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Tomographic Normal Values for Corneal Elevation and Pachymetry in a Hyperopic Population

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Abstract

Purpose: To establish a normative data base with respect to corneal pachymetry and elevation tomography appropriate for refractive surgery screening of hyperopic individuals.

Methods: 100 eyes of 51 consecutive hyperopic patients were examined with the Oculus Pentacam HR to determine corneal pachymetry and anterior and posterior elevation values at the apex and thinnest point. All patients were otherwise screened as normal and all principal meridians were hyperopic. Results were compared to a previously studied data base of myopic individuals from the same practice.

Results: The average corneal thickness at the apex and thinnest point was not significantly different between the hyperopic and myopic groups (P>0.05 at both locations). The mean anterior elevation at the apex was0.4 ± 1.9μm in the hyperopic group vs. 1.6 ± 1.3μm in the myopic group (P<0.001). The mean anterior elevation at the thinnest point was-0.1 ± 2.2μm in the hyperopic group vs. 1.7 ± 2.0μm in the myopic group (P<0.001). The mean posterior elevation at the apex was5.7 ± 3.6μm in the hyperopic group vs. 0.8 ± 3.0μm in the myopic group (P<0.001). The mean posterior elevation at the thinnest point was10.6 ± 5.7μm for the hyperopic group vs. 3.6 ± 4.1μm for the myopic group (P<0.001). When adjusted for age, the posterior elevation changes remained statistically significant.

Conclusions: Hyperopic individuals exhibited greater variation in posterior tomographic elevation values than a comparable myopic group. Currently used data bases need to be adjusted for screening hyperopic individuals to reduce the number of false positives associated with using a myopic biased data set.

Keywords: Tomography; Topography; Scheimpflug; Hyperopes; Elevation

Introduction

An increasing percentage of the estimated one million people in the United States who undergo refractive surgery annually, are hyperopic. To date, most topographic pre-surgical screening normal values have been based on a predominantly myopic population [1,2]. This is mainly due to the fact that, in the past, the vast majority of individuals undergoing refractive surgery were myopic, and published normal values often reflected the propensity of myopes in the early study populations. It was unknown; however, whether these myopic biased values were applicable to a hyperopic population.It is well-established that the myopic and hyperopic populations are diverse. Hyperopic eyes are associated with a shallower anterior chamber [3], increased incidence of narrow angle glaucoma [4], shorter axial length, higher sphericity, and higher total and corneal spherical aberration compared to myopic eyes [5]. Normative data bases that are not applicable to the subset being examined can lead to both false positives and false negatives. Specific population-based normal values can have important clinical implications.

Prior clinical observations have led us to believe that there is an increased variability in the posterior elevation in hyperopic eyes on tomographic evaluation. If this is true, it would lead to false positives when compared against a myopic biased normative database, and potentially exclude "normal" patients from consideration for refractive surgery. The goals of our study areto establish a hyperopic normative data base for elevation-based tomographyand to compare the data to a previously studied myopic group.

Materials and Methods

Institutional Review Board approval was obtained prior to beginning the study. We conducted a retrospective review of data from 100 normal hyperopic eyes of 51 patients who presented for refractive surgery evaluation. All eyes were hyperopic. Mixed astigmatic eyes were excluded, regardless of the spherical equivalent. Anterior and posterior corneal elevation measurements, as well as corneal pachymetry measurements at the apex and thinnest points were collected using a rotating Scheimplugtomographer, PENTACAM HR (OCULUS GmbH, Wetzler, Gemany), according to a previously published protocol. [6]

Calibration of the PENTACAM was performed by the manufacturer using a model eye and this was not repeated immediately prior to data collection. Images were obtained by techniciansswho had extensive prior experiencewith the PENTACAM. Contact lens use was discontinued at least two weeks prior to corneal imaging. Patients with previous ocular surgeryor known ectasia were excluded from the study, as well as any

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patient with a central pachymetry reading below 475μm or greater than 650μm, best spectacle-corrected visual acuity (BSCVA) below 20/20, visible slit lamp abnormalities, or a family history of keratoconus. Patients were asked to blink twice and then look at the PENTACAM fixation device. Image acquisition involved a 1-second scan of 25 rotational Scheimpflug images. Acceptable maps had at least 9.0 mm of corneal coverage with no extrapolated data in the central 8.0 mm zone. When the patient blinked during the scan or other artifacts were introduced, the PENTACAM flagged that scan as not acceptable. Scans not meeting acceptable criteria were repeated.

Anterior and posterior corneal elevation measurements and corneal pachymetry measurements were documented at the corneal apex and thinnest point. The elevation data used to calculate the best fit sphere (BFS) was gathered from a fixed 8.0mm diameter zone centered on the apex.There was no evidence of extrapolated data in this 8.0mm zone and no extrapolated data was used to calculate the BFS. Corneal elevation was measured off of a BFS as calculated by the PENTACAM. The mean, range and standard deviation for elevation at the apex and thinnest point of the anterior and posterior corneal surfacewas determined.The Kolmogorov-Smirnov test was used to evaluate for parametric data distribution. Both the Student T-Test (parametric data distribution) and Mann-Whitney Test (non-parametric distribution) were utilized to determine statistical differences between the two populations.

Results

A total of 100 hyperopic eyes of 51 patients were evaluated to determine normal values for corneal pachymetry as well as anterior and posterior elevation. The mean patient age was 53.5 ± 8.7 years (SD), with a range of 27 to 68years. There were 29 men and 22 women included in the study. The averagepachymetrywas 550 ± 33.0μm at the apex (range 484-626μm) and 545 ± 33.2 μm at the thinnest point (range 479-626 μm). Average anterior elevation values at the apex and thinnest points were 0.4μm and -0.1μm, respectively. Average posterior elevation values at the apex and thinnest points were 5.7μm and 10.6μm, respectively. The range and standard deviations of the elevation values are shown in Table 1.

An earlier studied myopic group from the same refractive practice included a total of 100 eyes of 50 patients [5].The mean patient age was 40.1 ± 10.1 years (SD), with a range of 18 to 60 years. There were 24 men and 26 women included in the study. The average pachymetry of these patients was 550 ± 36.1μm at the apex (range 453-661μm) and 548± 36.3μm at the thinnest point (range 446-660μm). Average anterior elevation values at the apex and thinnest points were 1.6μm and 1.7μm respectively. Average posterior elevation values at the apex and thinnest points were 0.8μm and 3.6μm respectively. The range and standard deviations of the elevation values for the myopic group are shown in Table 2.

The Kolmogorov-Smirnov test confirmed a normal data set for all the measurement groups, except the anterior elevation at the apex for hyperopes, and the anterior elevation at the apex and thinnest point in myopes. The results of the Student T-Test and Mann-Whitney Test are shown in Table 3.

Discussion

Increasing patient and professional expectations regarding refractive surgery requires us to continually refine our screening process in order to minimize avoidable postsurgical complications. Tomographic evaluation is becoming common practice for the pre-surgical evaluation of refractive surgery candidates. It creates a three-dimensional reconstruction of the anterior segment by measuring the anterior and posterior corneal surfaces, as well as the anterior and posterior lens and iris. Refractive screening concentrates more on the corneal surfaces and their spatial relationship (i.e. corneal thickness). The lack of standardized normal elevation values specific for the hyperopic populationhas likely led to false positives when these patients are screened against the currently used myopic biased measurements. We studied a hyperopic population in order to establish a normative database and to highlight any significant differences between myopic and hyperopic populations.

Statistical analysis detected significant differences between measurements in the hyperopic population compared to the myopic population. The differences in anterior elevation at the apex ($P=6.38x10^{-7}$) and at the thinnest point ($P=1.09x10^{-8}$) are highly significant. The differences in posterior elevation at the apex ($4.88x10^{-21}$) and at the thinnest point ($P=1.07x10^{-17}$) are of even greater significance. This confirms our observational hypothesis that there appears to be innate corneal elevation differences between the two populations.

Given that each eye is not a totally independent variable, analysis was carried out on each eye individually in addition to both eyescombined. [7] Similar significance was obtained in all groups.The right eye anterior elevation measurements at the apex and thinnest point were significantly different (P=0.0076 and P=0.00011, respectively), as well as the difference in posterior elevation at the apex and thinnest point ($P=2.23x10^{-12}$ and $P=1.14x10^{-10}$ respectively).Analysis of the left eye showed similar results.

Location	Average Elevation ± SD (μm)	Elevation Range (μm)	Elevation +1SD (μm)	Elevation +2SD (μm)	Elevation +3SD (μm)
Anterior Apex	0.4 ± 1.9	-3 to +13	2.3	4.2	6.1
Anterior Thinnest	-0.1 ± 2. 2	-6 to +4	2.1	4.3	6.5
Posterior Apex	5.7 ± 3.6	-1 to +14	9.3	12.9	16.6
Posterior Thinnest	10.6 ± 5.7	-2 to +30	16.3	22.1	27.8

Table 1: Average, range and standard deviation of normal hyperopic corneal elevation values.

Location	Average Elevation ± SD (μm)	Elevation Range (μm)	Elevation +1SD (μm)	Elevation +2SD (μm)	Elevation +3SD (μm)
Anterior Apex	1.6 ± 1.3	-5 to +4	2.9	4.2	5.5
Anterior Thinnest	1.7 ± 2. 0	-5 to +6	3.7	5.7	7.7
Posterior Apex	0.8 ± 3.0	-6 to +6	3.8	6.8	9.8
Posterior Thinnest	3.6 ± 4.7	-6 to +18	8.3	13.0	17.7

Table 2: Average, range and standard deviation of normal myopic corneal elevation values.

Location	Hyperopic Eyes AverageElevation ± SD (μm)	Myopic Eyes AverageElevation ± SD (μm)	Mann-Whitney Test (P-value)	Student T-Test (P-value)
AnteriorApex	0.4 ± 1.9	1.6 ± 1.3	< 0.0001	<0.0001
Anterior Thinnest	-0.1 ± 2. 2	1.7 ± 2. 0	< 0.0001	<0.0001
Posterior Apex	5.7 ± 3.6	0.8 ± 3.0	< 0.0001	<0.0001
Posterior Thinnest	10.6 ± 5.7	3.6 ± 4.7	< 0.0001	<0.0001

Table 3: Statistical comparison for all hyperopic and myopic eyes.

Population	Myopic	Hyperopic
Average Age (years)	40.1 ± 10.1	53.5 ± 8.7
Age range (years)	18 – 60	27 - 68
Males	24	29
Females	26	22

Table 4: Demographic information comparing the myopic and hyperopic populations.

Location	Hyperopic Eyes Average Elevation ± SD (μm)	Myopic Eyes Average Elevation ± SD (μm)	Mann-Whitney Test (P-value)	Student T-Test (P-value)
Anterior Apex	0.32± 2.0	1.03 ± 1.9	0.017	0.079
Anterior Thinnest	-0.28 ± 2. 1	0.91 ± 2. 4	0.29	0.017
Posterior Apex	5.57 ± 3.6	2.15 ± 2.9	< 0.0001	< 0.0001
Posterior Thinnest	10.28 ± 5.2	5.76 ± 4.9	< 0.0001	< 0.0001

Table 5: Age-matched subgroup analysis, when comparing all myopic and hyperopic eyes aged 45-62.

The demographics of the two populations (hyperopic and myopic) are compared in Table 4.The observed elevation differences between the myopic and hyperopic groups may have, in part, been influenced by the age variance between the two study groups [8]. Therefore, we analyzed an age-matched group from the myopic population (n=36) to within 1 SD of the average hyperopic population (n=75), which included those individuals between the ages of 45-62. The previously noted pachymetric values remained similar between age-matched groups. The changes in anterior elevation lost significance in the age-matched pairing, while the changes in posterior elevation remained highly significant (Table 5). The loss of significance for the anterior elevation values may be in part due to the smaller sample size, but likely has little clinical significance (see below).

While the posterior results substantiated our earlier clinical observations, the initial anterior results were unexpected. Although the differences in anterior measurements reached statistical significance, they are unlikely to appreciably alter our screening parameters as the +2 SD and +3 SD values, often used as screening gates, between the myopic and hyperopic groups are similar (within 1.4μm). The typically used screening gates (+2 SD/+3 SD) for the posterior surface would vary greatly as they differ by 6.1 &6.8μm for the apex and 9.1 & 10.1μm for the thinnest point. These differences must be accounted for when screening hyperopic refractive surgical candidates, and this highlights the need to define a normative database specific for a hyperopic population.

In this study we computed the BFS by fixing the area utilized to the central 8.0 mm zone. No extrapolated data was used to calculate the BFS as incorporation of extrapolated data may lead to inconsistencies in the calculation of the BFS. All of our previous studies have utilized an 8.0 mm zone and this is also the zone size utilized by the manufacturer for some of their fixed displays [6,9,10]

It should be noted that data was measured at the corneal apex and thinnest points only. These are two points that can be easily and consistently identified when looking at multiple elevation maps from different patients. Only elevation measurements at these two points can be compared to the normative data presented in this study. There may be significant areas of elevation in the peripheral cornea as a function of normal astigmatism. An accurate assessment of image quality must also be made.

While the PENTACAM has been shown to have excellent agreement with the ultrasound pachymeter with regard to central corneal thickness in both pre and post LASIK eyes [11], there are considerable variability in elevation values across different elevation based systems[12]. This potentially limits the normative data developed in this study to the PENTACAM Eye Scanner.

Our results suggest that anterior elevations greater than 4.2μm at the apex or 4.3μm at the thinnest point occur in less than 5% of normal hyperopic corneas (2SD). Anterior elevations greater than 6.1μm at the apex or 6.5μm the thinnest point occur in less than 0.3% of normal corneas (3SD). Posterior elevations of greater than 12.9μm at the apex and 22.1μm at the thinnest point occur in less than 5% of normal corneas (2SD). Posterior elevations of greater than 16.6μm at the apex and 27.8μm at the thinnest point occur in less than 0.3% of normal corneas (3SD). Anterior or posterior elevation values greater than 2 to 3 standard deviations above the mean should raise suspicion and may warrant further evaluation. The posterior values at both the apex and thinnest point are appreciably dissimilar from myopic values to warrant separate screening parameters for hyperopic patients.

Although our patient population was limited in size, and further reduced in the age matched comparison subgroup, there was sufficient diversity to maintain statistical significance for the posterior elevation data (Table 5). Future studies with a larger population would help validate this initial study. While a larger cohort may ultimately reach statistical significance for the anterior surface, the changes are not likely to be clinically relevant as the differences were small.Furthermore, while single topographic measurements may be helpful for screening purposes; no single parameter can reliably define a multi-factorial condition such as keratoconus. Other means of examining the topographic maps including pattern recognition, OD/OS comparison, and pachymetry should be utilized [13,14].

Financial Disclosure

Drs. Belin&Ambrosio serve as Consultants to Oculus GmbH (Wetzlar, Germany). The other authors disclose no commercial or financial interest.

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