Original Article

The effect of refractive surgery on blur thresholds

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Purpose: The aim of this study was to measure blur thresholds before and after refractive surgery. **Methods:** In this prospective cohort study conducted in a tertiary eye hospital in South India. Blur thresholds were measured for 30 young adult myopic patients 1 month prior to and after refractive surgery. Patients were asked to report three stages of blur, namely Detectable Blur (DB), Bothersome Blur (BB), and Non-resolvable Blur (NB). Blur was created by adding plus lenses (in steps of 0.12D) over their optimal subjective refraction. The blur judgments were made both monocularly and binocularly when looking through a 3 mm artificial pupil at one line above the best-corrected visual acuity. **Results:** A total of 30 participants were included in this study (mean age = 25.5 ± 3.8 (20–36) years; 77% female). The mean binocular preoperative blur of this group was: DB = 0.39 ± 0.26D, BB = 0.74 ± 0.28D and NB = 1.04 ± 0.42D. The corresponding mean binocular blur one-month post-operatively was DB = 0.46 ± 0.28D, BB = 0.83 ± 0.35D, and NB = 1.21 ± 0.44D. Although there was a marginal increase in the blur thresholds postoperatively, the difference was not statistically significant (DB: $P = 0.320$; BB: $P = 0.229$; NB: $P = 0.054$). **Conclusion:** All three blur thresholds showed an insignificant minimal increase at 1 month post-operatively suggesting that patients adapt to the induced blur following refractive surgery. A longer follow up would reveal how the adaptation to blur would change with time.

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Laser refractive surgery, a common treatment procedure for myopia has advanced significantly over the past few years leading to higher efficiency and accuracy in performance and a quicker visual recovery for the patient.[1-3] Despite the correction of the refractive error following the surgery, it has been noted that patients often tend to experience greater sensitivity to blur because of new state of blur induced by factors including microsurface corneal irregularities, Seidel aberrations, and partly due to unrealistic expectation.[4,5] It is known that the higher order aberrations increase following refractive surgery.[6] This induced blur decreases the overall patient satisfaction despite a good refractive surgery outcome.[7] In fact, blur is one of the most-highly reported symptoms in patients post-refractive surgery.[4] A constant exposure to a degraded stimulus modifies the mechanisms behind blur detection in the visual system.[8] Prolonged exposure to blur or retinal defocus results in perceiving a blurry image as clear.[9-11] This perceptual change is termed as blur adaptation. Many studies have looked at adaptation to blur caused by lower and higher order aberrations either by inducing blur optically or by using simulated images.[10-12]

After refractive surgery, the improvement in the uncorrected visual acuity has been attributed to the blur adaptation process, which is aided by the corneal healing effects, and in part by the neural adaptation.[13] The tendency to adapt to the blur varies with time after the surgery.[9] The measurement of these sequential stages of blur perception is known to be affected by many factors including target size, accommodative state, and pupil size.[8,11,14] Since patients complain of heightened sensitivity to blur after refractive surgery, studying blur sensitivity is of interest. Myopic patients especially early onset myopes have been shown to have a greater blur detection threshold or decreased blur sensitivity compared to late-onset myopes and emmetropes.[8,12,15] Blur is characterized as Detectable Blur (DB), Bothersome Blur (BB) and Non-resolvable Blur (NB).[14,16] These measurements are related to the patient's depth of focus. Depth of focus is a measure of blur sensitivity that is defined as the range of distance through which clear vision can be maintained or in other words, the amount of defocus that can be added to the focused vision without perceiving blur.[17] The first characterization, the detectable blur, measures the limit of depth of focus. The second, bothersome blur, indicates the functional aspect of blur perception.[14] It is when the added defocus becomes troublesome and annoying that it affects visual task performance such as reading and seeing fine details of the object. This is a measure of the limit of blur tolerance of the patient. At this point, the letter or the object is still recognizable. However, the final characterization in the sequence, non-recognizable blur,

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denotes the amount of added defocus that renders the target no longer readable or recognizable.

There is a paucity of published data on blur threshold estimates after refractive surgery over a period of time. The present study was aimed at measuring the blur thresholds in the clinical setting in the forms of detectable blur, bothersome blur and non-resolvable blur in patients undergoing refractive surgery.

Methods

The study was approved by the Institutional Review Board and followed the tenets of the Declaration of Helsinki. Written informed consent was obtained from all the patients.

Study participants consisted of patients who were examined in the Department of Cornea and Refractive surgery in a tertiary eye care center in Chennai, India from April 2019 to February 2020, who agreed to participate in the study and come for follow-ups. A young adult myopic population with a best-corrected visual acuity of ≥0.10 LogMAR distance visual acuity and N6 at near were included in the study. The type of refractive surgeries that patients underwent was either EpiLASIK or FemtoLASIK. Patients were excluded if they had any other comorbidities such as anisometropia, amblyopia, squint, binocular vision anomalies or retinal pathologies.

Ocular Assessments: Patients underwent blur threshold measurements along with a complete refractive surgery workup. Objective and subjective refraction was performed and the best-corrected visual acuity was measured both monocularly and binocularly using LogMAR (ETDRS) visual acuity chart at 4 m. Standard clinical tests such as the cover test, near point of accommodation, and near point of convergence were performed as a part of our pre-refractive surgery workup to screen for binocular vision problems and none of our study participants showed any abnormality in these tests.

Blur threshold assessment: In the literature, blur thresholds have been measured using many methods and instruments, including degraded images, and the Badal optical system. In the present study, we used small increments of plus lenses to measure the blur thresholds.[18-21] The advantage of using plus lenses is that it is a simple, quick, and accessible method to perform in a clinical setting using lenses in the trial box. The perceptual stages of blur were assessed by adding plus lenses over the optimal refractive correction. After determining the optimal refractive correction, blur threshold measurements were done by placing a 3 mm artificial pupil on the trial frame to maintain a constant pupil size. The trial frame was adjusted to maintain the proper pupil centration such that the patient could view the target through the center of the artificial pupil without any ocular decentration. All measurements were made in the same ambient room illumination, with the patients in an undilated pupillary condition. The patients were asked to maintain fixation at the eye chart during the measurements. The patient was shown a target that was 1 line above their best-corrected visual acuity on the eye chart positioned at 4 m from the patient. As the plus lenses were added in steps of 0.12 D, the patients were asked to report the three stages of blur i.e., Detectable blur, Bothersome blur, and Non-resolvable blur. Before the blur threshold assessment, the process was explained to the subjects. The definition of each blur response was given in the patient's vernacular and every patient was given a demonstration of each kind of blur using artificially blurred images. The amount of plus lens that gave rise to each of these blur responses was noted. The test was done monocularly and then binocularly, all measurements were done twice and averaged. The same procedure was then repeated 1 month post-operatively. A questionnaire to assess the quality of vision following refractive surgery was also administered. The questionnaire was adapted from a study conducted to measure the quality of life in post-refractive surgery by Chan *et al*.[22] There were 10 questions targeted to assess glare (during night and day time), haze, halos, clarity of vision (during day and night). The scoring was done on a scale from 0 to 10 based on the symptoms of the patients, where 0 represents no symptoms and 10 represents severe symptoms, giving a total maximum possible score of 100. A maximum score of 100 indicates that the patient had maximum symptoms, whereas a patient's aggregate score of 0 indicates he or she had minimum or no symptoms.

Statistical analysis

Statistical analysis was done using SPSS (version 23. IBM Corp.). If the variables satisfy the normality, parametric tests were used and if not nonparametric tests were used. The Mann-Whitney U test was used to test the difference in parameters between the two groups, and the Wilcoxon rank sum test was used for pre- and post- comparison, while a two-sample *t*-test was used for difference between the two groups and a paired-*t* test was used to analyze the change in parameters post-operatively from their respective preoperative values.

Association between two variables was described using the Pearson correlation. Any P value which was less than 0.05 was considered as statistically significant. A sample size of 30 subjects was recommended with an estimated study power of 80%, a confidence level of 95% for a difference of 10% in non-resolvable blur threshold values post-refractive surgery.

Results

Thirty patients participated in the study. Mean age of the participants was 25.5 ± 3.8 (20- 36) years with 77% of them being female participants. The Mean preoperative refractive error was -4.94 ± 2.04D (-1.5 to -10.5D). 21 (70%) patients underwent EpiLASIK and 9 (30%) patients underwent FemtoLASIK. Preoperative best-corrected visual acuity was 6/6 (logMAR 0.0) in both eyes in all patients. Post-operatively the uncorrected visual acuity was 6/6 (logMAR 0.0) in all patients except for one patient who had logMAR of 0.1. Following refractive surgery 85% of the eyes achieved emmetropia and the residual spherical equivalent was in the range of -0.37 to -0.5 D. in the remaining 15% of the eyes.

Table 1 shows blur threshold values for the right eye, left eye, and binocularly. The blur threshold values were progressively greater compared to the preceding blur criterion both pre-operatively and post-operatively. There was no significant difference in the blur thresholds between monocular and binocular testing conditions. The mean binocular preoperative detectable blur was 0.39 ± 0.26D, bothersome blur was 0.74 ± 0.28D and non-resolvable blur was 1.04 ± 0.42D. At 1 month post-operatively, the mean binocular detectable blur was 0.46 ± 0.28D, bothersome blur was 0.83 ± 0.35D and non-resolvable blur was 1.21 ± 0.44D. There was a marginal increase in all three blur thresholds at 1 month post-operatively, however, the difference was not statistically significant (DB $P = 0.320$, BB $P = 0.229$, NB $P = 0.054$) for all the three blur thresholds, [Fig. 1] showing box plots overlapping between the pre and postoperative blur thresholds. There was no difference in these blur thresholds between gender ($P = 0.559$) and age group ≤26 yrs and greater than 26 yrs ($P = 0.483$). There was no correlation between preoperative Spherical equivalent and the different categories of preoperative blur thresholds (DB: $r = 0.20$, $P = 0.30$; BB: $r = 0.06$, $P = 0.73$; NB: $r = 0.15$, $P = 0.43$).

We also looked for any correlation between the Questionnaire scores with the blur threshold values and found no significant correlation, detectable blur (r = 0.09, P = 0.62), bothersome blur (r = 0.26, P = 0.15) and non-resolvable blur (r = 0.10, P = 0.57).

Discussion

The present study assessed the three blur criteria, namely detectable blur, bothersome blur, and non-resolvable blur by adding plus lenses to the optimal refractive correction of young myopic patients before and after refractive surgery. Although the Badal system is widely used to measure blur thresholds, it is not a convenient tool to use in a clinical set-up, and therefore, a simple method of using plus lenses was adopted. Keeping the clinical application in mind, we have tried to incorporate dioptric blur through plus lenses rather than using Computer-generated Gaussian or defocus blur, such that it is similar to their perception in the natural environment. One month after their surgery, they were administered a questionnaire to assess the quality of their vision in addition to blur threshold assessments. From this study, we have found that blur threshold levels at one month following refractive surgery were similar to the pre-operative values, across all the three types of blur.

The measurement of the depth of focus was assessed by the detectable blur; the functional aspect of blur was assessed by the bothersome blur and the visually- impairing level of blur was assessed by the non-resolvable blur. The three types of blur have been selected to include both depth of focus measurements and functionality. The first blur criteria, i.e., the detectable blur, can be predicted from objective measures of depth of focus as given by wavefront aberrometers. There are mixed results in the literature on whether the subjective and objective depth of focus, as computed using wavefront aberrations data, are comparable. One study reports a larger subjective depth of focus than the objective, while contrary results are reported in another study.[23-25]

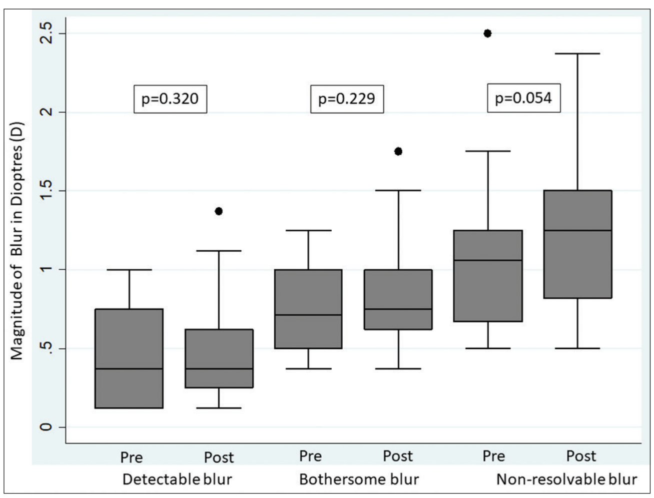

Figure 1: Box and Whisker plot of different categories of Binocular Blur Pre and Post refractive surgery

The three types of blur in question showed a significant difference amongst each other without any evident overlap indicating that they are perceptually differentiable from each other. This difference is in agreement with Ciuffreda *et al.*, who have used different types of targets to elicit similar responses from the participants.[14] Measures were taken to control factors that could affect the blur threshold namely, target size, room illumination, and pupil size. Standard clinical room illumination, standardized artificial pupils, and constant target size were maintained in the methodology to prevent any confounding bias.

Our symptoms questionnaire results revealed very low scores suggesting no major visual symptoms post-operatively and hence no significant correlation with the blur threshold values, which were noted across all the three blur criteria.

Understanding the blur threshold is crucial from a clinical point of view as even small amounts of blur could be detrimental to day-to-day activities such as night-time driving, across both young and old populations.[26] Using a Badal optical system, Sarkar *et al.*, have reported a significant increase in blur thresholds for all three categories of blur one month following refractive surgery.[27] Our results show higher blur threshold measurements both pre- and post-operatively and a marginal increase in the blur thresholds at one-month post-surgery, especially in non-resolvable blur, although the increase was not statistically significant. This variability could possibly be due to the difference in the experimental methodology and their use of cycloplegia for assessment. Besides, their study took only a single eye into consideration whereas we recorded binocular measurements and were able to correlate them with the symptom scores from the questionnaire. Most studies in the literature have measured blur thresholds with accommodation arrested using cycloplegia. A study which measured blur thresholds in young emmetropes without cycloplegia but by stabilizing accommodation using a target at a fixed distance emphasizes that the subjective depth of focus is a measurement of blur sensitivity of the perceptual/cognitive system.[23] In our study, however, we chose not to administer cycloplegia so that the responses are closer to naturalistic viewing conditions, as this would provide clinically relevant information to deal with post-refractive surgery-related visual complaints. None of our study participants had any binocular vision or accommodation related issues as revealed by

Table 1: Monocular and binocular measurements of different categories of Blur threshold pre and postoperative in Dioptres (D)

Blur thresholds	Pre-operative (D) Mean ± SD			Post-operative (D) Mean ± SD			Post-Pre (P)
	OD	OS	OU	OD	OS	OU	OU
Detectable blur	0.41 ± 0.25	0.38 ± 0.24	0.39 ± 0.26	0.33 ± 0.20	0.35 ± 0.24	0.46 ± 0.28	0.05 ± 0.05 (P = 0.320)
Bothersome blur	0.72 ± 0.31	0.64 ± 0.27	0.74 ± .28	0.66 ± 0.29	0.7 ± 0.35	0.83 ± 0.35	0.09 ± 0.07 (P = 0.229)
Non resolvable blur	1.09 ± 0.37	0.94 ± 0.40	1.04 ± 0.42	1.04 ± 0.36	1.12 ± 0.48	1.21 ± 0.44	0.17 ± 0.08 (P = 0.054)

standard screening tests. Moreover, the monocular and binocular blur threshold values were not statistically significantly different. In the presence of an accommodative dysfunction, the monocular blur threshold values are expected to be low and vice versa for a vergence dysfunction.[28]

The lack of difference in blur thresholds before and after surgery could also be attributed to the month-long gap after the refractive surgery. That time period could have served as an adaptation time for the participant to get accustomed to the quality of vision. A study by Pesudovs investigated blur adaptation in patients who had undergone refractive surgery by measuring uncorrected visual acuity before and after subjective refraction and he concluded that the tendency to adapt to blur varies with time after the surgery.[9] His results claimed that patients need at least ten-weeks to adapt to the blur. Adaptation to blur has been reported to improve visual acuity and could also influence the blur threshold levels, as they did in the study conducted by Pesudovs and Brennan.[29] Their study measured improvement in visual acuity alone where they claimed to see an improvement of 0.04 logMAR units.[29]

Myopic patients, especially early-onset myopes have been shown to have a greater blur detection threshold or decreased blur sensitivity compared to late-onset myopes and emmetropes.[12,15,17,30] The present results showed no correlation between the preoperative magnitude of refractive error and preoperative blur threshold levels. In general, adaptation to blur enhances the visual resolution, and the blur sensitivity is expected to increase, thus decreasing the blur threshold measurements but our results show no such relationship.

The study has some limitations such as the inability to objectively measure the image quality and to take measurements using cycloplegia. Frequent follow up after the surgery can reveal the changes in the blur threshold values and the time course of adaptation adequately.

There is scope to understand the blur adaptability of post-refractive surgery patients and assessment of blur threshold in other refractive errors such as hypermetropia and also in other procedures like Small Incision Lenticule Extraction (SMILE).

Conclusion

In our study, laser refractive surgeries do not have any significant effect on blur thresholds one month after the surgery. Longer follow-ups would be required to assess changes in the blur threshold following refractive surgery.

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Conflicts of interest

There are no conflicts of interest.

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