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Final Year Project Report 2017-2018

Effects of Pupil Dilation and Myopia on High Order Aberrations in Hong Kong Chinese

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Abstract

Purpose

To investigate the effects of degree of myopia and pupil dilation on HOA in Hong Kong Chinese.

Method

Thirty-eight myopic Hong Kong Chinese aged between 18 and 38 with good ocular health were recruited and divided into three myopia groups according to their non-cycloplegic spherical-equivalent (SE) refractive errors. Ocular aberrations and pupil offsets were obtained by using the NIDEK OPD-Scan III both before and after mydriasis. Analysis was done over 4mm pupil diameters.

Results

Pupil dilation had notable effects on HOA RMS and horizontal pupil shift in all of the myopia groups and in the moderate myopes respectively. The change of HOA RMS was not due to the pupil decentration. Degree of myopia significantly affected the corneal and internal horizontal coma, particularly in the highly myopic eyes.

Conclusion

This findings implied the significance of considering pupil offsets and degree of myopia in wavefront optimized refractive surgeries.

Introduction

Ocular aberrations (OA), described as deviations from the ideal wavefront exiting the eye (Unterhorst & Rubin, 2015), can be further classified into lower- (LOA) and higher-order aberrations (HOA). HOA have raised considerable interest among the ocular health care and research fields in recent years due to their non-visual aids correctable deleterious impacts on retinal image quality. This issue is especially significant in conventional refractive surgeries, which are often able to correct LOA only. HOA does not only remain uncorrected post- operatively, but also reported to be remarkably elevated (Lee et al., 2008, Padmanabhan et al., 2010). The post-operative HOA can lead to undesirable visual disturbances even in successful surgeries such as glares, haloes, reduced scotopic vision and decreased contrast sensitivity (Padmanabhan et al., 2010, Unterhorst & Rubin, 2015). A lot of researchers like Pan et al. (2012) have pointed out the high prevalence of myopia worldwide, especially in the Asian population. Thus, the demand for the refractive surgeries escalated rapidly, as well as the advancement of relevant technology.

As a result, a trend of wavefront-optimized refractive surgeries appeared lately among the ocular healthcare field to minimize the induction of post- operative HOA. Hence, research on HOA, such as their contributing factors and measurements, are

crucial to improve ophthalmic treatments, and to optimize the visual outcome after such interventions.

Although a great deal of previous studies has shown that HOA is affected by various factors such as pupil diameter, accommodation, myopia and astigmatism, none of the researches compared the degree of myopia and pupil decentration before and after dilation at the same time. The two factors have considerable significance in refractive surgeries due to two reasons- patients undergoing refractive surgeries are mainly myopic, and the obvious difference of HOA measurements before and after dilation due to pupil decentration mentioned by scholars like Yang (2002).

Zernike polynomials function series

The Zernike polynomials function is a standard method to represent optical aberrations (Carvalho et al. 2005). Each function can be expressed as (Z_j) by single indexing or as (Z_n^m) by double indexing method, with m and n representing angular frequency and the radial order respectively. The polynomials can be presented in a pyramid with n changes vertically and m changes horizontally. Zernike coefficients are measured in micrometers (μm).

The root-mean-square (RMS) value can be used to quantify OA in a single digit for simpler interpretation (Unterhorst & Rubin, 2015). As explained by Oberholzer et al.

(2016), it is calculated by the square-root of the squared individual Zernike coefficients with n and m equal to or greater than two. It is always positive and a zero RMS value indicates an optical system that is free of OA.

Higher- order aberrations

HOA involve OA that are in the third order and above. Among all the HOA, spherical aberration (SA) and coma are examples of some more important HOA. SA results from the defocus of peripheral light rays on the retina due to variable extent of refraction which results in symmetrical retinal image blur.

Coma, unlike SA, is a kind of asymmetric OA and can induce comet-like image blur. It is brought about by the imperfect alignment of ocular components or a decentered pupil.

Paquin et al. (2002) described it as the main source of retinal image degradation.

HOA and refractive surgery

It is well accepted that HOA can have deleterious effects on retinal image quality which cannot be corrected simply by conventional visual aids such as spectacles and contact lens.

Various researches have confirmed that refractive surgeries such as photorefractive keratectomy (PRK) and laser in situ keratomileisis (LASIK) dramatically induce HOA,

particularly SA and coma, leading to disturbing visual complaints including starbursts, double vision, halos and glare at night (Fang et al., 2010, Padmanabhan et al., 2010, Resan et al., 2012). A study done by Fang et al. (2010) proved that a prominent visual benefit could be achieved with the increase of corrected HOA in the myopia population. Hence, a more advanced technology- wavefront optimized laser intervention was introduced with the intention to minimize post-operative HOA. The intervention works by taking pre- operative OA into consider when creating an ablation profile to neutralize unwanted aberrations, and thus enhancing post-surgical visual performance (Resan et al., 2012). However, since the technology was introduced in recent decades, there are no standard guidelines on the surgical procedures, such as the ways of OA measurement for better profile modification and to optimize the surgical outcomes. As a result, researches on the contributing factors of HOA are fundamental for the development of such technologies.

Factors affecting higher order aberrations

Myopia

The relationship between HOA and myopia has been a controversial topic among the ocular research field. A great deal of papers have been conducted regarding this issue.

Collins et al. (1994) compared the OA in the eyes of emmetropes and myopes by photographing the aberroscope grids on the subjects' retina. He concluded that the HOA between the two groups were significantly different, specifically in the fourth- order. Some grids on the retinas of the myopic subjects were even too distorted to be analyzed, implying unexpected high level of HOA in the eyes.

Various scholars have also conducted researches on the association between degree of myopia and HOA. Paquin et al. (2002) observed a quasi-linear escalation of HOA with the degree of myopia, including SA and coma. This implied that the optical quality was relatively compromised in highly myopic eyes. He further pointed out that the amplified level of HOA in high myopes might be due to the special morphology of the eyeballs in this group (e.g. lengthened eyeballs), affecting the alignment of the ocular components. Similar results were found in a large scale population study conducted by Hartwig & Atchison (2012), most third- and fourth- order aberrations were significantly dependent on spherical equivalent (SE), especially the SA.

Contradictorily, Cheng et al. (2003) failed to show any correlation between HOA and

myopia. They claimed that the difference of HOA between myopes and emmetropes was not significantly different. This shows that the influence of myopia on HOA is still a controversial topic that needs further researches.

Pupil dilation

Shifting of pupil center after mydriasis

Shifting of pupil center after mydriasis has been noticed by researchers such as Yang et al. (2002). They found that there was increasing pupil decentration with increasing dilation. When the pupil was pharmacologically dilated, its center would move superotemporally. The significant difference of pupil shift before and after dilation has highlighted its importance in HOA measurements, as the results can be altered.

HOA in natural and pharmacological pupil dilations

In contrast, Yang & Wu (2007) found no difference in the Zernike coefficients between natural and pharmacological pupil dilations. Yet, they stated that the natural pupil diameter must be at least 5mm for no difference of HOA to occur, which is hard to achieve to some people in real life. Besides, they also noticed remarkable pupil shifting caused by pharmacological dilation. Therefore, the authors recommended to measure HOA under natural condition rather than post- mydriasis for customized

LASIK surgery.

The importance of pupil shift in refractive surgery

In order to investigate the HOA induced by wavefront-guided surgery due to shifts between the locations of natural and dilated pupil center, Porter et al (2006) first measured the amount of pupil shift on both natural and dilated pupils. They then determined the HOA pre- operatively and 6 months after the intervention.

They found that the pupil usually shifted in the inferonasal direction as it was dilated.

If aberration was measured over dilated pupils before wavefront- guided LASIK, a shift in ablation in the superotemporal direction would occur and induce HOA as the surgery typically use the undilated pupil center as a reference point. The writers' work highlighted the importance to consider pupil decentration in HOA measurements.

Gap of knowledge

Among the above researches on the relationship between HOA and myopia or pupil dilation, none of them compared the three variables at the same time. Considering myopia and dilation over HOA simultaneously is extremely important as the myopic population is the major group that undergoes wavefront optimized surgery, in which pupil offset plays an important role. If the factors are not appropriately considered, the induced HOA can cause unsatisfied surgical outcomes. Hence, in this study, the influence of myopia and pupil dilation on HOA are investigated.

Objectives

In our study, we aim to investigate the effects of degree of myopia and pupil dilation on HOA in Hong Kong Chinese.

Hypothesis

We hypothesize the HOA would be different with different degrees of myopia and before and after pupil dilation, presumably due to shifting of pupil decentration. The null hypothesis is that pupil dilation and myopia have no significant effects on high order aberrations.

Methods

Thirty-eight Hong Kong Chinese aged between 18 and 38 with good ocular health were recruited on voluntary basis. The subjects were divided into three groups according to their spherical-equivalent (SE) refractive errors: low myopia group (LM, $n=16$), with SE greater than or equal to -0.25 D and less than -3.0 D; moderate myopia group (MM, $n=11$), SE greater than or equal to -3.0 D and less than -6.0 D; high myopia group (HM group, $n=11$), with SE greater than or equal to -6.0 D. All subjects have astigmatism less than or equal to 0.75 DC due to its influence on corneal shape (Leung et al., 2015). Spectacle prescriptions were obtained by autorefraction using NIDEK OPD-Scan III under non-cycloplegic condition. Axial lengths were measured by using the IOL Master. The exclusion criteria were

- (1) dry eye patients;
- (2) history of ocular surgeries;
- (3) any type of ocular media opacities;
- (4) best corrected visual acuity worse than logMAR 1.0 in any eye;
- (5) rigid lens wearers.

The subjects were asked to stop soft contact lens wear for at least three weeks to avoid contact lens-induced corneal warpage to interfere refraction and other data (Wang et al., 2002). All experimental procedures were approved by the ethics

committee of The Hong Kong Polytechnic University.

Higher Order Aberrations

The NIDEK OPD-Scan III (Version 1.16.04) was used to determine HOA of the subjects. It provided the measurement of total ocular aberrations, corneal aberrations and the deduction of internal aberrations by subtracting the corneal aberrations from the total aberrations. Three optimized repeated measurements were taken and averaged both before and after pupil dilation in a dark examination room with the same settings. The subjects were asked to blink before each measurement to ensure even tear distribution on the eyes. Extreme data was excluded to avoid unreliable results. A drop of 1% tropicamide was instilled to dilate the pupil. The post-dilation aberrations were obtained after 30 minutes of drug instillation. HOA information obtained from the central 4mm of the pupil diameter was used for data analysis. As the data from some of the subjects' right eyes instead of the left eyes were chosen to be analyzed, the signs of bilateral asymmetrical Zernike terms i.e. Z_3 , Z_8 , Z_9 , Z_{10} , Z_{11} , Z_{18} , Z_{19} , Z_{20} , Z_{21} , Z_{22} , Z_{23} in the right eyes were reversed in order to compare the aberrations with the left eyes due to the enantiomorphism (Smolek, 2002).

Pupil shift

To compare the shifting of pupil center before and after mydriasis, OPD Scan III (version 1.16.04) was used to measure the decentration of the first Purkinje image from the pupil center both before and 30 minutes after instillation of 1% tropicamide. Figure 1A and 1B demonstrated exaggerated pupil decentrations for easier explanation. From Figure 1A, the small blue cross was identified as the first Purkinje image while the large white cross was the pupil center. As shown in Figure 1B, OPD Scan III represented the position and direction of pupil shift by the distance from Purkinje image to pupil center (in millimeter) @ angle of decentration (in degree). For more convenient data analysis, the position of pupil shift in mm@ degree was stratified into x and y coordinates as shown below in Figure 1B. The x coordinate represented horizontal pupil shift while the y coordinate implied vertical pupil shift. The signs of the x and y coordinates were indicated in Figure 2A (Left eye) and Figure 2B (Right eye) respectively. The signs of pupil shift in the right eyes were reversed horizontally for data analysis. After reversing the signs, for both left and right eyes, a positive x coordinate indicated a temporal shift and vice versa. Meanwhile, a positive y coordinate indicate a superior pupil shift and vice versa, no matter in the left or right eye.

Figure 1A. Location of the first Purkinje image and pupil center

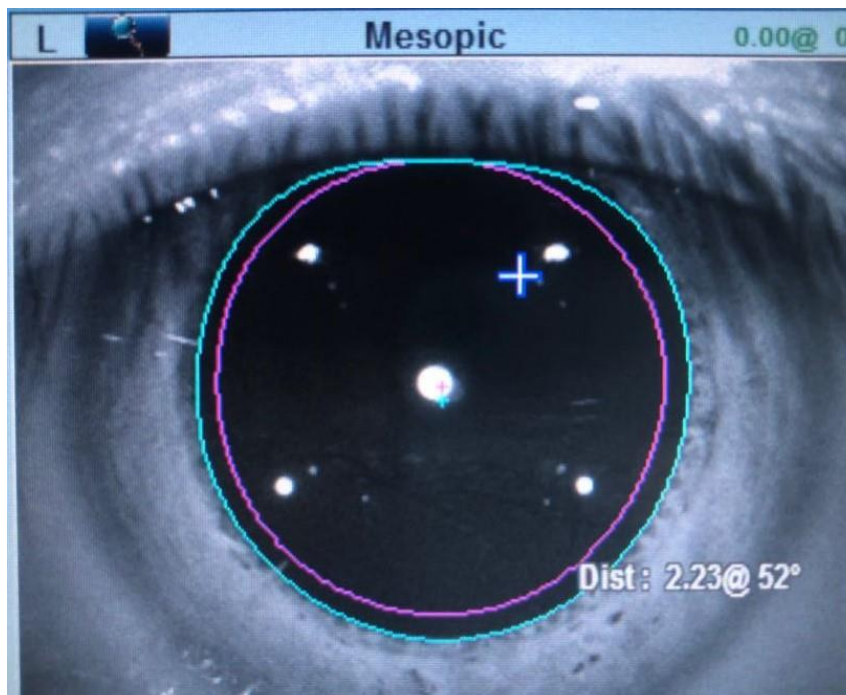


Figure 1B. Conversion of pupil shift into x and y coordinates

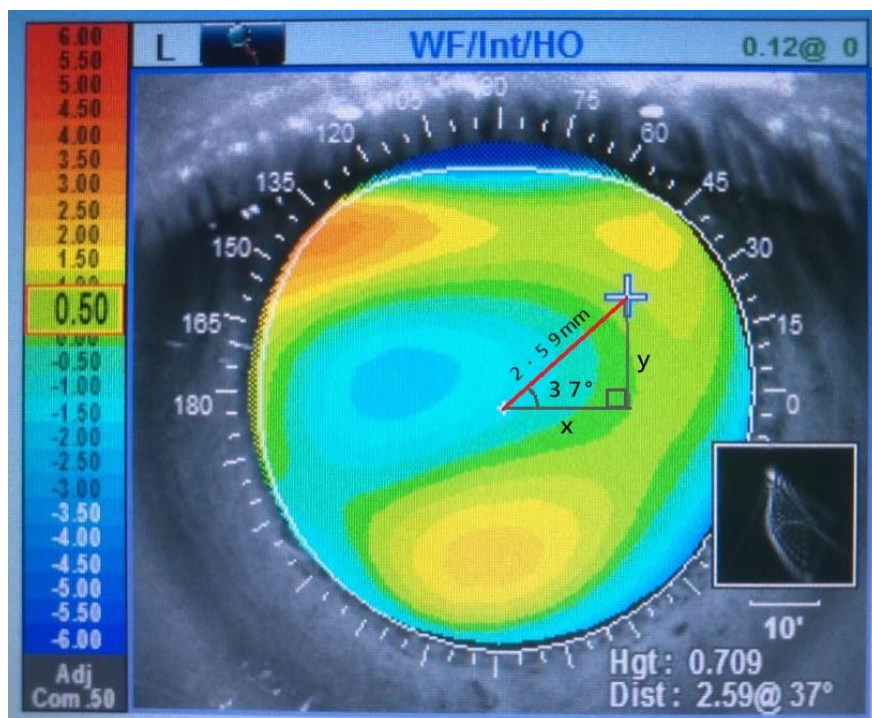


Figure 2A. Definition of signs of horizontal and vertical pupil shifts in LE

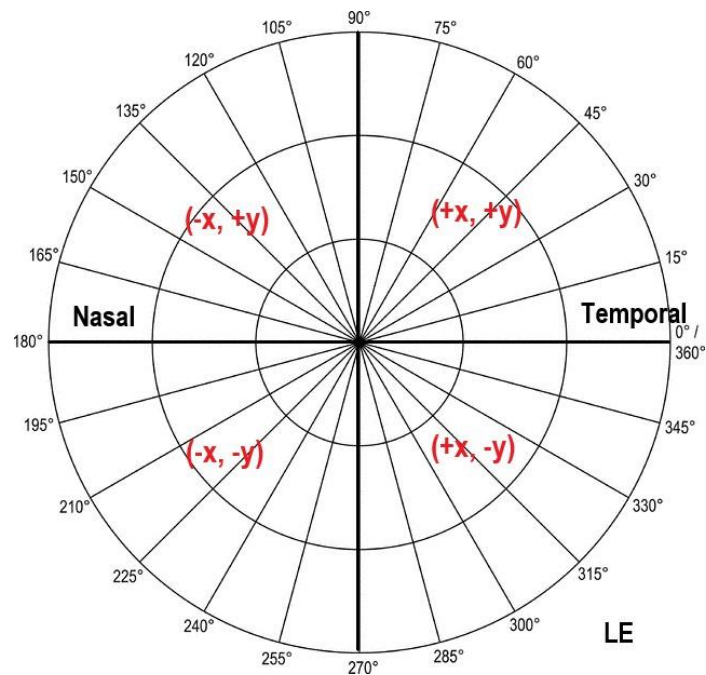
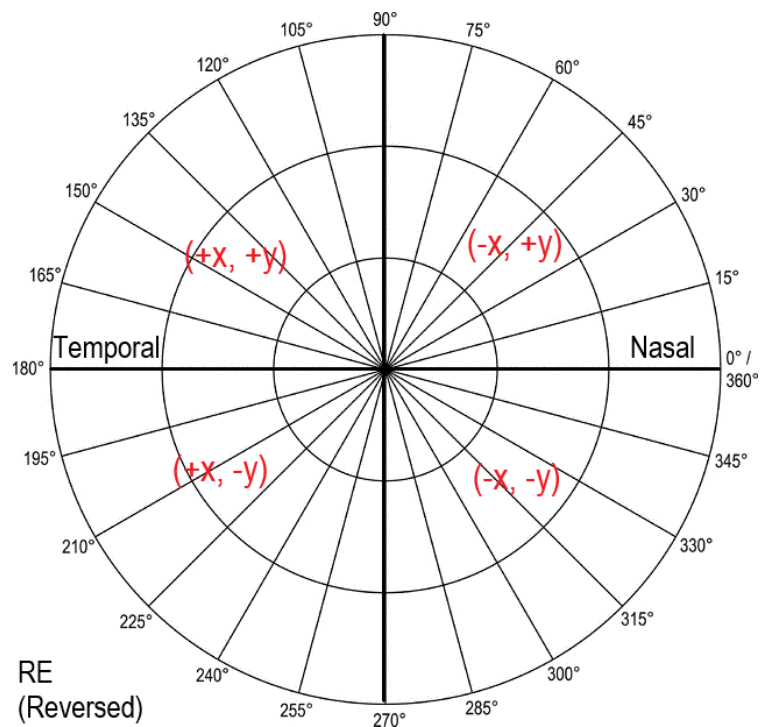


Figure 2B. Definition of signs of horizontal and vertical pupil shifts in RE (with signs reversed)



Statistical Analysis

Data from the subjects' left eyes (total, n=34; LM = 16, MM = 10, HM = 8) were used for analysis unless only the fellow eyes (total, n=4 MM = 1, HM = 3) fulfilled the SE inclusion criteria. The root mean square (RMS) value of High order aberrations (HOA) was calculated from the third- to the sixth-order Zernike terms.

Statistical analyses were done using IBM SPSS Statistics 25 with significance level set at $p < 0.05$. All data follow normal distribution. Two-way ANOVA repeated measure test was performed to determine the effects of pupil dilation (pre- and post- dilation) and degree of myopia (LM, MM, HM) on ocular aberrations. Bonferroni correction was used to reduce false-positive results (type I errors) as multiple pairwise tests were performed on the data. The results were expressed in mean $\pm$ standard error.

Pearson correlation analyses were also conducted to determine the strength of correlation between two variables.

Results

Demographic data

Table 1. Comparison of Demographic Information among the Three Myopia Groups

(mean $\pm$ standard error)

	HM	MM	LM	p
Age	21.091 $\pm$ 0.744	21.273 $\pm$ 0.304	19.875 $\pm$ 0.239	0.049
Sphere	-7.492 $\pm$ 0.435	-4.553 $\pm$ 0.241	-1.495 $\pm$ 0.199	0
Cylinder	-0.508 $\pm$ 0.082	-0.515 $\pm$ 0.073	-0.312 $\pm$ 0.071	0.094
SE	-7.746 $\pm$ 0.421	-4.811 $\pm$ 0.214	-1.651 $\pm$ 0.206	0
Axial length	26.784 $\pm$ 0.343	25.440 $\pm$ 0.245	24.101 $\pm$ 0.183	0

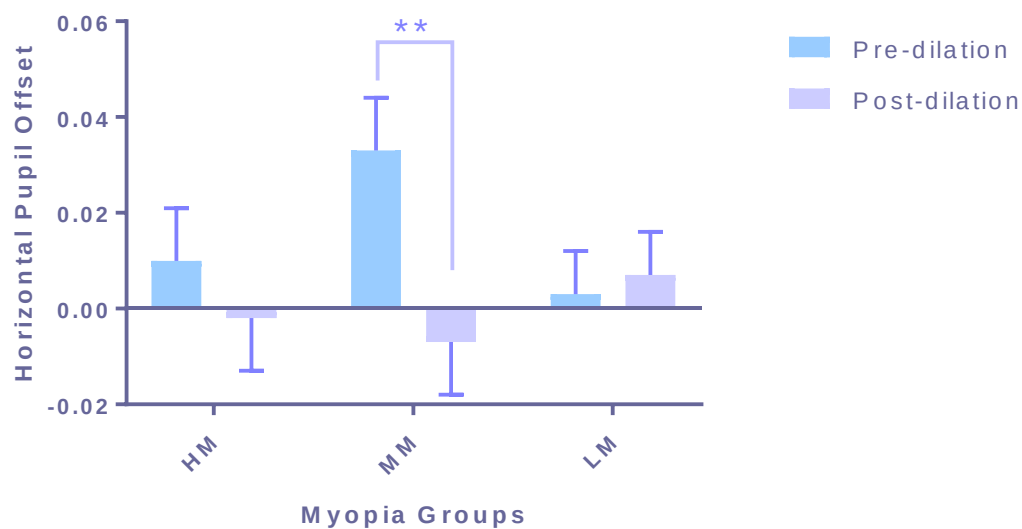
With regards to Table 1, spherical power (unpaired t-test, $p < 0.01$), SE (unpaired t-test, $p < 0.01$) and axial length (unpaired t-test, $p < 0.01$) were considerably different with variable degree of myopia as expected. The significant relationship between axial length and degree of myopia confirmed that the major group of our subjects had axial myopia.

Age only showed very weak significant difference among the three myopia groups (unpaired t-test, $p = 0.049$). The magnitude of cylinder was not significantly different between the groups under our inclusion criteria (unpaired t-test, $p = 0.094$).

Pupil Offset

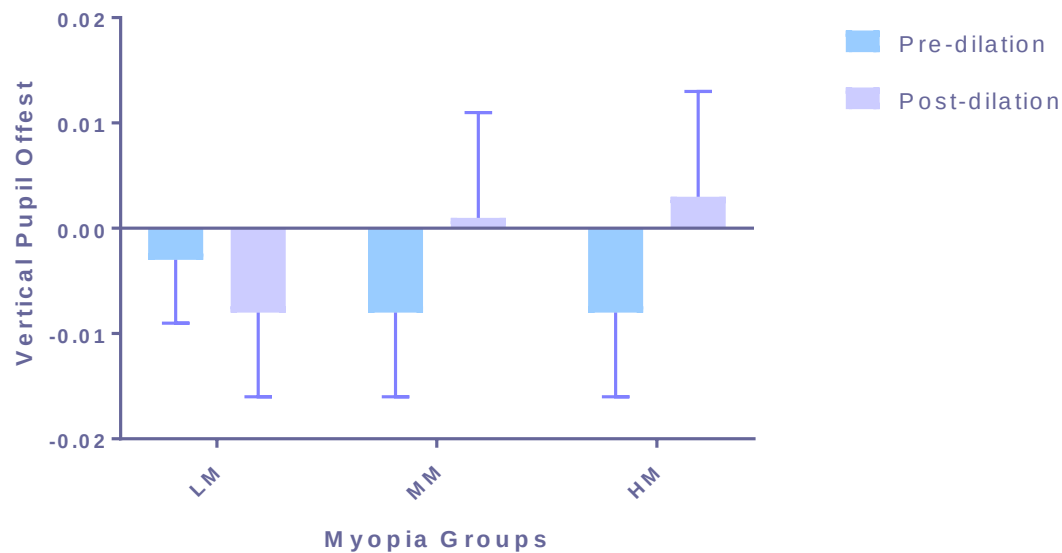
Two-way ANOVA repeated measure was carried out to evaluate the differences of pupil offset before and after dilation both horizontally and vertically among the three myopia groups. The results are shown in Figure 3 and 4.

Figure 3. Comparison of Pre- and Post-dilation Horizontal Pupil Offset among the Three Myopia Groups (mean $\pm$ standard error)



The asterisk indicates the significant level: ** $p < 0.01$.

Figure 4. Comparison of Pre- and Post-dilation Vertical Pupil Offset among the Three Myopia Groups (mean± standard error)



Refer to Figure 3, it was found that pupil dilation had remarkable effects on the horizontal pupil offset (ANOVA, $p=0.037$). Follow up investigation revealed that in the MM group, there was significant difference of the horizontal offset before and after dilation (ANOVA, $p=0.006$). Nevertheless, dilation did not have considerable effects on the HM (ANOVA, $p=0.381$) and LM (ANOVA, $p=0.782$) groups.

Furthermore, Figure 3 showed that SE has no significant effects (ANOVA, $p=0.679$) on horizontal pupil offset.

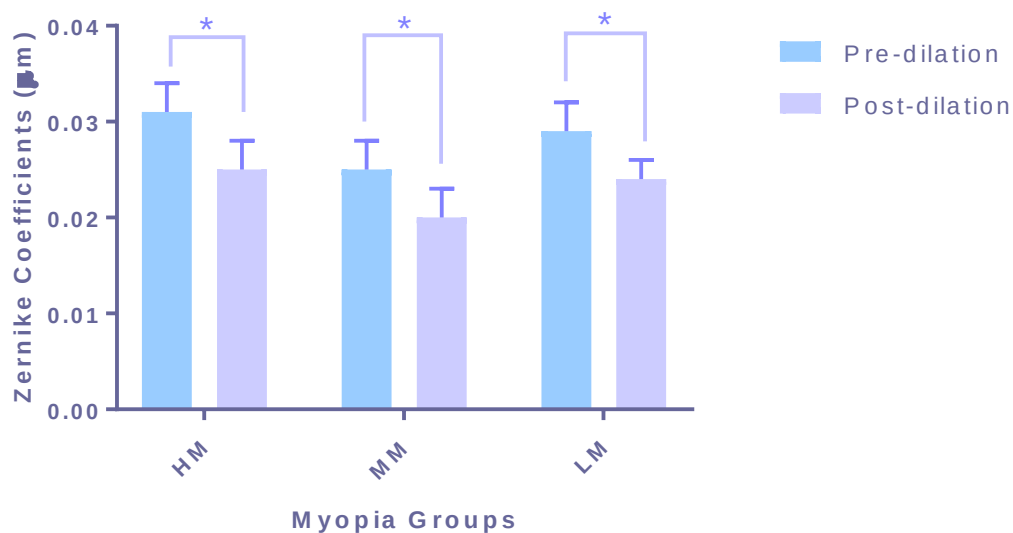
From Figure 4, neither pupil dilation (ANOVA, $p=0.396$) nor SE (ANOVA, $p=0.946$) had remarkable influence on the vertical offset.

Total High Order Aberration Root-Mean Square

Two-way ANOVA repeated measure was carried out to evaluate the differences of total high order aberration root-mean square (HOA RMS) before and after dilation among the three myopia groups. The results are shown in Figure 5.

Figure 5. Comparison of Pre- and Post-dilation HOA RMS among the Three Myopia

Groups (mean $\pm$ SE)



The asterisk indicates the significant level: * $p < 0.05$.

As shown in Figure 5, two-way ANOVA repeated measure showed that pupil dilation has significant effects on HOA RMS (ANOVA, $p < 0.001$). Further analysis figured out that there were significant effects of pupil dilation within each of the myopia groups: HM group (ANOVA, $p = 0.020$); MM Group (ANOVA, $p = 0.025$); LM Group (ANOVA, $p = 0.010$).

On the other hand, there was no significant difference in HOA RMS between the three myopia groups both before and after dilation (ANOVA, $p=0.390$).

Pearson correlation was conducted to investigate the relationships between HOA RMS change and pupil offset changes. The results are shown in Figure 6 and 7.

Figure 6. Correlation of Change of HOA RMS and Change of Horizontal Pupil Offset Before and After Dilation

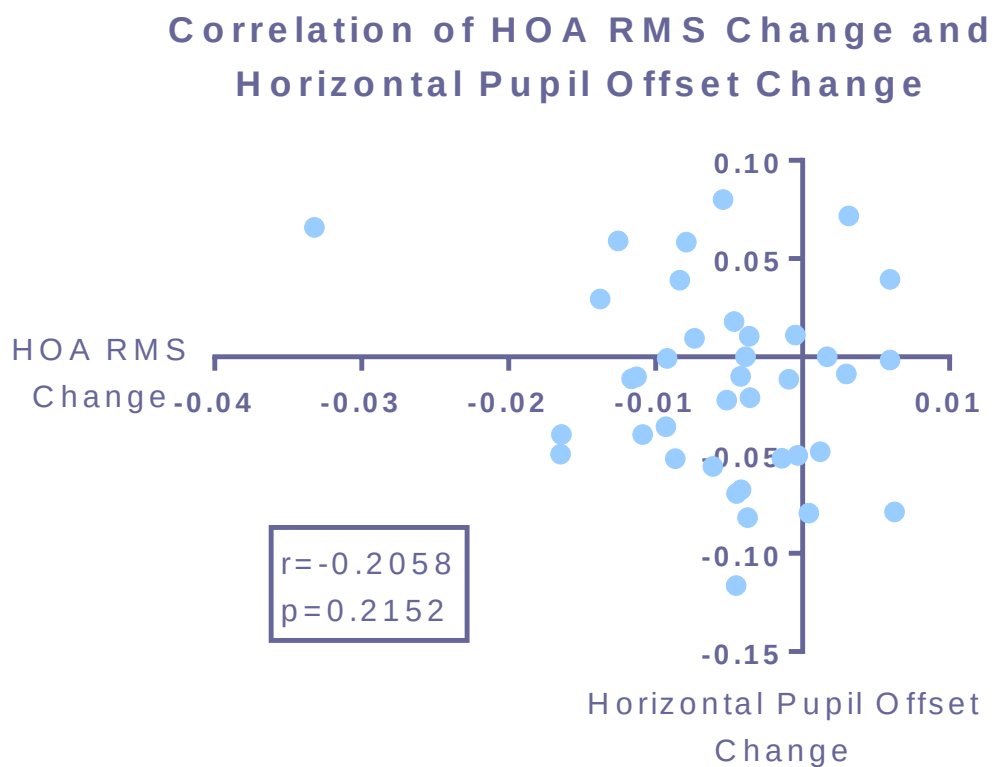
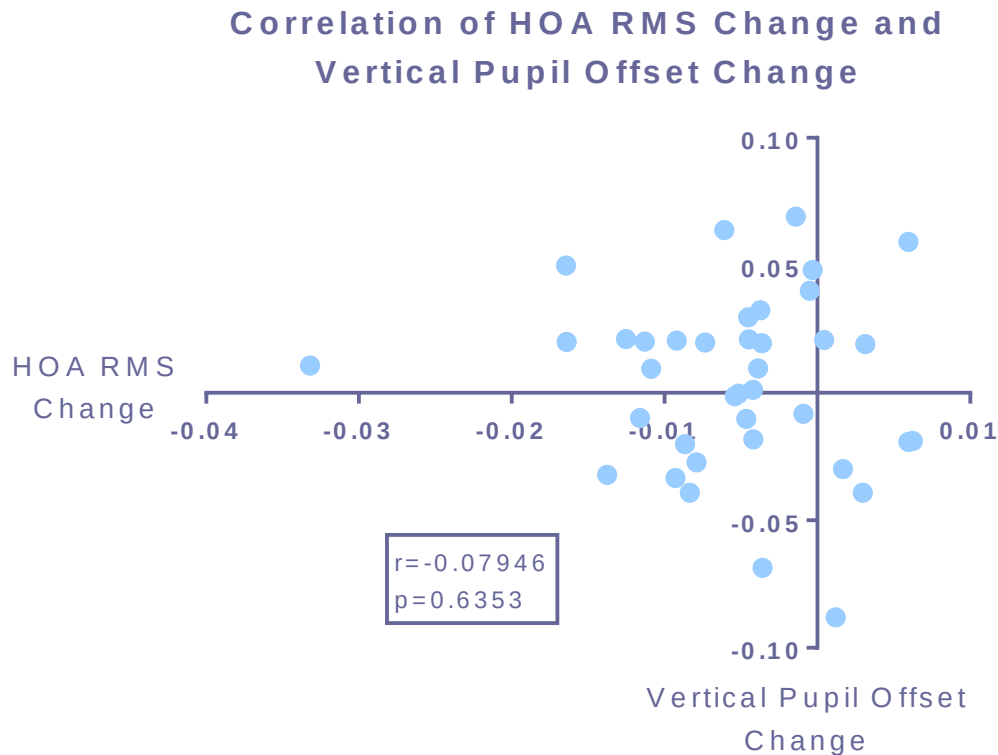


Figure 7. Correlation of Change of HOA RMS and Change of Vertical Pupil Offset

Before and After Dilation



Regarding to Figure 6, we could see that change of pre- and post- dilation HOA RMS has no correlation with the change of horizontal pupil offset (Pearson correlation, $r = -0.2058$, $p = 0.2152$).

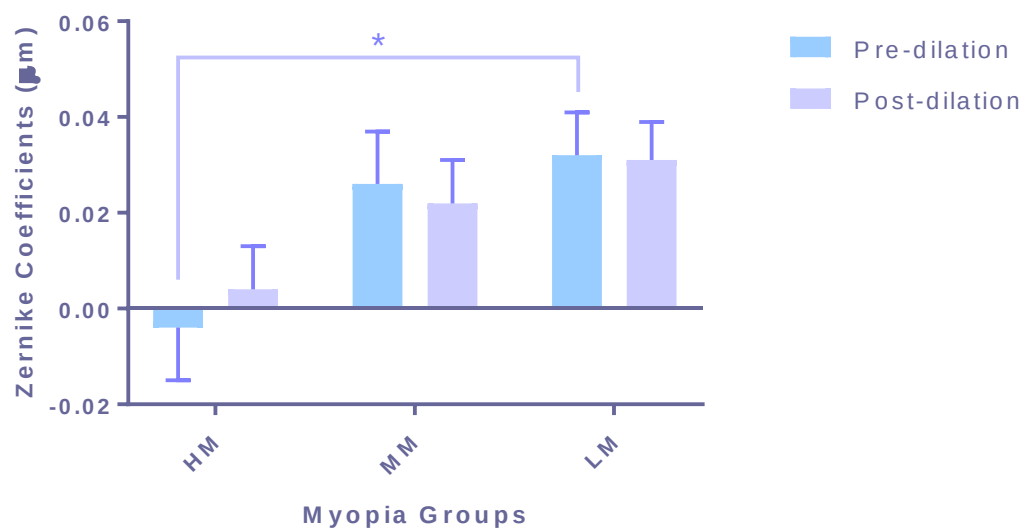
From Figure 7, the change of pre- and post- dilation HOA RMS was also not significantly correlated with the change of vertical pupil offset (Pearson correlation, $r = -0.07946$, $p = 0.6353$).

Corneal Horizontal Coma

Two-way ANOVA repeated measure was carried out to evaluate the differences of corneal horizontal coma before and after dilation among the three myopia groups.

The results are shown in Figure 8.

Figure 8. Comparison of Pre- and Post-dilation Corneal Horizontal Coma among the Three Myopia Groups (mean $\pm$ SE)



The asterisk indicates the significant level: $*p < 0.05$.

According to Figure 8, horizontal coma of the cornea was not significantly affected by pupil dilation within each myopia group (ANOVA, $p=0.854$).

However, significant difference of corneal horizontal coma was noticed among different degrees of myopia (ANOVA, $p=0.024$). Further analysis showed that corneal horizontal coma was significantly different between HM and LM groups (ANOVA,

p=0.039) before dilation, but not between HM and MM (ANOVA, p=0.151), nor MM and LM groups (ANOVA, p=1.000). After pupil dilation, no significance was found in the difference of corneal horizontal coma between HM and LM (ANOVA, p=0.074), HM and MM (ANOVA, p=0.470) and MM and LM groups (ANOVA, p=1.000). Pearson correlation was conducted to investigate the relationships between the degree of myopia and corneal horizontal coma. The results are shown in Figure 9 and 10.

Figure 9. Correlation of Pre-dilation Corneal Horizontal Coma and SE

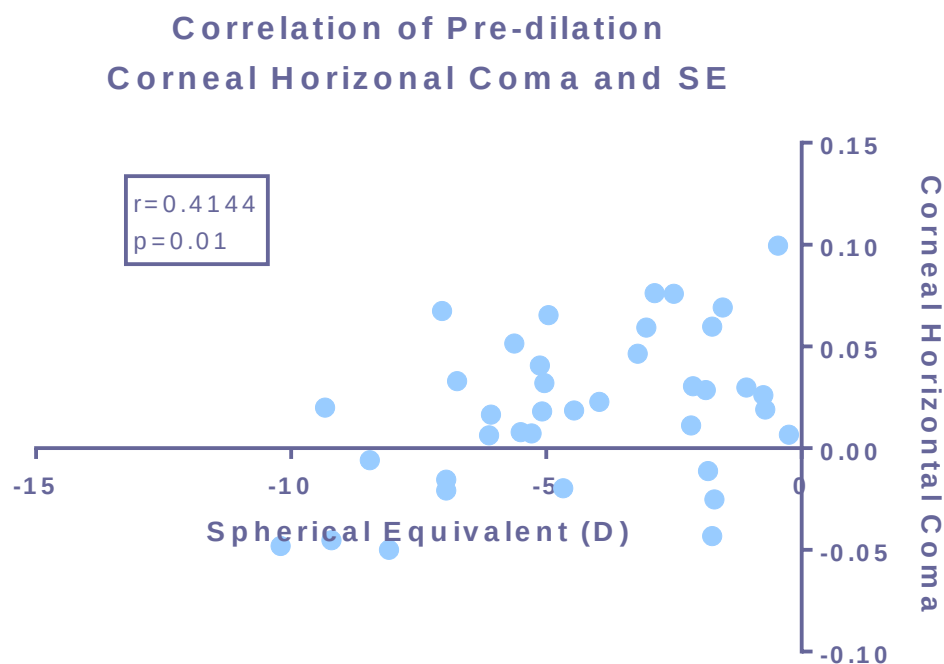
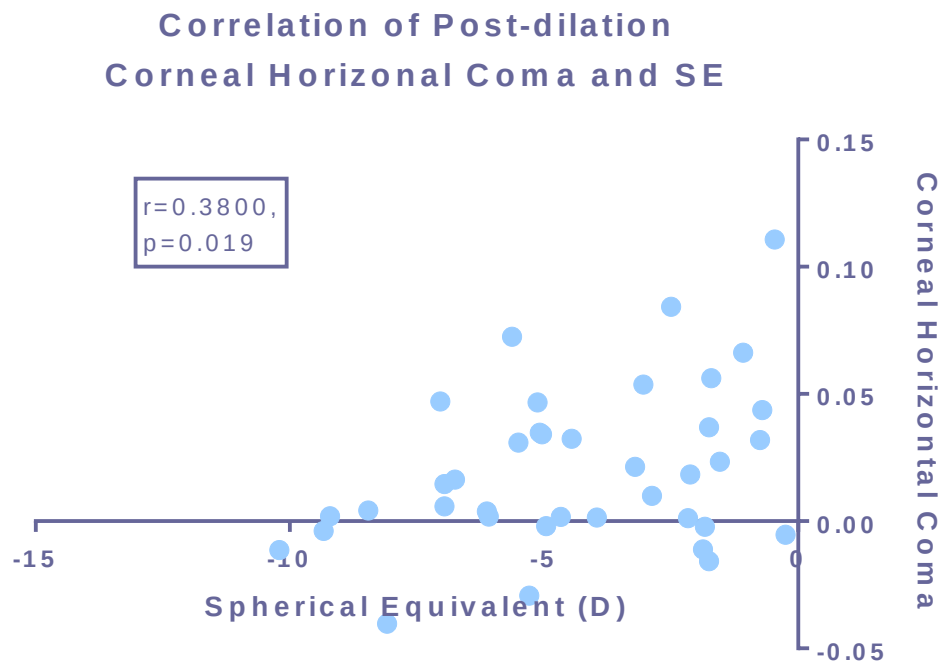


Figure 10. Correlation of Post-dilation Corneal Horizontal Coma and SE

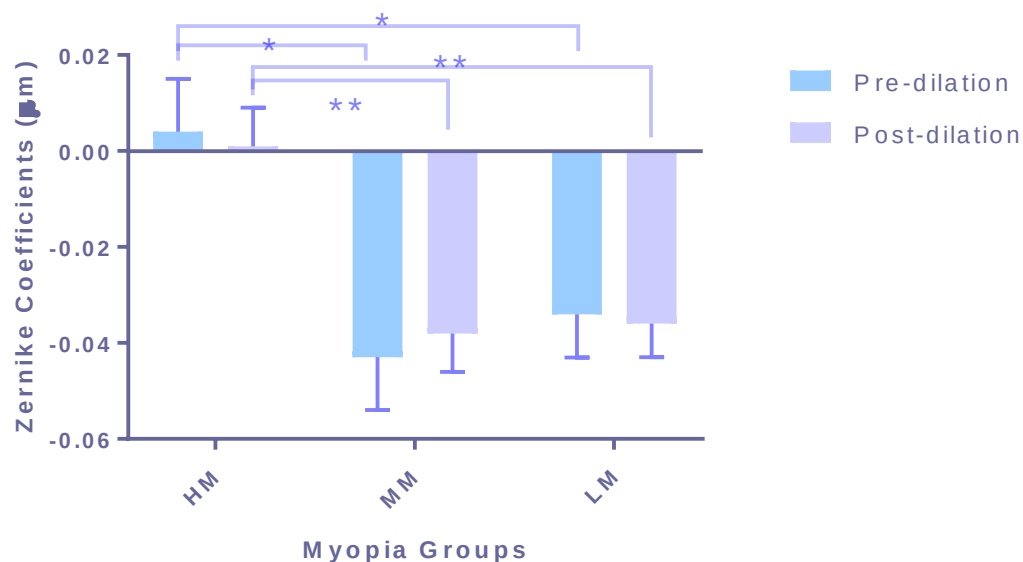


From Figure 9 and 10, we observed a positive correlation between SE and corneal horizontal coma before (Pearson correlation, $r = 0.4144$, $p=0.01$) and after pupil dilation (Pearson correlation, $r = 0.3800$, $p=0.019$) respectively.

Internal Horizontal Coma

By performing two-way ANOVA repeated measure, the differences of internal horizontal coma before and after dilation among the three myopia groups were investigated. The results are shown in Figure 11.

Figure 11. Comparison of Pre- and Post-dilation Internal Horizontal Coma among the Three Myopia Groups (mean $\pm$ SE)



The asterisk indicates the significant level: * $p < 0.05$, ** $p < 0.01$.

Regarding figure 11, no significant effects of pupil dilation on internal horizontal coma appeared was noticed in any of the three myopia groups (ANOVA, $p=0.966$).

In contrast, with different degrees of myopia, internal horizontal coma was detected to be remarkably different (ANOVA, $p=0.001$). Before the pupils were dilated, notable

differences were detected between HM and MM groups (ANOVA, $p=0.012$), and between HM and LM groups (ANOVA, $p=0.027$). Stronger significance was found after dilation between HM and MM groups (ANOVA, $p=0.005$), and between HM and LM groups (ANOVA, $p=0.005$). Yet, between MM and LM groups, no considerable difference was found both before (ANOVA, $p=1.000$) and after dilation (ANOVA, $p=1.000$).

Pearson correlation was carried out to evaluate the relationships between the degree of myopia and internal horizontal coma.. The results are shown in Figures 12 and 13.

Figure 12. Correlation of Pre-dilation Internal Horizontal Coma and SE

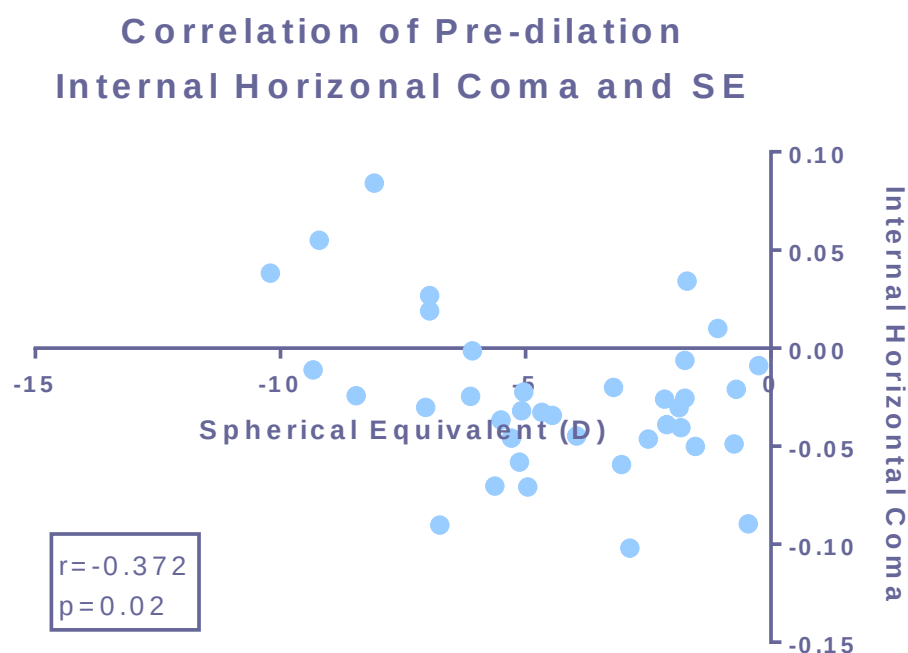
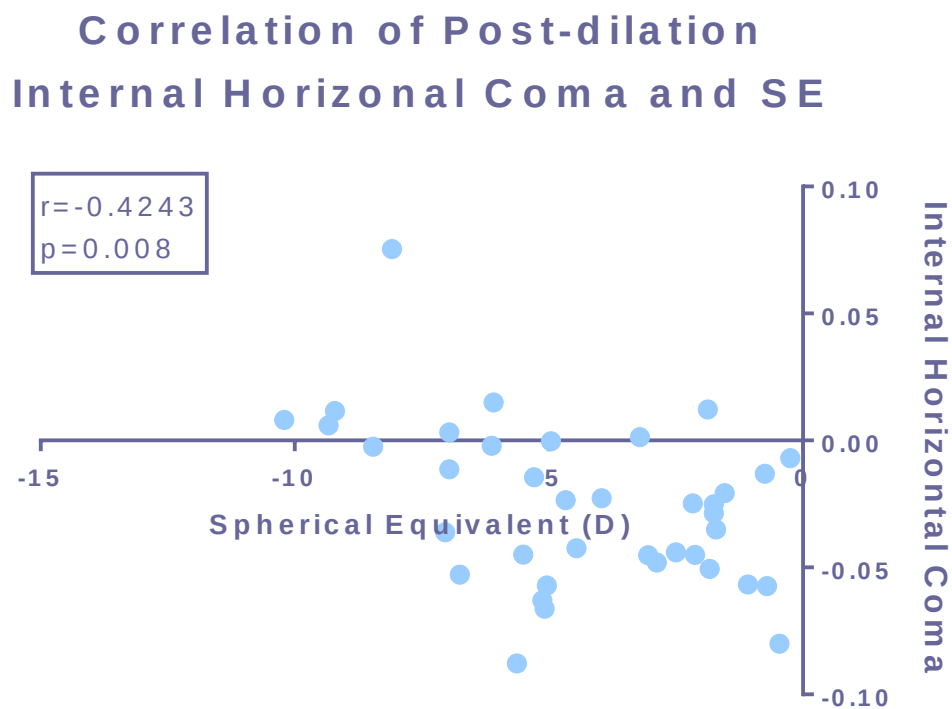


Figure 13. Correlation of Post-dilation Internal Horizontal Coma and SE



With regards to Figure 12, it was observed that SE was significantly correlated with internal horizontal coma before dilation (Pearson correlation, $r = -0.3752$, $p = 0.02$), while Figure 13 showed that the correlation also existed after dilation (Pearson correlation, $r = -0.4243$, $p = 0.008$).

Discussion

Effect of pupil dilation

Pupil offsets

In this study, we have found that there was significant horizontal shift of pupil center in the MM group after dilation, with no significant difference of pupil shift in other groups horizontally and in all groups in the vertical direction. In the MM group, the pre-dilation pupil offset was 0.033 ± 0.011 mm temporally which became 0.007 ± 0.011 mm in the nasal direction. It indicated that pupil dilation caused a mean nasal shift of 0.04mm in the MM group. The nasal direction of pupil center shift was consistent in higher degree of myopia, despite being insignificant.

The result of our study supported the conclusion of Yang et al. (2002)'s work, which also discovered significant pupil offset before and after dilation. However, unlike the nasal shift found in our study, the direction of pupil shift reported by Yang et al.

(2002) was towards the superotemporal direction. This might be due to the different SE of the subjects the two studies. A large proportion of the subjects in Yang et al.'s (2002) study was low myopes. In our studies, the pupil centers of the low myopia group also moved slightly towards the temporal side. This might imply despite the significant shift of pupil center due to dilation, the direction of shift might vary with different degree of myopia.

In wavefront optimized refractive surgeries, the shift of pupil center should be considered for certain myopic patients as the decentration may tremendously affect the ablation profile. It might be better to measure the OA before pupil dilation, which is the normal status of the eye, rather than over dilated pupils.

Total High Order Aberration Root-Mean Square

Pupil dilation caused considerable difference in the pre- and post- dilation HOA RMS in all of the three myopia groups in this study. According to the correlation analysis, neither the change of horizontal pupil offset nor the change of vertical pupil offset before and after dilation was significantly correlated with the change of HOA RMS. This indicated that the difference of pre- and post- dilation HOA RMS was not due to the shift of pupil center. As a result, although the hypothesis that pupil dilation changes the HOA of the eye was proven, the assumption that the change of HOA is due to shift of pupil center was rejected. One possible explanation for the effect of pupil dilation on HOA is due to the change of accommodation. Kim et al. (2009) noted that when the undilated or phenylephrine- treated eyes are compared with the tropicamide- or cyclopentolate- treated eyes, the SA measured was significantly different. They concluded that cycloplegic mydriatics might affect HOA. In our study, we have used 1% tropicamide to dilate the eyes, which has some cycloplegic effects.

The change of accommodation upon the instillation of the drug might have led to the notable changes of HOA after pupil dilation. Yet, further researches need to be done to evaluate the factors leading to the change of HOA RMS during pupil dilation.

The result of our study was unlike that of Yang & Wu's (2007) research, which claimed that the Zernike coefficients remained unchanged after pupil dilation. Yet, Yang & Wu (2007) emphasized that the HOA were analyzed over 5mm pupils, while we set 4mm as the analyzed size. This may be one of the reasons leading to the difference of our findings.

The change of HOA RMS after dilation implied that measurements of HOA over whether a dilated or undilated pupil should be considered for the calculation of customized ablation profile in wavefront optimized surgeries as the HOA measured may be remarkably different. Again, HOA measurements over physiologically dilated pupils rather than over pharmacologically dilated pupils was preferred in customized wavefront correction surgeries according to the results of this study as the status reveals the natural pupils in real life.

Effect of Degree of Myopia

We have found that degree of myopia, in terms of SE, contributed to significant changes in pre- and post- dilation Zernike coefficients, more specifically, corneal and internal horizontal coma.

For corneal horizontal coma, the difference between HM and LM groups before pupil dilation was found to be significant. The significance disappeared after pupil dilation.

Although the differences between other groups were not statistically significant, we could observe that with higher degree of myopia, the corneal horizontal coma tended to shift towards the negative side, thus a remarkable difference was found between HM and LM. The significant correlation found between corneal horizontal coma and SE both before and after pupil dilation further confirmed that the change of corneal horizontal coma between groups was due to degree of myopia.

For internal horizontal coma, the differences of the aberration between HM and the other groups were proven to be significant, especially after pupil dilation. We could see that the internal horizontal coma in HM tended to be positive while that in the other groups was negative. The correlation between internal horizontal coma and SE both before and after mydriasis indicated that the difference of the aberration between groups was due to SE, in other words, degree of myopia.

Our results were consistent with the research done by Paquin et al. (2002), which

also noticed changes of HOA with degree of myopia, with coma being the major contributor for the deformation of HOA. Paquin et al. (2002) suggested that the increase of coma in the highly myopia group may be due to the morphology of the eyeballs in high myopes. It is well accepted that high myopes have longer axial lengths and changes in ocular component curvatures such as steeper corneas (Llorente, 2004). These features can result in a misalignment of ocular components, hence inducing coma. The explanation also applies to the findings in our study.

Paquin et al. (2002) also found a quasi- linear increase in HOA RMS with increasing diopter of myopia, which is absent in our study. However, Paquin et al. (2002) set 5mm and 9mm as the size of pupil analyzed while we analyzed data with 4mm pupil size. According to Montes-Mico et al. (2004), HOA tend to vary more easily with a larger analyzed pupil diameter. Therefore, in our study, the non-prominent HOA RMS change among groups may be because of the smaller pupil diameter analyzed.

Since the highly myopic eyes are found to have higher coma in the eyes, their visual qualities are probably more compromised than the other groups (Paquin et al., 2002).

The indication of wavefront optimized refractive surgery may be more significant for the highly myopic population in order to eliminate the potential induced HOA after the intervention and thus to avoid more drastic visual disturbances.

Limitation

There were several limitations in our study which might vary the results.

Firstly, since we used 1% tropicamide as the mydriatic agent, which is a less effective cycloplegic than cyclopentolate (Egashira et al., 1993), the accommodation factor was not completely neglected, especially for the young subjects in our study.

Yet, 1% tropicamide was still chosen because of its reasonable recovery time compared to cyclopentolate and is a reliable agent to relieve the effect of accommodation during HOA measurements than Mydrin-P (Tropicamide 0.5%+phenylephrine HCl 0.5%).

Apart from accommodation, tear is another factor that may disturb HOA measurements (Montés-Micó et al., 2004). We excluded subjects that were previously diagnosed with dry eye diseases to lower the disturbance of HOA by tears. However, we could not exclude all potential dry eye subjects as some of them might be undiagnosed and the equipment in our research was too limited to screen for these subjects. Therefore, we tried to lower the disturbance of results by asking the subjects to blink for a few times before each HOA measurement to ensure the tear films were evenly distributed on the corneas as much as possible.

The analyzed pupil diameter was fixed to 4mm, as some of our patients could not achieve larger pupil size before mydriasis. Larger analyzed pupil size could allow us

to obtain more HOA information.

Besides, the procedures during data collection, OPD Scan III measurements, for example, were not all carried out by the same person. The ways of measurement might not be totally consistent due to inter- examiner variations.

Due to limited data collection period, the sample size in this study was relatively small. If the period could be extended and more subjects were recruited, the reliability of the results could be enhanced.

Conclusion

To conclude, pupil dilation caused changes of HOA RMS in all of the myopia groups in our study. Significant horizontal pupil shift was also found in the MM group.

However, the change of HOA RMS was not due to the decentration of pupil. Further researches need to be done to investigate the contributing factors to the change of HOA RMS during pupil dilation. Furthermore, degree of myopia significantly affected corneal and internal horizontal coma, particularly in the highly myopic eyes.

These findings have brought out the significance that wavefront optimized refractive surgeries might be more essential for the high myopia population. The measurements of HOA before such surgeries should be done over natural pupils rather than over pharmacologically dilated pupils as mydriasis may lead to changes in pupil decentration and HOA which do not reveal the patient's habitual condition and interfere the calculation of customized ablation profiles.

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Acknowledgements

I would like to express my gratitude to my supervisors- Dr. Chea-su Kee and Dr. Tsz-wing Leung for providing me with brilliant opinions and guidance throughout the project. I would also like to thank Prof. Pauline Cho, all the staffs in the Optometric Research Clinic and the Hong Kong Polytechnic University for their generous assistance. Last but not least, I would like to thank my groupmates- Miss Tsz-huen Shing and Mr. Tsz-him Ng for their great effort in the study.