Clinical and Epidemiologic Research

Visual Function and Functional Decline in Patients With Waterclefts

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Purpose. To investigate visual function in eyes with three subtypes of waterclefts (WCs).

Methods. Of patients in Kanazawa Medical University Hospital (2013–2017) and participants of Monzen Eye Study (2013–2016), 77 transparent lenses, mean age 66.7 years, and 70 eyes with only WC opacity of 70 patients, mean age 68.1 years, divided into peripheral-, central-, and total-type WC groups, were analyzed. Opacity was classified by one ophthalmologist using slit-lamp microscopy. Corrected-distance visual acuity (CDVA), contrast visual acuity (CVA), spherical equivalent (SE), astigmatism values, corneal refractive power (CP), axial length (AL), straylight, backward light scattering (BLS), and higher order aberrations (HOA) were measured and lenticular refractive power (LP) was calculated based on the values of AL, CP, and SE.

Results. Central-type WC showed significant decrease in CDVA and CVA and increase in straylight compared with control. Total-type WC showed significant decreases in CDVA, CVA, and LP, and increase in straylight, compared with control and peripheral-type WC. Total- and central-type WCs had significantly higher ocular total HOA and total-type WC had significantly higher internal total HOA than control. HOA correlated positively with CDVA ($P < 0.001$) and straylight ($P = 0.020$), and CDVA negatively with straylight in eyes with WCs ($P = 0.008$).

Conclusions. Total-type WC was associated with decreased LP, causing hyperopia, decreased CDVA and higher straylight; thus, such lenticular change should be considered for surgery indication. Significant correlations between HOA and both CDVA and straylight suggested increased HOA may decrease visual function in eyes with WCs.

Keywords: waterclefts, visual function, straylight, higher order aberration, hyperopia

Waterclefts (WCs) are formed by the separation of the cortex along the Y-shaped sutures of the superficial layers of the lens cortex, forming gaps. WCs are a type of cortical cataract in which clefts appear as white opacities in the lens cortex (i.e., at the outer edge).[1,2] In the presence of WCs, vision is affected by characteristic symptoms, such as diplopia and triplopia, in the affected eye with decreased visual function. Qu et al.[3] reported that eyes with WCs have significantly higher rates of higher-order aberrations (HOAs) than transparent eyes and that decreased corrected and contrast visual acuity (CVA) are frequently observed in the former. Apart from increased HOA,[4–7] increased backward light scattering (BLS)[4,8] was reported as factors decreasing visual acuity with lens alterations, and increased straylight[9–11] decreases visual function; however, there are no detailed studies on change in straylight or factors affecting decreased visual function in eyes with WCs to date. Furthermore, there are various types of WC morphology, including those with opacity only within the pupil center region, in its periphery, or in both, but the details on the underlying mechanism through which these morphologic differences may change visual function remain unclear.

In this study, we divided eyes with WCs into three groups based on their morphologic type, measured the visual function (corrected-distance visual acuity [CDVA], CVA, straylight) and optical properties (BLS, HOA) in each group, and compared those of each group with transparent lens eyes (control). In addition, the relationships among visual acuity, straylight, and HOA were considered.

Methods

Subjects

Study subjects were selected from patients with cataract who visited Kanazawa Medical University Hospital from October 2013 to November 2017 and from those belonging to the cross-sectional ophthalmic epidemiologic Monzen Eye Study (2013–2016) conducted since 1997 in Monzen-machi, Wajima City, Ishikawa Prefecture, Japan. Lens opacity was diagnosed by a single physician in eyes under maximum mydriasis by slit-lamp microscopy and classified into the three main types (cortical, nuclear, and posterior subcapsular cataracts) using the World Health Organization classification system[12] and two subtypes (retrodots and WCs) by Kanazawa Medical University Cataract Classification and Grading System.[13] Patients with eye diseases other than ametropia, including WC eyes comorbid with other opacities, were excluded. A total of 77 eyes of 77 patients with a transparent lens (mean age: 66.7 ± 5.0 years; control group) and 70 eyes of 70 patients with only WC opacity (mean age: 68.1 ± 6.9 years; WC group) were included for analysis. The WC group was further divided into the following three subgroups: 27 eyes with peripheral-type WC (WC-1) with

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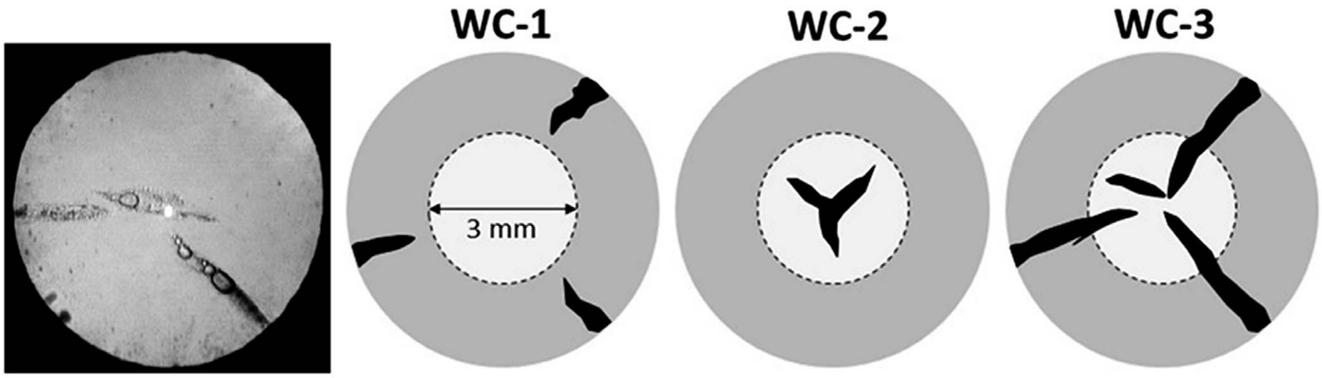

Figure 1. Classification of WC. Location of WC in relation to the central 3-mm zone of the pupil. WC-1: peripheral-type WC (outside the 3-mm zone). WC-2: central-type WC (within the 3-mm zone). WC-3: central- and peripheral-type WC (within and outside the 3-mm zone).

alterations outside the 3-mm pupillary zone, 20 eyes with central-type WC (WC-2) with alterations only within the 3-mm pupillary zone, and 23 eyes with central- and peripheral-type WC (WC-3) with opacity within and outside the 3-mm pupillary zone (Fig. 1).

All subjects received sufficient explanation about the study and provided signed informed consent under the Declaration of Helsinki and the protocol was reviewed and approved by the institutional review board at Kanazawa Medical University.

Measurements

CDVA at 5 m was measured using the Landolt ring chart. CVA was measured using a contrast sensitivity measurement device CAT-2000 (Neitz Instruments Co., Ltd., Tokyo, Japan),[14] including a Landolt ring chart of 12 sizes from 1.0 to –0.1 logMAR under four light conditions (mesopic: day, day + glare, photopic: evening, evening + glare) at 100% and 25% CVA with chart lighting of 5 and 100 cd/mm^2 in average, respectively. The glare light sources, 20 white light-emitting diode lights of 200 lux, were located in a circle of Φ49 mm and were irradiated to subjects' eyes through a diffuser panel from a distance of 80 mm. Further, spherical equivalent (SE), astigmatism values (sphere and cylinder), and corneal refractive power (CP) were measured using an auto ref/keratometer (ARK-730A; Nidek Co., Ltd., Aichi, Japan), whereas axial length (AL) was measured using an optical biometer (IOLMaster; Carl Zeiss Meditec, Inc., Tokyo, Japan). Lenticular refractive power (LP) was calculated following the method of Olsen et al.[15] using the following equation based on the values of AL, CP, and SE:

$$LP = (110 - 2.43 \times AL - 0.89 \times CP - SE) \div 0.62 \qquad (1)$$

Straylight was assessed using a straylight meter (C-Quant; Oculus Optikgeräte GmbH, Wetzlar, Germany) as log(s) of the internal light scattering value. Measurements were obtained using the natural pupil size. We set the estimated standard deviation (ESD) limit to 0.08,[16] which is reported to yield reliable results with this instrument. Eyes with refractive correction values of more than ±2 diopter (D) were measured following SE refractive correction with trial lenses. Further, BLS and HOA were measured in a dark room under maximum mydriasis using phenylephrine hydrochloride with 0.5% tropicamide, and BLS was measured by analyzing the lens images obtained on Scheimpflug slit-lamp microscopy (EAS-1000; Nidek Co., Ltd.) and calculated at the peak height of each layer of the lens (i.e., anterior subcapsule, anterior cortex, adult nucleus, fetal nucleus, and central clear zone), and the cumulative values from the anterior subcapsule to the central clear zone. HOA was measured with the pupil at 6-mm diameter using a wavefront analyzer (KR-1W; Topcon Corporation, Tokyo, Japan) under the following six conditions: ocular and internal total HOA, coma-like aberrations (S3+S5), spherical-like aberrations (S4+S6), trefoil aberrations, coma aberrations, and spherical aberrations.

Statistical Analysis

SPSS (version 21.0; IBM Corp., Armonk, NY, USA) was used for statistical analysis, the sex ratio difference of $P < 0.05$ in X^2 test and the intergroup differences of $P < 0.05$ in 1-way ANOVA and Tukey's tests were considered statistically significant. A Pearson's correlation coefficient in linear regression was performed to investigate the correlations among CDVA, straylight, and HOA in eyes with WCs.

Results

There were no significant differences in terms of age or sex among the WC-1, WC-2, WC-3, and control groups (Table 1).

Table 2 summarizes the CDVA, CVA, straylight, sphere, cylinder, and LP values of the four study groups. No significant differences were observed between the WC-1 and the control groups in terms of all parameters. However, the WC-2 group

Table 1. Subject Demographics

Parameter	Group				*P* Value
	WC-1	WC-2	WC-3	Control	
Eyes, *n*	27	20	23	77	–
Sex (male/female)*	11/16	9/11	9/14	31/46	0.980
Mean age, y ± SD†	67.6 ± 7.4	67.3 ± 8.2	69.3 ± 5.2	66.7 ± 5.0	0.349

* X^2 test.
† 1-way ANOVA test.

Table 2. Visual Acuity, Contrast Visual Acuity, Straylight, Astigmatism, and Lens Power by Group

	Group			
Parameter	**WC-1**	**WC-2**	**WC-3**	**Control**
CDVA, logMAR				
Mean ± SD	−0.08 ± 0.11	0.05 ± 0.19†‡	0.17 ± 0.19†§	−0.10 ± 0.12
Range	−0.18 to 0.22	−0.18 to 0.52	−0.20 to 0.50	−0.18 to 0.52
100% CVA, logMAR				
DAY				
Mean ± SD	0.13 ± 0.18	0.24 ± 0.25*	0.32 ± 0.23†§	0.12 ± 0.17
Range	−0.1 to 0.5	−0.1 to 1.0	0.0–0.9	−0.1 to 0.7
DAY + glare				
Mean ± SD	0.14 ± 0.16	0.16 ± 0.14	0.40 ± 0.25†§	0.13 ± 0.18
Range	−0.1 to 0.5	0.0–0.5	0.1–1.0	−0.1 to 0.9
EVE				
Mean ± SD	0.26 ± 0.20	0.36 ± 0.20*	0.50 ± 0.23†§	0.25 ± 0.15
Range	−0.1 to 0.7	0.1–0.8	0.1–0.9	0.0–0.7
EVE + glare				
Mean ± SD	0.31 ± 0.20	0.36 ± 0.16*	0.58 ± 0.22†§	0.27 ± 0.19
Range	0.0–0.7	0.0–0.6	0.2–1.0	−0.1 to 0.9
25% CVA, logMAR				
DAY				
Mean ± SD	0.26 ± 0.16	0.35 ± 0.20*	0.49 ± 0.22†§	0.24 ± 0.16
Range	−0.1 to 0.5	−0.1 to 0.7	0.1–1.0	0.0–0.7
DAY + glare				
Mean ± SD	0.28 ± 0.15	0.28 ± 0.16	0.52 ± 0.21†§	0.26 ± 0.20
Range	−0.1 to 0.6	0.0–0.6	0.2–1.0	−0.1 to 0.9
EVE				
Mean ± SD	0.47 ± 0.22	0.54 ± 0.20†	0.63 ± 0.18†§	0.40 ± 0.13
Range	0.1–0.9	0.3–0.9	0.2–0.9	0.1–0.8
EVE + glare				
Mean ± SD	0.59 ± 0.21	0.62 ± 0.21†	0.81 ± 0.18†§	0.51 ± 0.18
Range	0.3–1.0	0.3–1.0	0.5–1.0	0.0–0.9
Straylight, log(s)				
Mean ± SD	1.24 ± 0.37	1.48 ± 0.41*	1.59 ± 0.29†§	1.28 ± 0.36
Range	0.55–2.17	0.85–2.80	1.15–2.27	0.55–2.92
Sphere, D				
Mean ± SD	0.39 ± 1.29	−1.15 ± 3.64	−0.11 ± 3.01	0.55 ± 1.56
Range	−3.50 to +3.50	−9.00 to +2.50	−9.00 to +3.00	−6.50 to +3.00
Cylinder, D				
Mean ± SD	−1.00 ± 0.68	−1.45 ± 1.22*‡	−1.07 ± 0.82	−0.94 ± 0.69
Range	−2.50 to 0.00	−5.00 to 0.00	−3.00 to 0.00	−2.50 to 0.00
LP, D				
Mean ± SD	21.9 ± 2.6	22.3 ± 2.2	20.0 ± 1.8†§	21.8 ± 1.5
Range	17.0–28.1	18.8–28.0	16.7–23.2	19.1–26.1

DAY, day; EVE, evening.
* Significance test versus the control; 1-way ANOVA, Tukey tests $P < 0.05$.
† Significance test versus the control; 1-way ANOVA, Tukey tests $P < 0.01$.
‡ Significance test versus the WC-1 group; 1-way ANOVA, Tukey tests $P < 0.05$.
§ Significance test versus the WC-1 group; 1-way ANOVA, Tukey tests $P < 0.01$.

had significantly decreased CDVA and cylinder compared with the control group, and significantly decreased 100% and 25% CVA under the day, evening and evening + glare conditions, and increased straylight value, compared with the control and WC-1 groups. The WC-3 group had significantly decreased CDVA, CVA under all conditions, and LP value, and increased straylight value, compared with the control and the WC-1 group. The straylight values in the WC-2 group (1.48 ± 0.41 log(s)) was significantly higher than that in the control, and that in the WC-3 group (1.59 ± 0.29 log(s)) was significantly higher than that in the control and WC-1 groups, but not significantly that in the WC-1 group.

Table 3 presents the mean BLS values of the four groups. There were no significant differences among the four groups for all layers of the lens and the cumulative value from the anterior subcapsule to the central clear zone.

Figure 2 presents the ocular HOA results. The WC-3 group had significantly higher ocular total HOA, coma-like, spherical-like, and trefoil aberrations, and the WC-2 group had significantly higher ocular total HOA, coma-like, and coma aberrations than the control group. The WC-3 group had significantly higher ocular total HOA and coma-like aberrations than the WC-1 group. However, there were no significant differences in terms of ocular HOA between the WC-1 and control groups and in terms of spherical aberrations among the WC groups.

Figure 3 shows the internal HOA results. The WC-3 group had significantly higher values for all HOA types, except spherical aberrations, than the control and WC-2 groups, and

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Table 3. Backward Light Scattering Intensity by Group

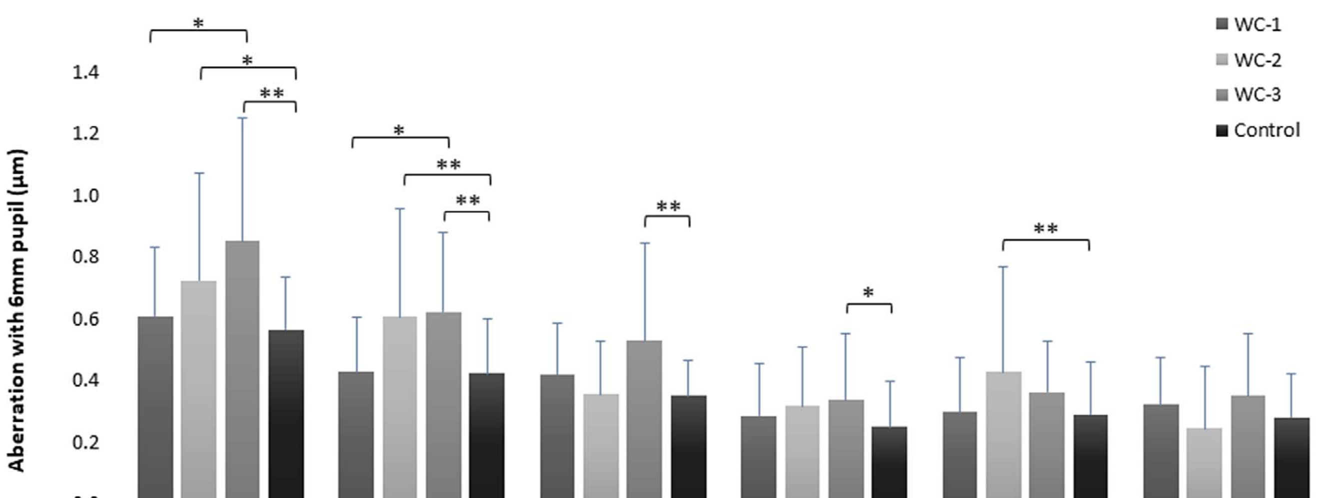
Parameter	Group: WC-1	WC-2	WC-3	Control
BLS, cct				
Anterior subcapsule				
Mean ± SD	92.3 ± 18.3	91.0 ± 20.3	92.2 ± 24.8	90.9 ± 16.9
Range	58–126	55–128	62–158	60–132
Anterior cortex				
Mean ± SD	56.4 ± 10.9	59.0 ± 17.3	52.1 ± 17.8	52.8 ± 11.5
Range	40–77	29–103	26–93	31–94
Adult nucleus				
Mean ± SD	156.7 ± 35.6	158.8 ± 40.9	159.3 ± 44.4	165.2 ± 34.9
Range	87–216	79–227	99–227	97–234
Fetal nucleus				
Mean ± SD	81.9 ± 15.1	79.8 ± 12.6	86.2 ± 22.0	89.2 ± 15.0
Range	54–112	57–109	43–121	49–122
Central clear zone				
Mean ± SD	64.3 ± 13.5	64.8 ± 11.5	67.1 ± 18.4	72.0 ± 13.5
Range	41–89	45–91	34–103	42–103
Cumulative value from anterior subcapsule to central clear zone				
Mean ± SD	8,489 ± 2,235	8,503 ± 1,690	8,996 ± 2,099	8,897 ± 1,525
Range	5,497–13,234	4,761–11,683	5,004–12,636	5,601–12,511

Significance test; 1-way ANOVA, Tukey tests = not significant; cct, computer-compatible tape.

significantly higher values for total HOA, coma-like, spherical-like, and coma aberrations than the WC-1 group. Further, the WC-1 and WC-2 groups did not show significant increases in terms of internal HOA compared with the control group. There was no significant increase in terms of spherical aberrations in any of the WC groups.

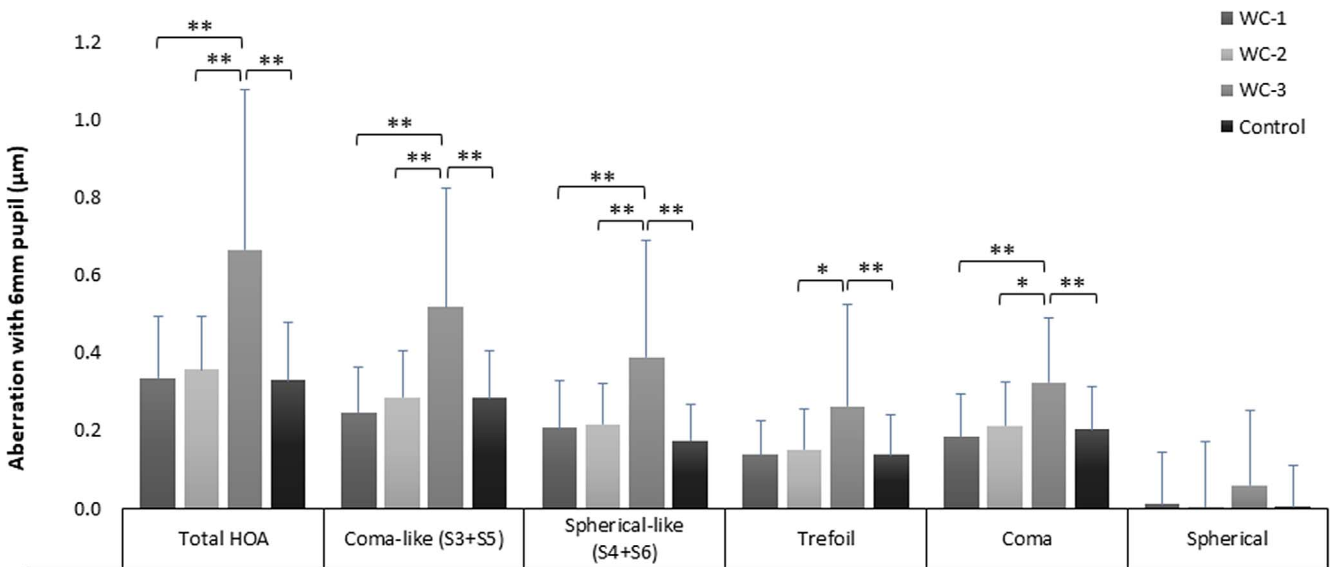
Table 4 shows the proportions of WC groups with better (logMAR <0.1) and lower (logMAR ≥0.1) CDVA and higher (≥1.4 log(s)) and lower (<1.4 log(s)) straylight values. Approximately 50.0% and 75.0% of WC-2 and WC-3 groups, respectively, showed better CDVA with higher straylight values, compared with only approximately 23% to 24% of the WC-1 and control groups, suggesting the possibility many cases had risk of decreased visual function with increased straylight even if CDVA had not been decreased in the WC-2 and WC-3 groups.

Figure 4 presents the correlations among CDVA, straylight, and HOA in eyes with WCs. There were significant correlations between HOA and both of CDVA ($P < 0.001$) and straylight ($P = 0.020$), suggesting that increased HOA may be a factor to decrease visual function. There was a significant weak negative correlation between CDVA and straylight in eyes with WCs ($P = 0.008$).



	Total HOA	Coma-like (S3+S5)	Spherical-like (S4+S6)	Trefoil	Coma	Spherical
WC-1	0.608	0.428	0.416	0.285	0.297	0.320
WC-2	0.725	0.605	0.355	0.315	0.426	0.244
WC-3	0.853	0.622	0.529	0.335	0.361	0.350
Control	0.564	0.423	0.350	0.249	0.290	0.279

Figure 2. Ocular higher-order aberration by WC type (1-way ANOVA, multiple comparison Tukey law; *$P < 0.05$, **$P < 0.01$).



	Total HOA	Coma-like (S3+S5)	Spherical-like (S4+S6)	Trefoil	Coma	Spherical
WC-1	0.336	0.248	0.207	0.138	0.184	0.012
WC-2	0.358	0.286	0.217	0.152	0.213	0.002
WC-3	0.666	0.519	0.389	0.263	0.324	0.060
Control	0.330	0.284	0.175	0.138	0.203	0.004

Figure 3. Internal higher-order aberration by WC type (1-way ANOVA, multiple comparison Tukey law; $^{*}P < 0.05$, $^{**}P < 0.01$).

Discussion

To the best of our knowledge, no study has yet investigated visual function changes focusing on CDVA, CVA, straylight, and LP in eyes with WC-type cataracts classified by morphology and severity into peripheral (WC-1), central (WC-2), and total (WC-3) types. Accordingly, this study is the first to examine the optical property and factors associated with decreased visual function of eyes with WC. The results revealed the WC-3 group had the most significantly decreased CDVA and CVA, and the WC-2 group with only central zone opacity had decreased CDVA and CVA compared with the control group, but the WC-1 group with only peripheral opacity did not have decreased CDVA and CVA compared with control and the other two WC groups. The WC-2 and -3 groups had a significant increase in straylight, causing decreased visual function. Furthermore, this study is the first to clarify that LP is significantly decreased in eyes with WC-3–type opacity and that this could be a factor for hyperopia.

Increased straylight[9–11] was reported as a factor for decreased quality of vision (QOV) in eyes with cataracts. In this study, straylight was significantly increased in eyes with WC-2– and -3–type cataracts. Straylight involves scattering toward the retina; thus, increased scattering decreases retinal image contrast, which is believed to contribute to decreased CVA. Among the eyes with WC-1– and -2–type cataracts, there were many in which CDVA was not decreased, but the possibility for many cases with decreasing visual function by increasing straylight was shown. CDVA measured using Landolt's ring has a threshold in identification of minimum separable acuity, such that as patients recognize the separation of two points in retinal image, their CDVA may be improved. However, increase in straylight revealed poor QOV, suggesting that straylight might be an indicator of surgical indication for eyes with WCs.

BLS was not significantly higher in any of the WC groups than in the control group. An increase in BLS causes visual function deterioration by decreased retinal illumination. Although increase in BLS may be a factor to decrease visual function in nuclear cataract, cortical cataract with strong pupillary opacities, and posterior subcapsular cataract, it was confirmed that WC is less affected by BLS in this study.

Ocular HOA (total HOA, coma-like, spherical-like, and trefoil aberrations) were significantly increased in the WC-3 group at a pupil diameter of 6.0 mm, suggesting that increased HOA is a factor for decreased visual function in eyes with WC-3–type cataracts. Internal HOA (6.0-mm diameter pupils) may be highly affected by the crystalline lens and significantly increased in total HOA, coma-like, spherical-like, trefoil, and coma aberrations (i.e., in all aberrations except spherical aberrations), suggesting that the increased ocular HOA in the WC-3 group is attributable to increased HOA of the lens.

Table 4. Proportions of Visual Acuity and Straylight in Each WC Group

CDVA, logMAR	Straylight, log(s)	Group: WC-1	WC-2	WC-3	Control
<0.1	<1.4	20/26 (76.9%)	8/15 (53.3%)	3/12 (25.0%)	57/75 (76.0%)
	≥1.4	6/26 (23.1%)	7/15 (46.7%)	9/12 (75.0%)	18/75 (24.0%)
≥0.1	<1.4	1/1 (100%)	2/5 (40.0%)	2/11 (18.2%)	0/2 (0%)
	≥1.4	0/1 (0%)	3/5 (60.0%)	9/11 (81.8%)	2/2 (100%)

Significance test; 1-way ANOVA, Tukey tests = not significant.

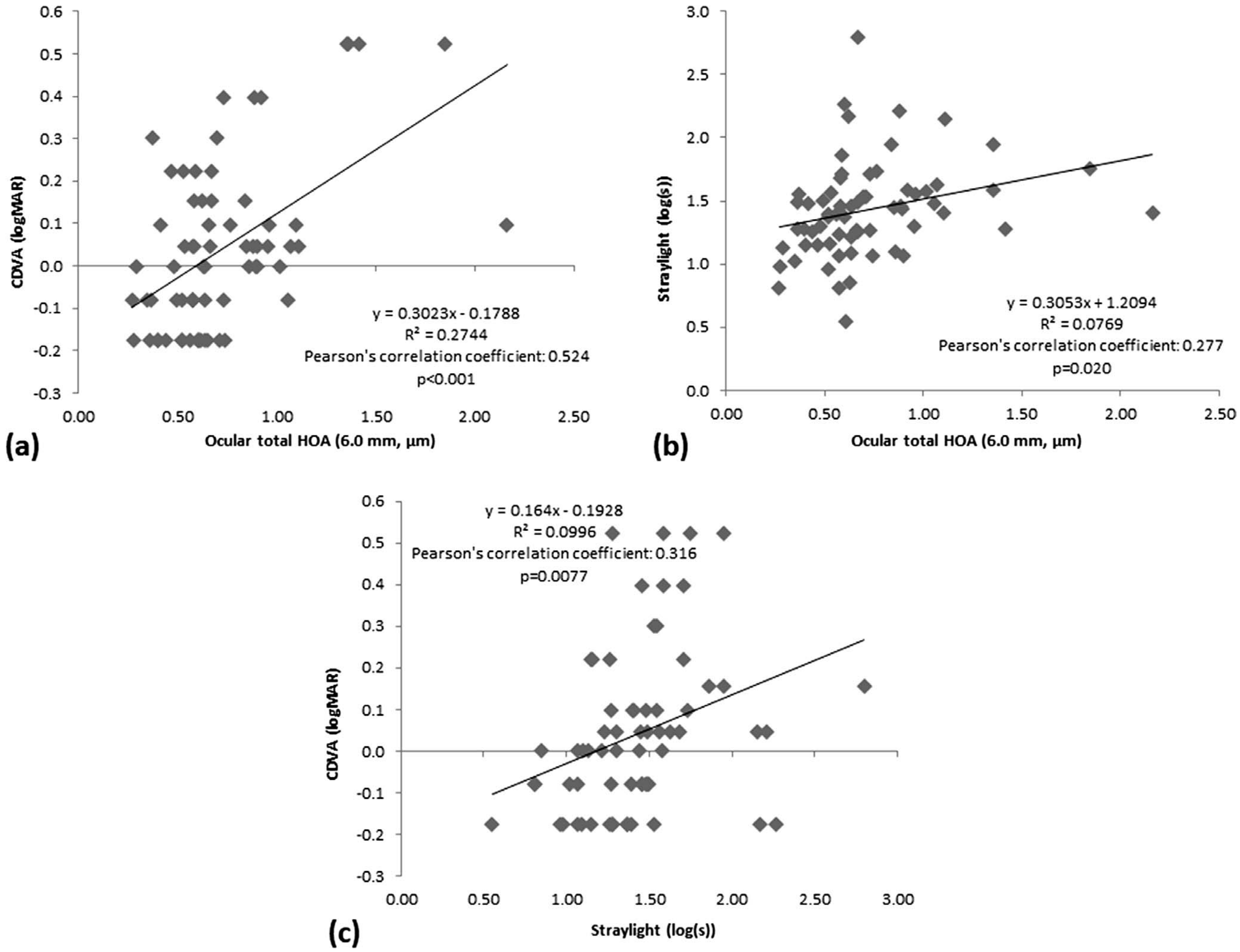


Figure 4. Correlations among visual acuity, straylight, and higher-order aberration in eyes with WCs. (**a**) Correlation between HOA and CDVA. (**b**) Correlation between HOA and straylight. (**c**) Correlation between straylight and CDVA. Pearson's correlation coefficient in linear regression.

Furthermore, the WC-2 group had significantly higher ocular HOA (total HOA, coma-like, and coma aberrations) than the control group, although not as high as did the WC-3 group, suggesting that increased HOA is the primary cause of decreased CDVA in eyes with WC-2–type cataracts. The results of this study are consistent with those of a study by Qu et al.[3] who reported increased coma and trefoil aberrations in eyes with WC linked to decreased visual acuity in the participants of the Reykjavik Eye Study. Furthermore, the results of this study showed that WC localized in the periphery (WC-1 group) were not associated with increased HOA nor decreased visual acuity, revealing that the location of WC is another important factor in decreased visual function. Several studies have reported that increased HOA due to cataracts amplifies a distortion of the retinal image and is a cause of decreased visual function and acuity[17–19]; however, these studies focused on the three main types of cataracts (cortical, nuclear, and posterior subcapsular cataracts), and few studies have evaluated HOA in eyes with subtypes of cataracts, such as WC.

WC-3–type cataracts are associated with significantly higher rates of trefoil aberrations of internal HOA, which are assumed to be HOA that follow the tridirectional lines comprising the Y-shaped suture. The Y-shaped suture of the superficial layer of the cortex is on the anterior and posterior surfaces of the lens, and the Y's on each side are in inverted positions. WCs often embody a separation of the cortical layer along the Y-shaped suture of the anterior surface of the lens, but they can occur on the posterior surface. Complications with WCs on the anterior and posterior cortices may involve different degrees and types of HOA, warranting further investigation.

WC-1–type cataracts have a minimal effect on HOA, and HOA increase may be minimal with WC-2–type cataracts with smaller volumes. HOA dramatically increases in eyes with WC-3–type cataracts and distorting retinal images, suggesting that this type of WC cataract leads to a major decrease in visual function. Investigation of the relationships between the area and volume of WC, its localization in the anterior or posterior cortex, and HOA may further elucidate the association between the degree of WC and visual function.

Considering the relationship among CDVA, straylight, and HOA in eyes with WCs, it is suggested that increased HOA may be involved in decreased CDVA and increased straylight. A weak correlation between CDVA and straylight was reported in eyes with cataracts,[20] and the same result was obtained in this study, too. In eyes with WC-3–type cataract, if there are both decreased CDVA and increased straylight, which are important indicators of visual function, in addition to increased HOA, eyes with only WCs may be considered as an indication for cataract surgery.

In the present study, we found that WC-3–type cataracts were associated with marked LP decrease, causing hyperopia. Because WCs are formed by the separation of the cortex along the Y-shaped suture of the superficial layer of the lens, the interior portion is presumed to be filled with fluid. Although the normal lenticular refractive index is 1.386 to 1.406,[21] it tends to change with aging and cataractous lens change. Because it is likely that the refractive index of the fluid components within a WC is close to that of aqueous humor (1.336), the presence of WCs may have caused the decrease in the LP. Compared with the LP of the control group (21.8 ± 1.5 D), that of the WC-3 group was slightly lower (20.0 ± 1.8 D). In the present study, the SE calculated with mean AL (23.59 mm) and mean CP (44.14 D) was estimated to be −0.12 D for the control group and +0.99 D for the WC-3 group, revealing an approximately 1.1-D hyperopic shift in eyes with WC-3 compared with those with transparent lenses. Aging is a factor involved in natural and gradual LP decrease in transparent eyes,[22] but WCs tend to rapidly decrease LP, inducing further hyperopia. Decreased visual function and refractive errors such as hyperopia may lower quality of vision and quality of life of patients with WC-3–type cataracts (total WC cataract).

There are several limitations to this study. First, eyes with WC often show progression to cortical cataracts; thus, it is possible that there were a few subjects in this study with complex cortical opacity. Second, the possibility that the cortical opacity of interior WC increased the LP cannot be excluded, warranting further investigation to compare LP and visual function of eyes with WC and of those with WC that develop cortical opacity. Third, this study classifies the degree of WC into only three types; however, WCs with different areas, volumes, and locations (anterior or posterior cortex) are likely to be observed with differences in terms of straylight, HOA, and LP, but these considerations were not within the scope of this study. Future studies are required to conduct investigation based on more detailed classifications of WCs. Last, WCs are often observed with granules, such as presence of vacuoles interiorly, but these differences were disregarded in this study. WCs subclassified based on the presence or absence of intra-WC granules are likely to result in distinct effects on visual function and warrant investigation on this difference in future studies.

In summary, in the WC-3 group (total WC cataract), decreased LP was associated with hyperopia and significant increase in straylight. HOA was associated with lower CDVA and CVA. Increased HOA is the factor with the strongest effect on decreased visual function. Total WC is a possible independent factor for marked decline of visual function, and it is a type of lens alteration that should always be considered as an indication for surgery.

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