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**Changes in Higher-order Aberrations following Scleral Buckling Surgery for
Rhegmatogenous Retinal Detachment**

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Short title: Higher-order aberrations in scleral buckling surgery

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Abstract

Purpose: To evaluate changes in higher-order aberrations (HOAs) following scleral buckling surgery for the treatment of rhegmatogenous retinal detachment (RD).

Design: Prospective observational comparative case series.

Participants: The study included 67 eyes of 67 RD patients undergoing scleral buckling surgery, and the fellow normal eyes comprised the control group.

Twenty-seven eyes were treated with segmental buckling procedure and 40 eyes received encircling buckling procedure alone.

Methods: Hartmann-Shack wavefront analysis was performed at 2 weeks, 1 month, and 3 months postoperatively.

Main Outcome Measures: Time course of changes in HOAs.

Results: The scleral buckling surgery significantly increased HOAs at 2 weeks ($p < 0.0001$), 1 month ($p < 0.0005$), and 3 months ($p < 0.05$) postoperatively as compared with the control group. At 3 months postoperatively, the HOAs were significantly lower in the encircling group than in the segmental buckling group ($p < 0.05$). The vertical coma (Zernike Z_3^{-1}) became negative (significantly lower than zero, $p < 0.01$) in patients who received segmental buckling in the upper quadrant. The ocular HOAs and logMAR (logarithm of the minimum angle of resolution) best-corrected visual acuity significantly correlated at three months postoperatively (third-order root mean square (RMS): $r = 0.445$, $p < 0.0005$; fourth-order RMS: $r = 0.489$, $p < 0.0001$).

Conclusions: Scleral buckling surgery significantly increased HOAs. The segmental buckling procedure increased the HOAs to a greater extent and for a longer duration than the encircling procedure. The direction of coma aberration corresponded to the location of the segmental buckle. The increase in HOAs can be one of the factors

responsible for visual disturbances after scleral buckling surgery.

Introduction

Current techniques of rhegmatogenous retinal detachment (RD) repair allow most detachments to be repaired successfully. Even after the successful retinal reattachment, the postoperative vision may be unsatisfactory in some cases. Previous studies have demonstrated that the scleral buckling surgery alters the shape of the globe, resulting in changes in the refractive power¹⁻⁴ and increases in corneal astigmatism.⁴⁻⁶ In addition, several studies using videokeratography quantitatively revealed that the scleral buckling surgery increases corneal irregular astigmatism.⁷⁻¹³

Recent studies using wavefront analysis technology reported that higher-order aberrations (HOAs) significantly increase after refractive procedures such as radial keratotomy,¹⁴ photorefractive keratectomy,¹⁵ and laser in situ keratomileusis.¹⁶ These increases are known to be related to the deterioration of visual function.¹⁴⁻¹⁶ However, no reports have addressed the changes in ocular aberrations after scleral buckling surgery by search using Pub Med. We conducted the current prospective study to quantitatively evaluate changes in HOAs after scleral buckling surgery for the treatment of RD.

Methods

Patients

We analyzed 67 eyes of 67 consecutive RD patients who were successfully treated with scleral buckling procedure. Surgery was performed at our clinic by 2 experienced vitreoretinal surgeons from July 2003 through June 2004. Their age averaged 46.6 ± 17.8 years (mean \pm SD), and there were 42 males and 25 females. Fifty healthy contralateral eyes of 50 unilateral RD patients among these 67 subjects served as normal controls. We conducted this study in accordance with the Declaration of Helsinki, and we received

approval from the institutional review committees of Tsukuba University Hospital. Prior to inclusion in the study, all patients provided informed consent after the nature of the study was explained to them. Exclusion criteria included patients with previous history of ocular surgery in the study eye and ophthalmic disorders except refractive errors and mild cataract. Patients with astigmatism of 3.00 diopters or greater were also excluded because high natural astigmatism can reduce the image quality of Hartmann-Shack wavefront sensing.²⁵ Patients treated with primary vitrectomy and/or cataract surgery were not included in the current subjects.

The patients' eyes were stratified into 2 groups based on the type of buckling surgery performed: 27 eyes were treated with segmental buckling procedure and 40 eyes received encircling buckling procedure alone. Scleral buckling was performed using standard explant techniques. A circumferential silicone sponge buckle (no. 506, MIRA, Waltham, MA) was used for the segmental and encircling buckling surgeries. Mattress sutures with 5-0 Dacron (Alcon Surgical, Fort Worth, TX) were placed to groove the silicone elements. Cryopexy was routinely performed on the sclera corresponding to the retinal tears. Subretinal fluid drainage was accomplished using either an endophotocoagulator or a 27-gauge needle after the choroid was exposed by a scleral dissection of 2.0-mm length. Sulfur hexafluoride (SF₆) gas was injected when required.

Measurement of HOAs

The HOAs were measured at 2 weeks, 1 month, and 3 months postoperatively. Measurements were done for 6-mm pupils with the Hartmann-Shack wavefront analyzer (KR-9000PW, Topcon Corp., Tokyo, Japan) after pupillary dilation with 1% tropicamide eye drops. Data were obtained by an experienced examiner in a masked fashion. The

measurements were repeated 3 times for each eye, and their mean was used for data analyses. All Hartmann images were revised to the pupil center images.¹⁷⁻¹⁹ The obtained data were expanded into a set of orthogonal Zernike polynomials. The magnitudes of the coefficients of the Zernike polynomials are represented as the root-mean-square (RMS) and are used to show the wavefront aberrations. The zero-order component in the Zernike polynomials has one term that represents a piston. The first order represents tilt with two terms. The second order includes three terms that represent defocus and astigmatism. The third order has four terms that represent coma and trefoil astigmatism. The fourth order has five terms including the spherical aberrations. Spectacles can correct only the second-order aberrations. The RMS of third- and fourth-order Zernike components (Z_3^{-3} to Z_3^3 , Z_4^{-4} to Z_4^4 , respectively) were used to represent coma- and spherical-like aberrations, respectively.²⁰⁻²⁴

Results

There were no significant intra- and postoperative complications, such as subretinal hemorrhage, intraocular pressure elevation, and choroidal detachment, and cataract formation. SF₆ gas was used in 14 patients (20.9%), and subretinal fluid drainage was performed in 40 patients (59.7%). Logarithm of the minimum angle of resolution best corrected visual acuity (logMAR BCVA) was 0.699 ± 1.011 preoperatively and 0.095 ± 0.347 at 3 months postoperatively.

The time course of changes in corneal and ocular HOAs in all eyes is shown in Figure 1. The buckling surgery caused significant increases in both corneal and ocular third-order RMS at 2 weeks ($p < 0.0001$, Mann-Whitney *U* test), 1 month ($p < 0.0005$), and 3 months ($p < 0.05$) postoperatively (Figure 1A). Significant increases in ocular fourth-order RMS

were found at 2 weeks ($p < 0.0001$), 1 month ($p < 0.0001$), and 3 months ($p < 0.05$) postoperatively (Figure 1B). Corneal fourth-order RMS did not show any significant changes throughout the study period (Figure 1B).

At 3 months postoperatively, significant positive correlation was observed between corneal and ocular HOAs (third-order RMS: $r = 0.690$, $p < 0.0001$; fourth-order RMS: $r = 0.552$, $p < 0.0001$; Pearson's correlation coefficient) (Figure 2A,B) and between ocular HOAs and logMAR BCVA (third-order RMS: $r = 0.445$, $p < 0.0005$; fourth-order RMS: $r = 0.489$, $p < 0.0001$) (Figure 3A,B).

The time course of changes in corneal and ocular HOAs based on the type of surgical procedures is shown in Figure 4. The mean pre- and postoperative logMAR BCVA did not differ significantly between the groups. In the segmental buckling group, ocular third- (Figure 4A) and fourth-order RMS (Figure 4B) was significantly higher than the control group throughout the study period. In the encircling buckling group, increases in HOAs were transient. Ocular third- (Figure 4A) and fourth-order RMS (Figure 4B) significantly increased in the early postoperative period, but returned to the normal level by 3 months. At 3 months postoperatively, the ocular HOAs were significantly lower in the encircling group than in the segmental buckling group (third-order RMS: $p < 0.005$, fourth-order RMS: $p < 0.05$) (Figures 4A, 4B).

The relationship between the location of buckling and the direction of coma aberration was assessed in 17 eyes that received segmental buckle in the upper quadrant. At 3 months postoperatively, the vertical coma (Z_3^{-1}) became negative (significantly lower than zero, $p < 0.01$) (Figure 5A), while the horizontal coma varied considerably (Figure 5B).

The corneal and ocular HOAs were not significantly different between cases injected

with gas and those without gas tamponade. Further, the corneal and ocular HOAs did not significantly differ between cases with subretinal fluid drainage and those without subretinal fluid drainage.

Discussion

To the best of our knowledge, no studies have addressed the changes in HOAs after scleral buckling surgery. As shown in the results, scleral buckling surgery significantly increased HOAs. Postoperative ocular HOAs significantly correlated with corneal HOAs, indicating that increases in corneal aberrations were responsible for the rise of ocular aberrations. There are several reports on the changes in the corneal shape after scleral buckling surgery.⁴⁻¹³ Induced corneal astigmatism is usually transient, and returns to the baseline level by 1–3 months after surgery.^{7,9,11-12} Similar results have been reported regarding changes in corneal irregular astigmatism, such as asymmetry and higher-order irregularity on videokeratography.^{9,11} In contrast, other studies have reported persistent increases in corneal regular and irregular astigmatism for more than 3–6 months after scleral buckling surgery.^{10,13} In the present study, the level of HOAs remained increased for at least 3 months after surgery.

We examined the influence of the surgical procedure on the induced changes in aberrations and found that the level of HOAs remained high for a longer duration after the segmental buckling procedure than after the encircling procedure alone. It has been suggested that scleral indentation during suturing of the buckle caused corneal distortion, resulting in astigmatism induction.^{4,6} Moreover, segmental buckles induced greater astigmatism than widely spanned or encircled ones.^{6,8-9} In our study, the silicone sponge was used for encircling buckling surgeries. If we use solid silicone elements for encircling procedure, these results may change. We did not evaluate the influence of

different buckle types; however, we observed that the increase in HOAs by the segmental buckle was more prolonged than that by the encircling buckle. It was found that the segmental buckling procedure increased not only corneal astigmatism but also corneal and ocular HOAs.

The relationship between the direction of coma aberration and the location of segmental buckles was also investigated. The vertical coma became significantly negative in cases of upper quadrant segmental buckling, indicating that the wavefront in the area corresponding to the buckle had advanced. The direction of coma and location of buckling was thought to be reasonable. Kinoshita et al investigated the changes in corneal astigmatism in 125 eyes treated with scleral buckling surgery by using the vector method with 2-fold-angle rectangular coordinates. They observed that differential vectors tended to direct toward the buckles.⁶ Okada et al observed that the differential map of astigmatism obtained using a photokeratoscope revealed that astigmatism was induced in the direction of the center of the buckle.⁴ The current results for HOAs are in good agreement with these previous studies.

In the current study, significant correlation was found between the ocular HOAs and logMAR BCVA at 3 months postoperatively. The relationship between visual function and ocular HOAs has been studied in a variety of ocular diseases.¹⁴⁻¹⁷ Eyes with cataract showed decreased contrast sensitivity and increased HOAs.¹⁷ Applegate et al reported that the area under the contrast sensitivity function decreases as the wavefront variances increase after radial keratotomy.¹⁴ A study using aberrosopy demonstrated that low-contrast visual acuity and glare visual acuity were adversely influenced by the increase in total ocular HOAs after photorefractive keratectomy.¹⁵ Yamane et al demonstrated that conventional laser in situ keratomileusis significantly increases ocular

HOAs, which compromise the postoperative contrast sensitivity functions.¹⁶ Based on the abovementioned previous and current findings, it appears that the increase in HOAs after scleral buckling surgery deteriorates visual function. However, this may not be the major cause of visual disturbance after scleral buckling surgery. Several pre- and postoperative factors such as the long duration of macular detachment, alterations in retinochoroidal circulation, and ciliary edema have been reported to be associated with poor visual outcomes of the scleral buckling surgery.²⁶⁻³⁰ Our results revealed that the mean coma- and spherical-like aberrations at 3 postoperative months were 0.385 ± 0.267 and 0.271 ± 0.156 , respectively. Pesudovs et al revealed that coma- and spherical-like aberrations for 6-mm pupils in patients with various types of spherical intraocular lenses (IOLs) were 0.37–0.51 and 0.36–0.60, respectively.³¹ Oshika et al described that third- and fourth-order RMS in 7-mm pupils were 0.883 and 1.455 after photorefractive keratectomy, respectively, and those after laser in situ keratomileusis were 1.436 and 1.941, respectively.²³ The amount of HOAs after scleral buckling surgery was similar to that after cataract surgery and lower than that after excimer laser refractive surgery. Thus, the increase in HOAs after scleral buckling surgery may be less important than other anatomical and functional factors with regard to visual function.

We acknowledge certain limitations of our study, including the lack of baseline data on RD patients. The Hartmann-Shack wavefront analyzer enables the correct assessment of HOAs in the absence of macular detachment but not in its presence. Since we could not measure the preoperative HOAs in the RD patients, we used the value of HOAs in the fellow eyes as a control.

In conclusion, scleral buckling surgery increased corneal and ocular HOAs. The level of HOAs remained high at least for 3 months after the surgery. The segmental buckling

procedure increased the HOAs for a longer duration than the encircling procedure. The increase in the HOAs may be one of the causes of visual disturbance after scleral buckling surgery.

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