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Correlations between Corneal and Internal Wavefront Aberrations through Zernike Coefficients Analysis

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Abstract

Objectives: To examine corneal aberrations are offset by internal aberrations more closely, the Zernike coefficients of corneal aberrations and internal aberrations were compared and analyzed. **Methods/Statistical Analysis**: Measurements of higher-order aberrations were performed with KR-9000 PW (Topcon Corp., Japan), a Hartmann-Shack Wavefront aberrometer. The coefficients from the 2nd to 4th expressions on Zernike Polynomials were analyzed for cornea and internal optics within 6mm measurement zone. 342 healthy eyes of 171 young adults who have never received eye surgery and do not wear contact lenses were selected as subjects of this study. **Findings**: There were significant negative correlations among all Zernike coefficients of corneal and internal aberrations. In Z31(r=-0.887, p=0.00), Z4-4(r=-0.698, p=0.00), and Z44(r=-0.688, p=0.00), there were high correlations between corneal and internal aberrations. On the other hand, the correlation coefficients of Z20 and Z22 that belonged to lower-order aberration were very weak at -0.129 and -0.136 respectively, having almost no correlation. **Improvements/Applications**: Since some signs of their Zernike coefficients are different, it is considered necessary to analyze not the both eyes but a single eye to identify the accurate RMS values of each Zernike coefficients and not only the correlations.

Keywords: Corneal Aberration, Higher-Order Aberration, Internal Aberration, Zernike Coefficients, Zernike Polynomials

1. Introduction

Traditional orthokeratologic surgery could improve visual acuity by correcting ametropia such as myopia, astigmatism, and farsightedness. However, they caused problems and side effects such as glare, halo, starburst, decline in night vision, low contrast sensitivity[1-4], which are considered to be caused by increased higher-order aberrations after the surgery[5-8]. Thanks to the development of aberrometer that can measure higher-order aberrations, wave front surgery was implemented instead. Wave front surgery was expected to eliminate higher-order aberrations but most studies showed that it halted the increase of higher-order aberrations only by little unlike the expectations[9-12].

Ocular aberrations are classified into the anterior corneal aberration and internal aberration, and internal aberration is defined as a concept including posterior cornea, eye lens, and vitreous body. The anterior corneal aberration is usually called corneal aberration, and aberrations that occur from other parts except anterior cornea is briefly defined as internal aberration[13,14].

While the previous study result showed that there were very high correlations between corneal aberrations and internal aberrations[15], it could not express the direction of all aberration that had positive values because the study compared the RMS value of each individual aberration. As a result, this study aimed to directly compare the Zernike coefficients of corneal and internal aberration and identify their relationship.

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2. Method

The study examined 342 eyes of 171 university students aging from 19 to 28 year old who do not have the history of eye disease and eye surgeries. The subjects did not wear hard contact lens from 6 weeks before the measurement and stopped wearing soft contact lens from 2 weeks before.

To measure high-order aberrations, KR-9000PW (Topcon Corp., Japan) was used as it is a wave front aberrometer using Hartmann-Shack method. Next, to reduce errors according to the measurer and device, one skilled tester measured the subjects 5 times for each using the same device and analyzed 3 values with decent measurements.

The coefficients from the 2^{nd} to 4^{th} expressions on Zernike Polynomials were analyzed for cornea and internal optic within 6mm measurement zone. Statistical treatment was done using PASW (SPSS) 18.0, and the results were considered as significant when $p<0.05$.

3. Results

The RMS of total higher-order aberration was 0.501 ㎛ for cornea, 0.396 ㎛ for internal optics, and 0.383 ㎛ for the entire eyes, and thus the corneal aberration was higher than the ocular aberration. The individual higher-order aberration in the cornea was 0.220 ㎛ for trefoil and 0.291 ㎛ for coma aberration, and it was measured to be tetrafoil 0.117 ㎛, 2^{nd} astigmatism 0.096 ㎛, and spherical aberration 0.221 ㎛. However, for the higher-order aberration of entire eye, trefoil was 0.189 ㎛, coma 0.211 ㎛, tetrafoil 0.082 ㎛, 2^{nd} astigmatism 0.081 ㎛, and spherical aberration 0.104 ㎛. As in the previous study result[16], not only the total higher-order aberration but also all individual aberrations of cornea had higher aberrations than the aberration of entire eye shown in Table 1.

To identify whether the internal aberration occurs in an opposite direction that offsets corneal aberration, aberrations for each Zernike coefficients were compared and analyzed. The corneal and internal aberrations for all Zernike coefficients from the 2^{nd} to 4^{th} expressions of Zernike Polynomials were shown on Table 2.

In all analyzed Zernike coefficients, there were significant negative correlations between the corneal aberrations and internal aberrations. Also, the correlation of corneal aberration and internal aberration was relatively higher in the Zernike coefficients of 3^{rd} or 4^{th} expression—which was the higher-order aberration—than the Zernike coefficients of 2^{nd} expression—the lower-order aberration.

In Z31, a vertical coma aberration, the correlation ($r=-0.887$, $p=0.00$) between the corneal and internal aberration was the highest. In addition, the correlation between the corneal and internal aberration was high in Z4-4($r=-0.698$, $p=0.00$) and Z44($r=-0.688$, $p=0.00$) which were Tetrafoil aberrations. However, the correlations of Z20 (defocus) and Z22 (astigmatism) that belonged to the lower-order aberration were very weak with the correla-

Table 1. Mean RMS(μm) of corneal, internal, and ocular higher-order aberrations for a 6mm pupil zone; Total HOA (Z3-3, Z33, Z3-1, Z31, Z4-4, Z44, Z4-2, Z42, Z40), Trefoil (Z3-3, Z33), Coma (Z3-1, Z31), Tetrafoil (Z4-4, Z44), 2nd Astigmatism (Z4-2, Z42), Spherical (Z40).

Mean (±SD) RMS ( )			
Aberration	**Ocular HOA**	**Corneal HOA**	**Internal HOA**
Total HOA	0.383 (±0.157)	0.501 (±0.298)	0.396 (±0.276)
Trefoil	0.189 (±0.101)	0.220 (±0.201)	0.147 (±0.179)
Coma	0.211 (±0.136)	0.291 (±0.187)	0.250 (±0.156}
Tetrafoil	0.082 (±0.048)	0.117 (±0.117)	0.098 (±0.134)
2nd Astigmatism	0.081 (±0.056)	0.096 (±0.090)	0.075 (±0.095)
Spherical	0.104 (±0.077)	0.221 (±0.103)	0.117 (±0.089)

Table 2. Correlations between corneal and internal Zernike coefficients for a 6mm pupil zone.

Zernike Term		Corneal Aberration	Internal Aberration	Correlation coefficient	p-value
Z2-2(4)	Astigmatism	-0.009	0.046	-0.456	0.000
Z20(5)	Defocus	-0.691	4.045	-0.129	0.017
Z22(6)	Astigmatism	-1.317	0.641	-0.136	0.012
Z3-3(7)	Trefoil	-0.078	0.005	-0.567	0.000
Z3-1(8)	Coma	0.019	0.080	-0.507	0.000
Z31(9)	Coma	0.008	0.021	-0.887	0.000
Z33(10)	Trefoil	0.011	-0.027	-0.567	0.000
Z4-4(11)	Tetrafoil	0.003	-0.005	-0.698	0.000
Z4-2(12)	2nd Astigmatism	0.006	-0.007	-0.484	0.000
Z40(13)	Spherical	0.201	-0.116	-0.380	0.000
Z42(14)	2nd Astigmatism	-0.046	0.028	-0.620	0.000
Z44(15)	Tetrafoil	0.045	-0.031	-0.688	0.000

tion coefficient of 0.129 and -0.136 respectively shown in Figure 1 -12.

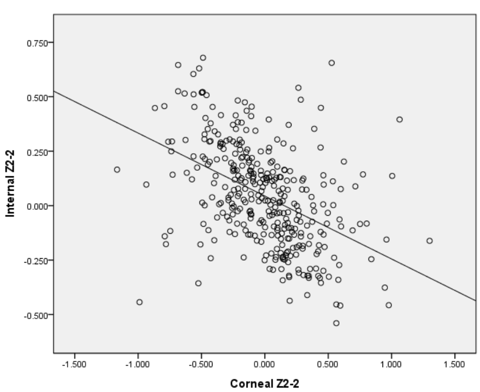

Figure 1. Correlation between corneal and internal aberrations of Z2-2.

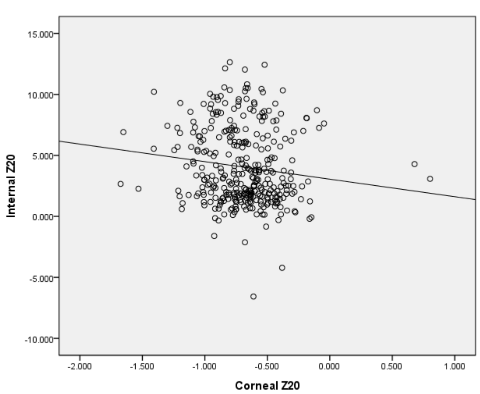

Figure 2. Correlation between corneal and internal aberrations of Z20.

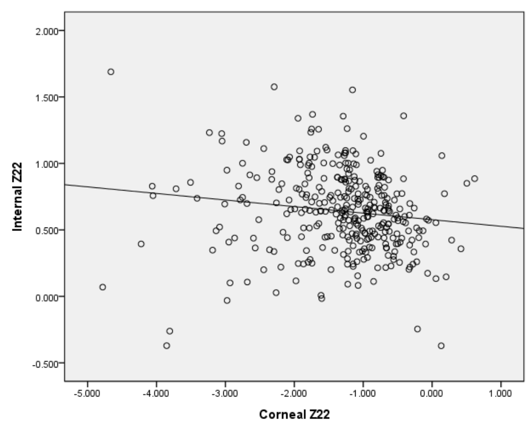

Figure 3. Correlation between corneal and internal aberrations of Z22.

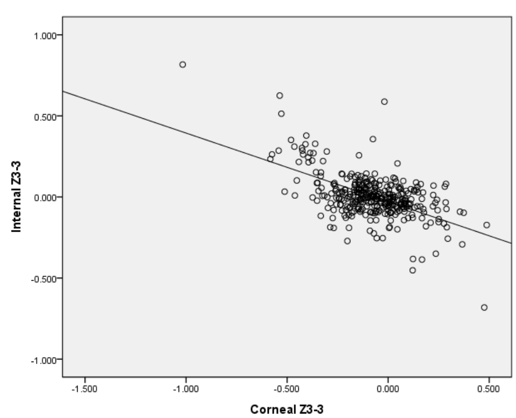

Figure 4. Correlation between corneal and internal aberrations of Z3-3.

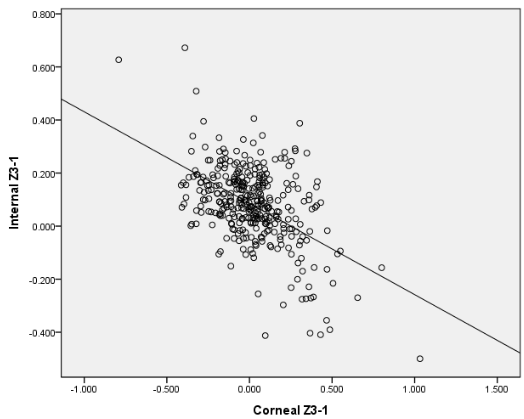

Figure 5. Correlation between corneal and internal aberrations of Z3-1.

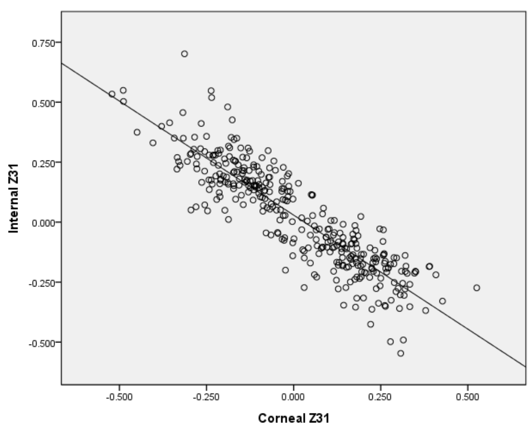

Figure 6. Correlation between corneal and internal aberrations of Z31.

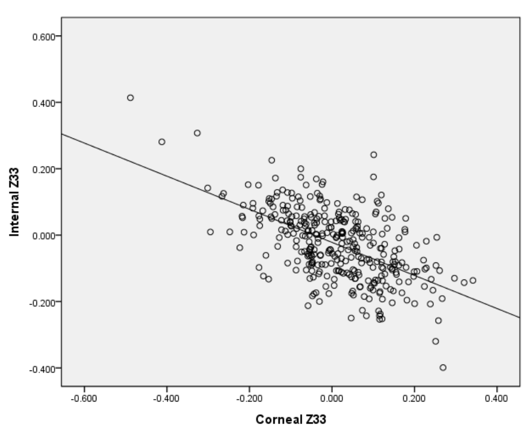

Figure 7. Correlation between corneal and internal aberrations of Z33.

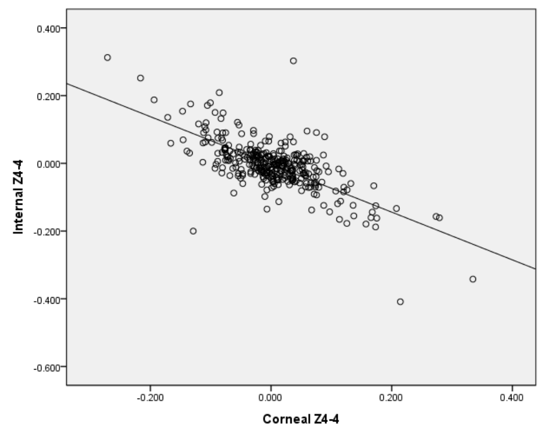

Figure 8. Correlation between corneal and internal aberrations of Z4-4.

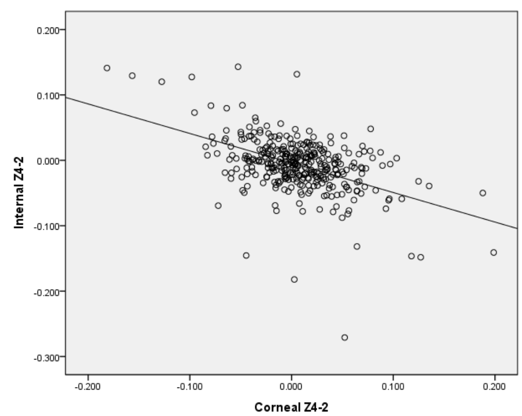

Figure 9. Correlation between corneal and internal aberrations of Z4-2.

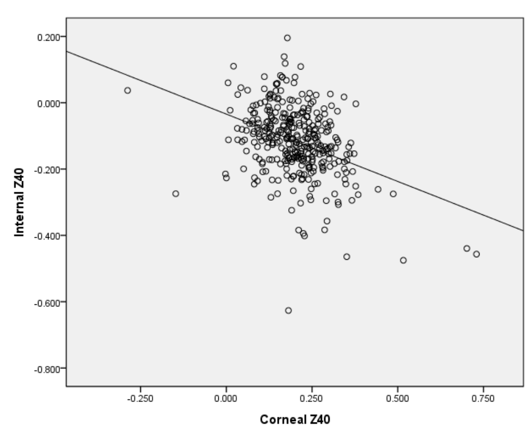

Figure 10. Correlation between corneal and internal aberrations of Z40.

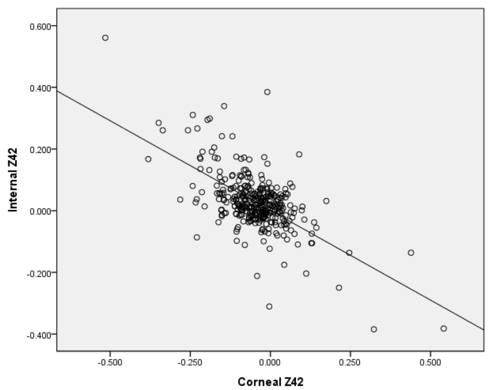

Figure 11. Correlation between corneal and internal aberrations of Z42.

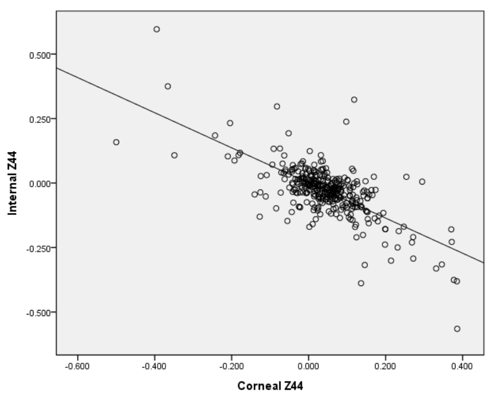

Figure 12. Correlation between corneal and internal aberrations of Z44.

4. Conclusion

There were negative significant correlations between corneal aberrations and internal aberrations for all coefficients from the 2nd to 4th expressions of Zernike Polynomials. Therefore, if corneal aberration increased, internal aberration increased in an opposite direction to offset this. The relationship between the corneal aberration and internal aberration were quite different based on the coefficient, and the correlation was higher in the higher-order aberration coefficients of 3rd and 4th expressions than the lower-order aberration coefficients of 2nd expression.

This study included both the left eye and right eye, but since some signs of their Zernike coefficients are different, it is considered necessary to analyze not the both eyes but a single eye to identify the accurate RMS value of each Zernike coefficients and not only the correlations.

5. Acknowledgment

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