE seems to have the deepest lid indentation, as compared to the RE; which might be related to the fact that the left eye originally had a thinner corneal thickness than the right eye (490 and 510 µm, respectively).

• **Multifocal Cornea**

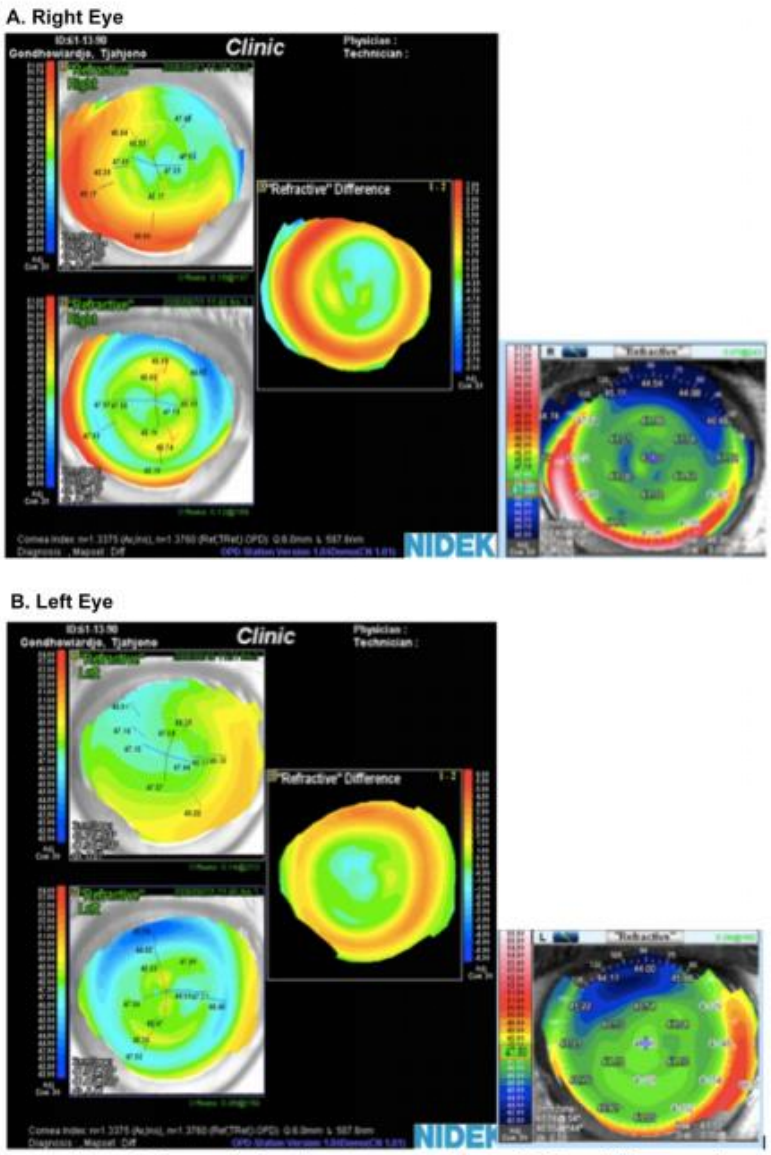

Figure 2. Corneal refractive state, pre- and post-PAC, and 13 years afterward.
The upper and lower left figures respectively represent pre-surgical condition, and two weeks after the PAC. The middle figures represent the refractive differences between pre- and post-s PAC intervention; while the right figure represents the 13 year follow up

The idea of a central cornea for distance vision and a steep peripheral corneal ring for reading can be seen in Figure 2. The corneal profile is the safest approach for presbyopia correction in the cornea, since for far vision the depth of field is very important, and is correlated with pupil diameter.

Guttering of the mid peripheral cornea, eventually disrupted the lamella of the stromal layer of the cornea, and subsequently flattened the central optical zone of the cornea, and steepened peripheral cornea. The steepening curvature of the inferior peripheral cornea reflected increase negative spherical power, which is needed for distant reading. A negative spherical power reflects an increase depth of focus [3-5] (see Figure 2 A and B).

Prior to the PAC treatment the infero posterior of the cornea of the RE seems to be steeper than that of the LE. Thus, guttering of the mid-peripheral cornea, subsequently has a higher refractive impact on the right cornea. The bright blue color in the superior peripheral cornea; is assume to be due to the upper eyelid's pressure, flatening the superior cornea and steepening the inferior corneal curvature. The bright blue color in the

superior cornea is transformed into a dark blue area at the thirteen-years evaluation, and seems to be more intense or deepeer in the left eye as than the right eye.

The beauty of using the Nidek OPD-Scan machine is that it can provide the refractive condition or power of the crystalline, as well as of the artificial intra ocular lens [7]. Thus, we could also observe the impact of the PAC treatment in the cornea on the refractive power of the natural lens (see Figures 3 A and B).

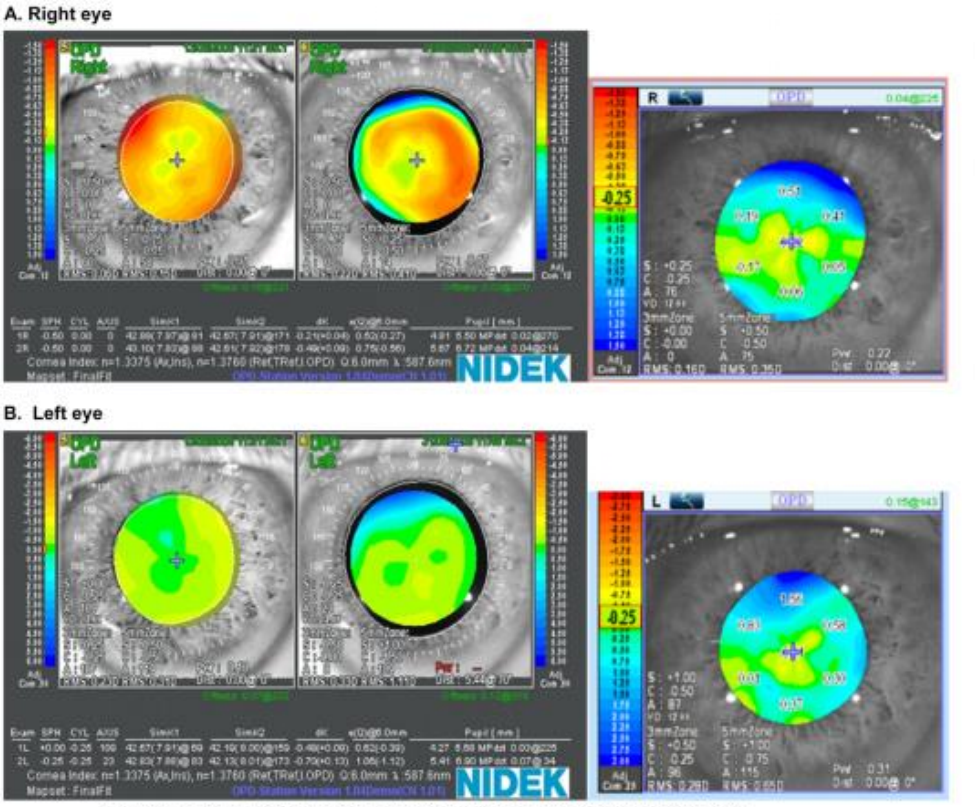

Figure 3. Lens refractive state, pre and post PAC, and 13 years afterward

Figure left to the right represent the pre-surgical condition, and the condition two weeks after PAC, as well as 13-year follow up

Assesments prior to, and two weeks after the PAC treatment showed that the lens refractive power of the right eye was “hotter” or in the lens’ accommodative state (Figure 3 A, left) as compared to the cooler, resting state lens of the left eye (Figure 3 B, left). The long-term, follow up the lens of both eyes seemed to reflect a hyperopic state (Figures 3 A and B,right) concomitant with increasing age.

The decreased near focus several years after LASIK was mainly due to the “lens sclerosis”, wheby the elasticity of the lens decreases over time [2]. This condition explained the decrease in reading capacities after 13 years of LASIK while the corneal multifocality was still preserved.

Subjective experiences

Practically, there was no pain during the treatment, except of slightly panic situation, especially during the treatment of the dominant left eye. The pain, tearing and eye lid spasms were diminished about 3 - 4 hours after surgery; though the vision remained hazy. The next day, the far vision was clear, as well as the reading capabilities, though there were some eye dryness. However, I have has successfully performed two uneventful phaco surgeries.

On the fourth postoperative day, after had an overnight flight abroad, to a different climate zone, i.e a lower temperature and humidity level; one or two hours afterward, my vision was directly abrupted. These symptoms were aggravated after the deliberate administration of the

tear substitute. Fortunately, two weeks afterwards, no tears-film substitute administration are needed.

The first three or four months after the PAC, the main subjective visual perception was the decrease of contrast sensitivity, especially for reading at the bedroom, which required a higher intensity room lighting. The other subjective feeling was a headache. These mild, but unexplained headache lasted about six to eight months, and reoccured irregularly.

About four or five years after the PAC, while watching television, unintentionally, I have put on my-own old spectacles. Surprisingly, it's felt very comfortable, after compared the vision of the right and left eyes; then it was realized that my old vision perception was fixed and still dominated by the left eye, eventhough, objectively, the right eye, had a better coneal contour and refractive indicators (see Figures 1 and 2). This unintentional awareness, subsequently triggered an interest in determining the interaction amongst the objective visual indicators and subjective experience.

The main differences in the PAC intervention within both eyes was the higher order abrasion correction which applied to the fellow right eye. Higher order abrasion data revealed that the fellow right eye gained a better shape after the intervention, and progressively became more fo-cused than the left eye in the long-term follow up (see Figures 4 A and B).

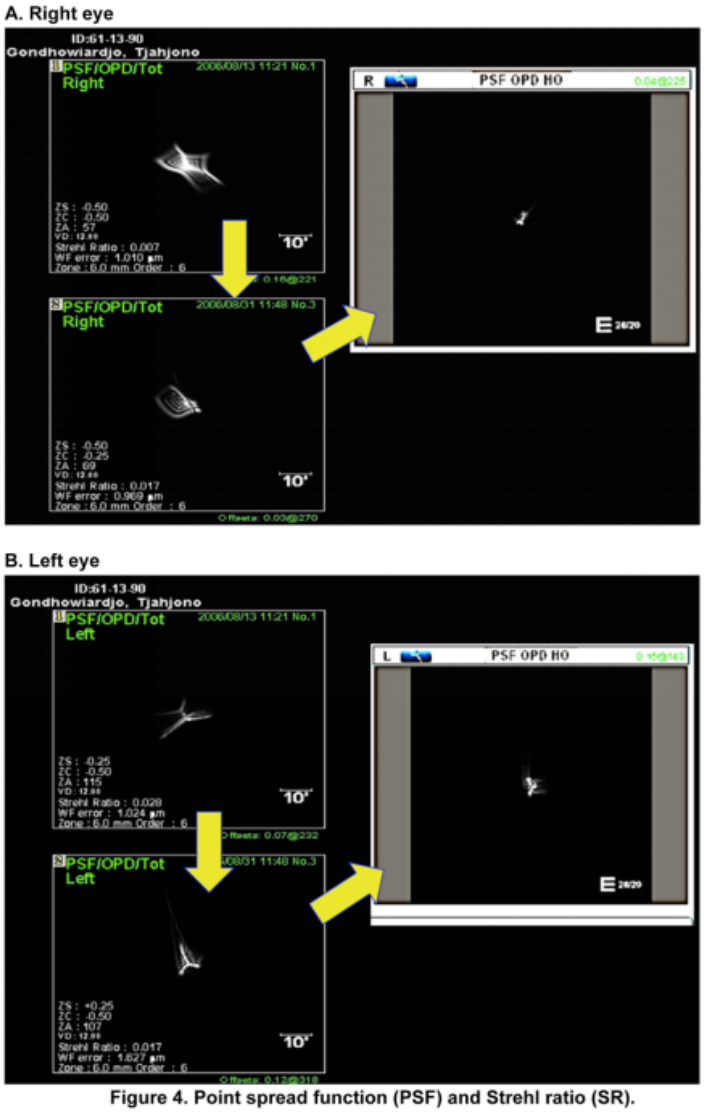

Figure 4. Point spread function (PSF) and Strehl ratio (SR).

The left figures represent pre-surgical condition, followed by the condition two weeks after the PAC. The right figure is the 13 years follow up.

The dominant, left eye, was originally have a trefoil pattern and a better Strehl Ratio (SR 0.028) as compared to the more disperse light reflection in the fellow, right eye (SR 0.007); which become similar in both eyes (SR of 0.017) two weeks after PAC with corneal' higher order abration correction in the right eye; and have had refining process in the long term follow up. The Strehl ratio, which simply equals to the peak intensity of the PSF of the aberrated system, could be used as a measure of objective visual performance since it is highly consistent with patients' subjective experiences. The range of SR is between 0 to 1, and the perfect optical system will have a SR of 1.0, while the SR of the human eye is usually very low [8].

These data, interestingly showed that there may be an internal corneal tissue reorganization which refines the light reflection in both eyes. If this hyphothesis is true, it opens the door to future research in this direction.

Decreased contrast sensitivity (CS) after Lasik treatment is well known to be a common sensation [1] (see Table 2); though it is not a spesific indicator but may subjectively disturb a patient's quality of vision, or even quality of life.

Table 2. Contrast sensitivity

	90%	10%
Right Eye		
Pre	- 0.1 + 0.00 = - 0.20	- 0.00 + 0.00 = 0.00
Post	- 0.2 + 0.02 = - 0.18	- 0.10 + 0.04 = + 0.04
F.U.*	+ 0.04	+ 0.12
Left Eye		
Pre	- 0.1 = 0.00 = - 0.10	- 0.00 + 0.00 = 0.00
Post	- 0.1 + 0.02 = - 0.12	- 0.10 + 0.02 = + 0.12
F.U. *	- 0.06	+ 0.14

* F.U.: 13 years follow up.

The PAC combined with higher order abrasion correction demonstrated an increase in the bright light's CS value in the right eye; in contrast to the PAC only treatment which decreased the bright light CS of the left eye. This finding is consistent with an earlier report which stated that wave front-guided Lasik improved CS while standard Lasik diminished CS [9]. However, both modes of treatment resulted in a decreased dimmed light CS' value. Moreover, surprisingly, in the long-term evaluation, the dominant (left) eye had a better capacity for recovery; while, changes to the dimmed light CS value may have paralelled the decreased accommodation capacity of the crystalline lens due to aging process.

DISCUSSION

The successful result of corneal refractive surgery (LASIK) in correcting myopia and astigmatism especially among young populations has triggered a higher demand from older populations to be free from reading glasses too. To address this demand, Alain Telandro [2], who was inspired by the use of multifocal intra-ocular lenses, which have a refractive anterior surface and a diffractive posterior surface to exchange the decrease of accommodative amplitude (depth of focus) in cataract surgery; propose the concept, of corneal multifocality to increase the depth of focus. The central optical zone for far vision, and peripheral cornea for the near vision, however, it should have a jointless optical transition (smooth ablation profile); he has named this

innovation as the pseudo-accomodative cornea (PAC).

The PAC treatment, have proven to be highly effectively in achieving spectacle-free vision for near-sighted or reading distant within two weeks of an operation. However, in my case, there was a slight worsening of my far vision in my dominant, left eye. In contrast to the impact of higher order abrasion correction to the fellow right eye, which resulted in better far-vision capability. These visual outcomes (see Table 1) are clearly in paralel with the objective changes in the topographic corneal contour (see Figure 1) as well as the corneal refractive power (see Figure 2). Combining pre-post and long-term evaluation of the topographic corneal contour and refractive power of the cornea, revealed that there was a slight flattening of the central optical zone as a result of a certain level of corneal stromal tissue re-organization of the mid-corneal guttering which showed up as a smaller and shallower blue ring. Moreover, the two sets of figures (Figures 1 and 2, respec-tively) do demonstrate the effect of the continu-ous and rhythmic upper eye lid pressure, which could be seen as the deep, dark blue indentation in the blue encircling gutter area, and its impact on the lasting inferior peripheral cornea steepening. This is consistent with facts are coupling phenomenon in corneal refractive surgery principle [6].

An interesting finding was revealed by simultaneously analysing the relationships of the corneal refractive power (Figure 2) and the natural lens refractive power (Figure 3). Pre-operatively, the non-dominant, right eye seems to be in a higher accommodative state than the dominant, left eye. This could be seen as the yellowish to red infero-nasal corneal refractive power, and a similar yellowish redish lens state of the right eye; as compared to the light blue, green and yellowish cornea and lens of the left eye. It seems that the lens condition of the dominant left eye is less responsive to the corneal refractive changes; while the lens of the fellow right eye seems to be remained in a high accommodative state two weeks after the PAC treatment, despite the change in the corneal refractive power. Additionally, the upper eye lid pressure seems to be more prominent in the left eye (see Figure 2 and 3). These facts, directly demonstrate that the upper eye lids, the corneal contour and corneal refractive state, as well as the lens' refractive state are complementary and inextricably link to produce a good focus on of the visual object. Furthermore, such an interplay within the eyeball and its adnexa do show that the eyeball is one functional compartment which have it's own optical refractive equilibrium.

Moreover, it has been indirectly shown that, prior to the PAC intervention, the fellow, right eye was in a constant accommodative state in order to produce a good visual input to the brain; and needed an adaptation period to release the pupillary and ciliary muscle contraction. In fact, the pre-PAC pupilary size, was relatively smaller in the right eye (3.0 – 3.5 mm) as compared to 3.0 – 4,2 mm in the left eye. However, such a situation seems to be reversed at long-term follow up, whereby the right eye's pupil is 4.8 - 5.6 mm v.s 4.2 – 5.4 mm (left eye). It is reported that in the young adults, normal vision populations with a 5.7 – 6.00 mm pupil diameter, the Strehl ratio values are 0.14-0.15, 0.15-0.27, and 0.11-0.12 respectively, for coma, trefoil and spherical abrasion [12]. Our data revealed that prior to the PAC intervention, nearly similar SR values could only be obtained with a smaller pupillary size. The goals of patients who are willing to have a Lasik procedure are to have an immediate, good visual outcome. Such a demand has grown among PAC candidates, who are active, have a social

lifestyle, are middle-aged and from mid to upper socio-economic class. Patients demand to be satisfied. This report, clearly showed that spectacle-free reading and a near normal far vision, may not fully satisfy patients due to a certain degree of negative subjective feeling.

The first reason for such a negative subjective feeling may due to the fact that the vision of the dominant left eye was deteriorated, due to the increased optical abrasion which is objectively shown by the decreased Strehl ratio (SR) as compared to the fellow right eye (see Figure 4). The decrease in the optical clarity of the dominant left eye subsequently increased the accommodative state of the lens (see the Figure 1, 2 and 3), and lead to a smaller pupillary size. It is shown that the shifted accommodative state of the lens, is automatically involves the sub-conscious contraction of both intra, and extra-ocular muscles.

Secondly, in the early PAC intervention state, the objective visual focus as well as the subjective contrast sensitivity quality of the dominant, left eye seem to be worsening, in contrast to the fellow right eye, which showed a better negative log value in the high luminance light. Both eyes demonstrated a worsening effect in the dimmed light luminance. However, at the long term follow up, the dominant left eye showed a better contrast sensitivity in the bright illumination light (see Table 2).

The contrast sensitivity test revealed an objective measure to quantify of the ability to detect the threshold luminance differences between a target and its surroundings. In reality, there are two polarities in CS. Negative polarity (NP dark letters on bright background) and positive polarity (PP, bright letters in dark background). It is known that negative polarity induces a higher disability glare than positive polarity. Furthermore, binocular vision will have a better contrast sensitivity due to the summation of the CS value [11].

The contrast sensitivity test is known as highly sensitive measurement device, but does not necessarily become a specific diagnostic indicators. This is due to the fact that the results are derived from combining the quality of all optical refractive parts, and the neurosensory part of the eyeball. It seems that the dominant left eye may have a more developed neurosensory tract than the right, fellow eye. These premise is subject to further exploration.

Moreover, the CS is strongly correlated with the PSF [8], which explains why during the initial results after LASIK, the contrast sensitivity is not as good as several years after LASIK. The tear film stability also plays a very important role which explains why the PSF value during the first month after LASIK showed a higher values [8]. In this report, the homeostasis of the tear film seems to be back to normal in less than 1 month.

The term, ocular dominance refers to the superiority or preference of one eye over the other in term of sighting, and sensory function or persistence in binocular rivalry [12]. Sighting dominance involves the extra-ocular muscle contraction at various target distances, gaze direction etc. This report, showed, that although, the objective sensory indicators (quality of optical media, the visual acuity, and contrast sensitivity) are shifted to the fellow right eye; subjectively, sighting dominance remains in the left eye; which may be due to persistent perception in binocular rivalry. In view of the neural adaptation to blur and to aberrations, Villegas et.all [10] have concluded that in normal healthy populations, if the subjects can adapt to their specific aberration patterns, the amount of aberrations may have a smaller effect on vision.

The proportions of left eye dominance are about 38.6% and 29.5% by the sensory and sighting

methods, respectively. The dominant eye tends to have a higher refraction correction [13]; which does not seem to match this report, since that the dominant left eye has less refractive power correction. On the other hand, this left eye does represent a good example of neural adaptation and plasticity capability, capable of maintaining its function as dominant eye though diminished optical media quality. This situation, may refer to the strong-dominance term, which is again, characteristic of only a significant minority (39%) per Li et.al. [14]. Thus, in this case an individual variation may play an important role.

Conclusion

In summary, though this is just a single case, the PAC concept of corneal multifocality to increase the depth of focus of the natural lens of the presbyopic patients among aging populations has been proven effective for a certain period. Moreover, a laser-assisted higher order aberration correction to the cornea did reveal the successful improvement of the optical clarity.

The main objective of any type of corneal refractive surgery (i.e Lasik and its derivates) is visual optimization, which will subsequently improve one's future quality of life. Thus, to fulfil this objective and satisfy patients, the surgeon has to consider many aspects of the immediate impact, and longterm tissue healing reformation, as well as the functional interplay within and between the dominant and fellow eye; and its interaction with the brain processes. Therefore, in order to meet patients' demands and satisfy them a clear and extensive explanation concerning the intervention and its impact should be properly done.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Not applicable

HUMAN AND ANIMAL RIGHTS

Not applicable

CONSENT FOR PUBLICTION

Not applicable

CONFLICT OF INTEREST

None

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