Corneal First Surface Wavefront Aberrations Before and After Pterygium Surgery

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ABSTRACT

PURPOSE: To determine the higher order aberrations at the corneal first surface before and after surgery for pterygium.

METHODS: Data were drawn from a longitudinal study of patients undergoing pterygium excision at Royal Victoria Infirmary, Newcastle upon Tyne, England between September 1998 and May 2004. Corneal topography was taken with the TMS-2 Topographic Modeling System (Computed Anatomy Corp) prior to and 6 months after surgery, exported to VOLPro software v7.08 (Sarver & Associates), and wavefront aberrations were derived for a 5.0-mm pupil using a 10th order Zernike polynomial expansion. Pre- to postoperative changes were assessed for significance using analyses of variance, and the relative risk of significant postoperative aberrations by pterygium size was determined.

RESULTS: Satisfactory corneal topography was available on 67 eyes (mean age 53.8±16.7 years [range: 25-86 years]). The root-mean-square (RMS) fit error in preoperative eyes was 0.15±0.10 µm. Preoperatively, the total higher order RMS wavefront aberration was 0.94±0.83 µm. All Zernike modes were elevated, with trefoil being the major contributor 0.52±0.50 µm. Pterygium excision significantly reduced wavefront aberrations across all modes and orders ($F_{1,129}$=6.7 to 22.6, P<.01): total higher order RMS_{postop} 0.45±0.35 µm. Cases with visually significant postoperative aberrations occurred and were more likely with larger pterygia: relative risk compared to pterygia 1.0 to 1.9 mm was 1.3 for 2.0 to 2.9 mm, 8.5 for 3.0 to 3.9 mm, 13.3 for 4.0 to 4.9 mm, and 10.2 for 5.0 to 5.9 mm.

CONCLUSIONS: Zernike polynomial fitting well describes wavefront aberrations in eyes with pterygia. Pterygia are associated with wavefront aberrations, especially trefoil, but these were largely eliminated by surgery. Earlier excision of pterygia reduces the likelihood of significant residual aberrations. [*J Refract Surg*. 2006;22:921-925.]

Pterygia have long been known to induce astigmatic refractive changes.[1,2] However, the description of optical "distortion" or "irregular astigmatism" has only presented more recently.[3-8] Most of these reports have used the simple topographical descriptors surface regularity index and surface asymmetry index.[3-7] One study derived dioptric higher order irregularity using Fourier analysis,[8] but no study has described in detail the wavefront aberrations induced by pterygia and the impact of surgery on these aberrations. Therefore, we set out to determine the higher order wavefront aberrations at the corneal first surface before and after pterygium excision. In accordance with the American National Standards Institute (ANSI) standard,[9] we report these results using the Zernike polynomial expansion. Various authors have argued that Zernike polynomial does not fit some complex shapes that occur in eye disease.[10,11] Therefore, we also aimed to determine whether the Zernike polynomial expansion provides a satisfactory fit to corneal shape induced by pterygium.

Significant visual problems due to irregular astigmatism remaining after the excision of large pterygia have been reported.[12] This raises the question of whether the existence of residual wavefront aberrations after pterygium excision can be predicted from the preoperative wavefront aberrations or pterygium size. If so, it may be possible to determine the optimal stage for pterygium excision to avoid postoperative visual complications. Therefore, we also set out to determine

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whether preoperative parameters predict the likelihood of significant residual wavefront aberrations after surgery.

PATIENTS AND METHODS

Data were drawn from a larger prospective longitudinal study: a single series of consecutive patients undergoing pterygium excision by one surgeon (F.C.F.) at Royal Victoria Infirmary, Newcastle upon Tyne, England between September 1998 and May 2004. Informed consent was obtained from all patients after the nature of the procedure had been fully explained. The tenets of the Declaration of Helsinki were followed and registration was obtained with the Royal Victoria Infirmary for a prospective audit of pterygium surgery outcomes. Inclusion criteria were pterygium deemed in need of excision and surgery performed by one surgeon (F.C.F.) with at least 6-month follow-up. Exclusion criteria were the absence of pre- and postoperative corneal topography or corneal topography of insufficient quality to submit to wavefront analysis.

Pterygia were measured at the slit lamp with the eye in the primary position, the oculars and the slit beam coaxial, and the slit positioned horizontally. The measurements were taken from the limbus to the leading edge of pterygium and recorded in millimeters. A standardized approach to pterygium surgery was used: excision with free conjunctival autograft and adjunctive triamcinolone (10 mg subconjunctival injection). Free conjunctival autograft was the preferred surgical option as this reconstructs normal limbal anatomy and has a low recurrence rate without serious complications.[13] Postoperatively, patients received topical prednisolone acetate 1% tapered over 10 to 12 weeks and topical chloramphenicol four times daily for 3 to 4 weeks. Sutures were removed after 3 to 4 weeks.

Clinical assessment was performed prior to, 1 week, and 1, 2, 4, and 6 months after surgery, but data were collected for this analysis on preoperative and 6-month postoperative examinations. High contrast visual acuity was measured with the patient's optimal refractive correction in place using Snellen charts. By-letter scoring was used. Snellen scores were converted to logMAR scores for calculation of descriptive statistics. Corneal topography was taken with the TMS-2 Topographic Modeling System (Computed Anatomy, New York, NY). Topography maps were assessed for completeness of data. Maps with incomplete data or artifacts within the central 5-mm diameter were excluded. Topography data were exported to VOLPro software v7.08 (Sarver and Associates, Carbondale, Ill) for calculation of wavefront aberrations. The corneal wavefront aberrations were calculated as the optical path difference between the chief ray and a general ray refracted at the corneal surface. The reference focal length is calculated from the apical radius of the corneal topography examination.[14] A 10th order Zernike expansion was used. A 5.0-mm pupil was chosen to reduce the likelihood of artifacts associated with the leading edge of the pterygium while including a significant portion of the optical pathway. Pupil center was assumed to be at the corneal vertex. Corneal topography was used for wavefront aberration calculation rather than whole eye wavefront sensing, because the corneal first surface is the optical element most affected in pterygium, and corneal data were available. Left eyes with nasal pterygium were flipped to mimic right eyes with nasal pterygium to avoid cancellation due to sign when averaging results.

One-way analyses of variance (ANOVA) were used to determine whether pre- and postoperative wavefront aberrations were significantly different. Pre- and postoperative wavefront aberrations were compared to previously published normal values using a *t* test. The relationship between pre- and postoperative aberrations was assessed with linear regression. The relationship between pterygium size and residual aberrations was examined. Using published normative data, the relative risk of abnormally high levels of postoperative wavefront aberrations were calculated for each pterygium grade. All statistical analyses were performed on the SPSS software package v12.0.1 (SPSS Inc, Chicago, Ill).

RESULTS

The larger longitudinal study from which these data were drawn included 89 eyes (51 right eyes and 38 left eyes) of 80 consecutive patients. Seventeen eyes were excluded for missing corneal topography or inadequate follow-up. Therefore, 72 eyes of 66 patients were considered. Five eyes with poor quality topography (incomplete data or artifacts within the central 5-mm diameter) were excluded from the pterygium outcome study. The final dataset comprised 67 eyes of 62 patients (49 men and 13 women). Mean patient age was 53.8±16.7 years (range: 25 to 86 years).

Preoperatively, the mean total higher order root-mean-square (RMS) wavefront aberration was 0.94±0.83 µm, which is much higher than previously published normal values for corneal total higher order RMS scaled for 5.0 mm: 0.26±0.05 µm; t=6.69, P<.001.[15] All Zernike orders were elevated, with third order being the major contributor 0.70±0.60 µm (Fig 1A). All Zernike modes were elevated, with trefoil being the major contributor 0.52±0.50 µm (Fig 1B). Pterygium excision significantly reduced wavefront aberrations: total higher order RMS 0.45±0.35 µm $F_{1,129}$=19.9,

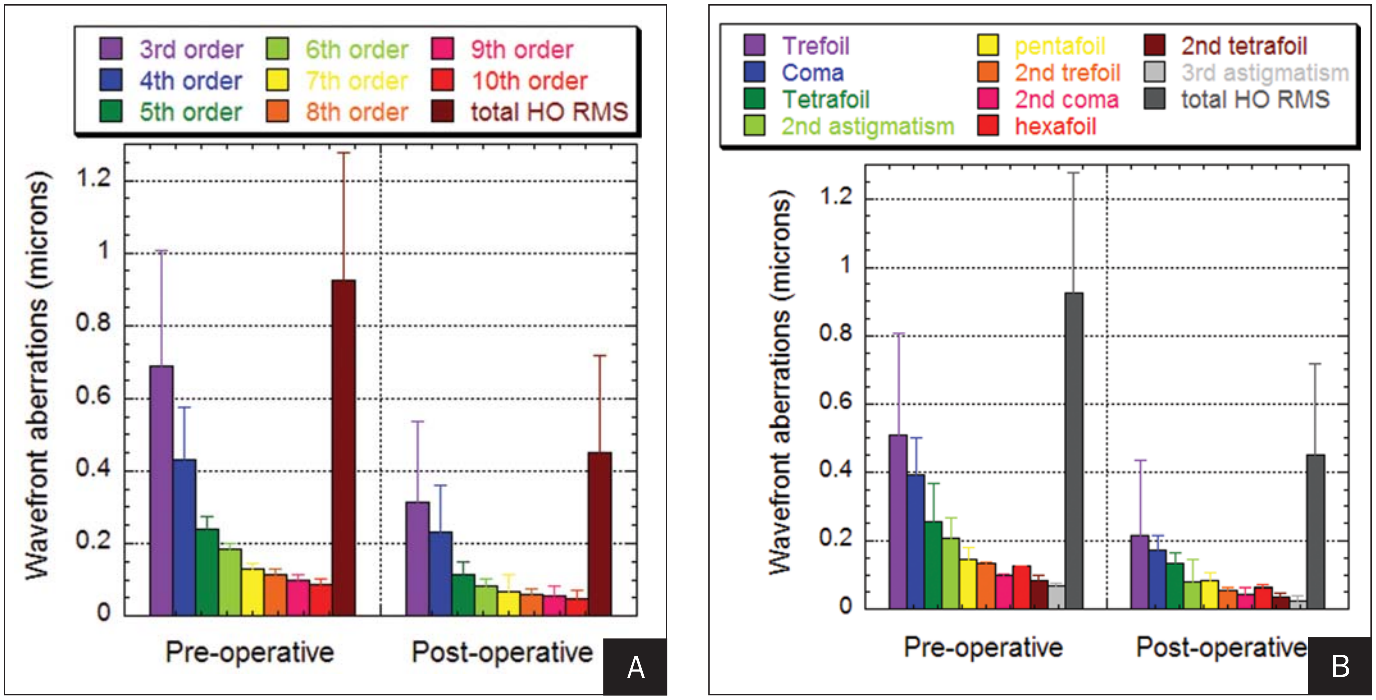

Figure 1. A) Corneal first surface wavefront aberrations by Zernike order for pre- and postoperative pterygium surgery. All orders were significantly different by ANOVA at $P<.05$ except eighth and tenth. Although all orders were elevated preoperatively, third order provides the major contribution. **B)** Corneal first surface wavefront aberrations by Zernike mode for pre- and postoperative pterygium surgery. All modes were significantly different by ANOVA at $P<.05$ except hexafoil. Although all modes were elevated preoperatively, trefoil provides the major contribution.

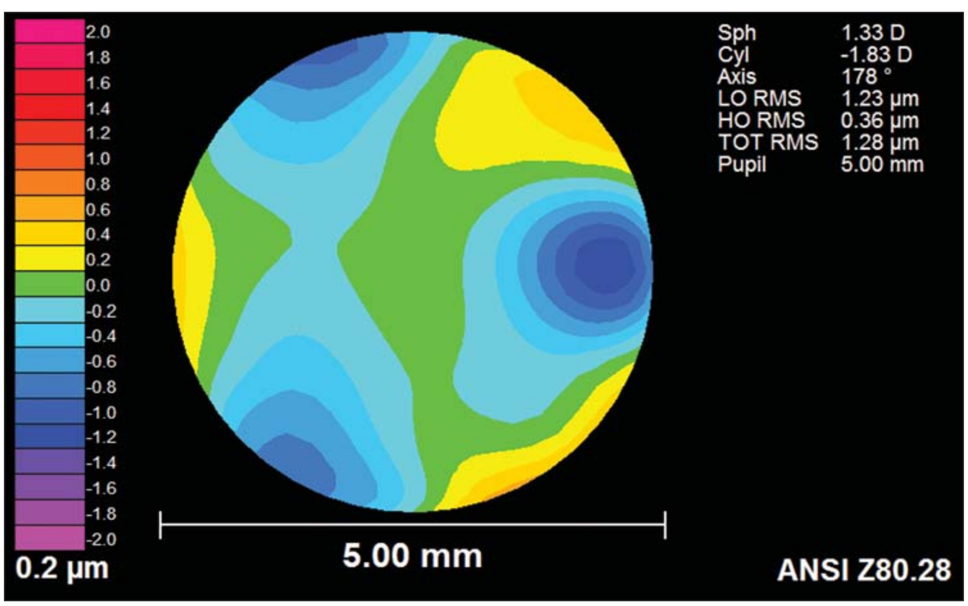

Figure 2. The average higher order wavefront error removed by pterygium excision (oriented for a right eye with a nasal pterygium). Note the pattern is dominated by the three-lobed appearance of trefoil.

$P<.001$. Although the postoperative wavefront aberrations approach previously published normal levels,[15] these are still significantly different: $t=4.40$, $P<.001$. The change in aberrations due to surgery reflects those aberrations that were chiefly raised prior to surgery, especially trefoil 0.22±0.19 µm, $F_{1,129}=20.6$, $P<.001$ (Fig 2). The change in aberrations induced by surgery was statistically significant at the $P<.01$ level by ANOVA with $F_{1,129}$ ranging from 6.7 to 22.6 across all orders and modes tested up to 10th order and tertiary astigmatism. The reduction in aberrations was reflected in an improvement in logMAR visual acuity from 0.03±0.17 (6/6.5) to −0.04±0.17 (6/5.5).

Preoperative higher order aberrations were predictive of postoperative higher order aberration: total higher order RMS_{postop} = 0.26 + 0.19 total higher or-

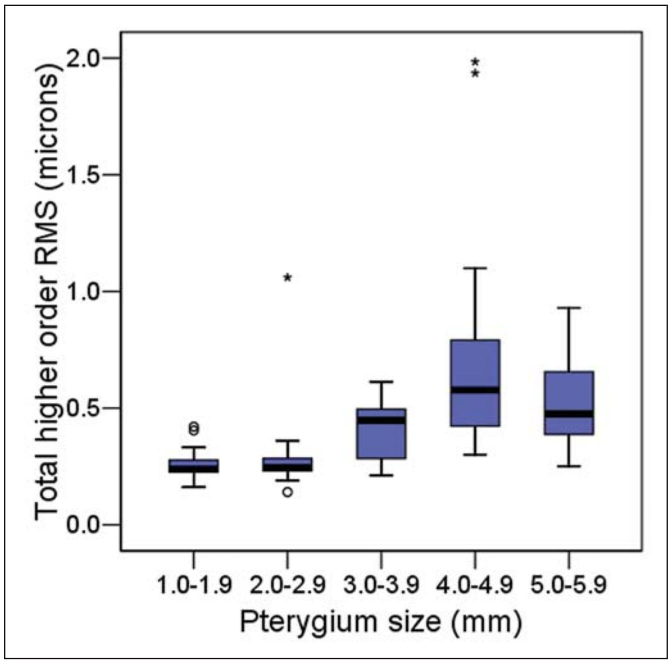

Figure 3. Postoperative total higher order RMS as a function of pterygium size (limbus to leading edge). The likelihood of high postoperative aberrations increased with pterygium size.

der RMS_{preop}, R^2=21%, suggesting that those cases with high preoperative wavefront aberrations were more likely to suffer elevated residual aberrations. The size of the pterygium prior to excision was also predictive of residual higher order aberrations (Fig 3). This relationship was quantified with relative risk. Using the previously published normal values cited above, an arbitrary limit for normal total higher order RMS was defined at the 99th percentile: 0.41 µm. The relative risk of abnormal postoperative total higher order RMS was calculated for increases in size of 1 mm over pterygia sized between 1.0 and 1.9 mm (three cases had missing grade data). The risk of residual total higher order RMS rises markedly with pterygium size (Table).

The average RMS fit error in preoperative eyes was 0.15±0.10 µm, and in postoperative eyes was 0.16±0.04 µm. There were no outlying cases with high fit error (outside the distribution defined by the mean and standard deviation). If the five eyes excluded for poor quality topography (eg, with missing data) were analyzed, the RMS fit error was much higher: 0.85±0.50 µm.

DISCUSSION

This is the first known report of the wavefront aberration outcomes of surgery for pterygium; however, previous studies have shown pterygia induce irregular astigmatism, which is reversed by excision.[3,5,6,8] In this study, eyes with pterygium had increased higher order wavefront aberrations for all Zernike orders and modes tested, with trefoil accounting for the majority of the wavefront error. Importantly, surgical excision eliminated most, but not all, of the induced higher order aberrations; cases with abnormal levels of higher order aberrations occurred postoperatively.

These results demonstrate that earlier excision of pterygia reduces the likelihood of significant residual aberrations. Specifically, significant residual aberrations are unlikely if the pterygium is removed when <3 mm in size and likely when >4 mm in size. Pterygia between 3 and 4 mm pose a significant risk for residual aberrations. Therefore, we encourage surgeons to consider removal of pterygia before they grow to 4 mm in size and at the very least include discussion of residual wavefront aberrations as a risk of non-removal of pterygium when informing a patient of the risks and benefits of pterygium excision.

TABLE

Relative Risk of Abnormally High Residual Total Higher Order Root-Mean-Square (>0.41 µm) by Pterygium Size

	Pterygium Extent Over Cornea (mm)				
	1.0 to 1.9	**2.0 to 2.9**	**3.0 to 3.9**	**4.0 to 4.9**	**5.0 to 5.9**
N	17	13	6	18	10
tHORMS (µm)	0.26±0.07	0.31±0.23	0.42±0.15	0.73±0.49	0.54±0.23
N (%) with tHORMS >0.41 µm	1 (6)	1 (8)	3 (50)	14 (78)	6 (60)
Relative risk increase compared to 1.0 to 1.9 mm size	0	1.3	8.5	13.3	10.2

tHORMS = total higher order root mean square
Note. Increased pterygium size increases the likelihood of visually significant residual wavefront aberrations.

Zernike polynomial fitting describes wavefront aberrations in eyes with pterygia. This is a large dataset, so this is a persuasive finding as to the adequacy of the Zernike polynomial for fitting diseased eyes. This casts doubt on the findings of others who suggested the Zernike polynomial was inadequate for diseased eyes.[10,11] However, analysis of the five eyes excluded for artifacts or missing topographical data revealed that these eyes were poorly fit by the Zernike polynomial. It may be that the real cause of poor Zernike polynomial fit in other studies was missing data within the analyzed area due to poor quality topography data rather than an inherent inadequacy of the mathematical approach.

This large dataset demonstrates the nature of the wavefront aberrations associated with pterygium and their reversal with surgery. The likelihood of significant residual wavefront aberrations is reduced if excision is performed prior to the pterygium growing to 4 mm in length, and is low if operated before they grow to 3 mm in length. The Zernike polynomial adequately characterizes the shape changes associated with this disease.

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