Corneal Thickness and Intraocular Pressure in the Barbados Eye Studies

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Objectives: To describe the distribution of central corneal thickness (CCT) and evaluate its relationship to intraocular pressure (IOP) in the predominantly black population of the Barbados Eye Studies (BES).

Methods: Participants received a standardized examination, including pachymetry, applanation tonometry, and a comprehensive ophthalmologic evaluation. Analyses were based on data from all eyes, and generalized estimating equation methods were applied to account for the correlation between eyes.

Results: Among the 1142 consecutive participants with pachymetry measurements, the mean age was 64.3 years, and 58% were women. Black participants tended to have thinner corneas (mean thickness, 529.8 µm) than mixed (black and white) (537.8 µm) and white participants (545.2 µm), respectively. Among black participants, increasing values of CCT were significantly related to younger age (P<.001), diabetes history (P=.03), and refractive error (P=.03); a marginally significant relationship (with thinner corneas) was found with a clinical diagnosis of glaucoma (P=.07). Intraocular pressure was not associated with CCT in this population.

Conclusions: Although other studies have reported a positive correlation between CCT and IOP, such a relationship was not substantiated in the black BES population. Black participants tended to have thinner corneas than white participants, whereas younger individuals, as well as those with a history of diabetes and more positive refractive errors, had thicker corneas.

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TODATE, the majority of studies describing the distribution and factors related to central corneal thickness (CCT) have been conducted in predominantly white populations. Data are limited, however, for populations of African descent, despite recent reports indicating that CCT may be related to race. Other factors associated with CCT include age, sex, diagnosis of glaucoma, diurnal changes, refractive error, genetic influences, diabetes, and intraocular pressure (IOP). The relationship between CCT and IOP has been of interest since Goldmann and Schmidt introduced the applanation tonometer in 1957. They calibrated the instrument assuming a “standard” corneal thickness of 500 µm (based on white populations) and indicated that corneal thickness would have some effect on the resulting IOP measurement. They believed, however, that variation of CCT was inconsequential in the absence of corneal disease. This assumption was later shown to be incorrect. As a result, various correction methods have been proposed.

Although the majority of studies have reported that CCT and IOP are positively correlated, this relationship was not corroborated in 2 recent reports by Feltgen et al and Shah et al. The existence (or lack) of such correlation has clinical implications, since the lower IOP readings of persons with thinner corneas would lead to an underestimation of their true IOP values. The purpose of this article is to present the distribution of CCT in a predominantly black population and to evaluate the relationship between corneal thickness and IOP in this population, which is known to have higher IOP measurements than white populations.

METHODS

The Barbados Eye Studies (BES) were designed to investigate the prevalence, incidence, and risk factors for the major causes of visual impairment or loss in the predominantly black population of Barbados, West Indies. The Barbados Incidence Study of Eye Diseases II (1997-2002) is a 9-year follow-up to the initial baseline prevalence study, the Barbados Eye Study (1988-1992), with the cohort representing a simple random sample of...
the country’s adult population (40-84 years of age at baseline).

The baseline and follow-up examinations followed standardized protocols, as detailed elsewhere. In summary, the examinations included anthropometric and blood pressure measurements; refraction and best-corrected visual acuities (Early Treatment Diabetic Retinopathy Study criteria); applanation tonometry; Humphrey automated perimetry; lens gradings by slitlamp (using the Lens Opacities Classification System II); color stereo fundus photography (of disc and macula); an interview, including medical, ocular, and family history information; and a comprehensive ophthalmologic examination.

In April of 1999, pachymetry measurements were added to the follow-up protocol to determine the distribution of corneal thickness and to assess the relationship between CCT and other variables in this population. Consecutive participants attending their study visit between April of 1999 and February of 2001, had 5 measurements of corneal thickness in each eye using a KMI ultrasonic RK5000 pachymeter (KMI Surgical, Paoli, Pa.). We achieved good reproducibility for the CCT measurements, with intraclass correlation coefficients from 0.69 to 0.97.

**RESULTS**

**CHARACTERISTICS EVALUATED/RISK FACTOR ANALYSIS**

Demographic, medical, and other characteristics were evaluated to determine possible associations with CCT. These factors included: age, sex, body mass index, waist-hip ratio, IOP (average of 3 measurements), refractive error (spherical equivalent), systolic and diastolic blood pressure (average of 2 measurements using a Hawksley random zero sphygmomanometer), hypertension (average systolic blood pressure [BP] $\geq 140$ mm Hg and/or diastolic blood pressure [DBP] $\geq 90$ mm Hg and/or antihypertensive treatment), history of diabetes, smoking, and alcohol use, family history of glaucoma, sunlight exposure, use of hat or sunglasses, and season and time of examination.

In addition to these factors, the relationship between CCT and clinical diagnosis of glaucoma was evaluated. Open-angle glaucoma (OAG), as indicated by the study’s ophthalmologists, was based on the presence of optic disc and/or visual field defects not attributable to other causes. Individuals with some but not all of the necessary optic disc and visual field criteria were classified as glaucoma suspects. A clinical diagnosis of ocular hypertension resulted from an IOP greater than 21 mm Hg and/or treatment for elevated intraocular pressure. A few individuals (n = 3) had other types of glaucoma, owing to trauma or other causes. The remaining participants were considered to be “nonglaucoma.”

**STATISTICAL ANALYSIS**

Since participants had 5 pachymetry measurements in each eye, the average for each eye was computed, and the data for all eyes were subsequently pooled. Generalized estimating equations (GEE) were used to account for the correlation between eyes and were applied to identify factors potentially associated with CCT. Parameter estimates and $P$ values are presented based on the GEE model.

**Table 1. Age-Sex Specific Distribution of Central Corneal Thickness Measurements**

<table>
<thead>
<tr>
<th>Age, y</th>
<th>Male Participants</th>
<th>Female Participants</th>
<th>Total (n = 2276 Eyes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of Eyes</td>
<td>CCT, µm</td>
<td>No. of Eyes</td>
<td>CCT, µm</td>
</tr>
<tr>
<td>50-59</td>
<td>383</td>
<td>536.1 ± 38.7 (534.4)</td>
<td>504</td>
</tr>
<tr>
<td>60-69</td>
<td>278</td>
<td>534.0 ± 38.0 (534.8)</td>
<td>422</td>
</tr>
<tr>
<td>70+</td>
<td>299</td>
<td>525.1 ± 36.2 (523.8)</td>
<td>390</td>
</tr>
<tr>
<td>Total</td>
<td>960</td>
<td>532.1 ± 38.0 (529.9)</td>
<td>1316</td>
</tr>
</tbody>
</table>

**Abbreviation:** CCT, central corneal thickness.

**Table 2. Distribution of Intraocular Pressure and Central Corneal Thickness Measurements by Self-reported Race**

<table>
<thead>
<tr>
<th>Race</th>
<th>No. of Eyes</th>
<th>Mean ± SD (Median) IOP, mm Hg</th>
<th>Mean ± SD (Median) CCT, µm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black</td>
<td>2120</td>
<td>16.7 ± 4.0 (16.3)</td>
<td>529.8 ± 37.7 (528.8)</td>
</tr>
<tr>
<td>Mixed (black and white)</td>
<td>96</td>
<td>16.1 ± 3.9 (15.5)</td>
<td>537.8 ± 34.0 (538.3)</td>
</tr>
<tr>
<td>White</td>
<td>50</td>
<td>14.6 ± 3.0 (14.2)</td>
<td>545.2 ± 45.7 (549.1)</td>
</tr>
</tbody>
</table>

**Abbreviations:** CCT, central corneal thickness; IOP, intraocular pressure.

*Table excludes 5 participants with self-reported race as “other.”

(REE) presents the age-sex distribution of CCT among 1142 participants (2276 eyes) with a mean age of 64.3 years; 58% were women. On average, mean±SD corneal thickness decreased from 533.3±37.2 µm among individuals aged 50 to 59 years, to 532.4±38.6 µm among those aged 60 to 69 years, and to 525.0±37.8 µm among those 70 years and older. Although an inverse relationship was found between CCT and age ($P<.001$), there were no significant differences in corneal thickness between men and women ($P>.05$).

Among the 1142 participants, the majority self-reported their race as black (n = 1064), followed by fewer numbers of mixed (black and white; n = 48), white (n = 25), and other (n = 5) participants. Table 2 presents the distribution of IOP and CCT by ethnicity. Mean IOP was highest among black participants (16.7 mm Hg), followed by mixed/other (16.1 mm Hg), and white participants (14.6 mm Hg). Black participants, however, tended to have thinner corneas (mean, 529.8 µm) than white participants (mean, 545.2 µm) ($P=.09$). Although correlations between CCT and IOP were close to zero among black ($r=0.06$) and mixed ($r=0.08$) participants in this study, a positive and significant correlation was found among the small number of the study’s white participants (Pearson $r=0.36$; $P=.01$).

Owing to the small number of mixed, and white/other participants, the remaining analyses are based on BEs black participants only. The Figure presents the distribu-
Numerous studies on corneal thickness have been conducted in white populations during the last few decades and have reported mean CCT measurements ranging from 520 µm to 579 µm. Data relating to the distribution of corneal thickness in populations of African descent, however, are limited. In the Ocular Hypertension Treatment Study (OHTS), the average CCT was thinner in black participants (555.7 µm; n=318) compared with whites (mean, 579.0 µm; n=912), a race difference that is consistent with our findings. The specific pachymetry values in OHTS were likely higher than they were in other reports due to the inclusion criteria for the trial, which required participants to have ocular hypertension (IOP≥24 mm Hg and ≤32 mm Hg) without coexisting OAG (ie, normal visual fields and optic discs). Individuals meeting these criteria have thicker corneas than individuals with a diagnosis of glaucoma or controls. Therefore, corneal thickness measurements from OHTS participants may not be comparable with those in other populations. The distribution of mean CCT in Barbados is consistent with findings from 2 other reports, with the average corneal thickness among 1064 black BES participants being 529.8 µm.

La Rosa et al suggest a possible underestimation of IOP in the black population due to thinner corneas than are apparent in white individuals. Although a positive correlation between CCT and IOP has been demonstrated in some studies, this result was not confirmed in 2 recent reports. Results from our study indicate a positive correlation between IOP and CCT among the 25 black participants, but not among the large number of black participants. This finding is not likely due to age differences, as the mean ages for black and white participants were 64.2 years and 64.8 years, respectively. Additionally, glaucoma status is not a likely explanation, as the lack of association between CCT and IOP in black participants remained after omitting individuals with OAG. Potential differences may be related to higher mean IOP levels in the black population, as well as a high prevalence of diabetes. Although several correction factors have been recommended to rectify the influence of IOP on CCT, in other populations, these do not appear to be necessary in the black BES population, since CCT was unrelated to IOP. Thus, IOP measurements are not likely influenced by CCT.

CENTRAL CORNEAL THICKNESS, INTRAOCULAR PRESSURE, AND OPEN-ANGLE GLAUCOMA

COMMENT

La Rosa et al suggest a possible underestimation of IOP in the black population due to thinner corneas than are apparent in white individuals. Although a positive correlation between CCT and IOP has been demonstrated in some studies, this result was not confirmed in 2 recent reports. Results from our study indicate a positive correlation between IOP and CCT among the 25 black participants, but not among the large number of black participants. This finding is not likely due to age differences, as the mean ages for black and white participants were 64.2 years and 64.8 years, respectively. Additionally, glaucoma status is not a likely explanation, as the lack of association between CCT and IOP in black participants remained after omitting individuals with OAG. Potential differences may be related to higher mean IOP levels in the black population, as well as a high prevalence of diabetes. Although several correction factors have been recommended to rectify the influence of IOP on CCT, in other populations, these do not appear to be necessary in the black BES population, since CCT was unrelated to IOP. Thus, IOP measurements are not likely influenced by CCT.
Several studies have found that persons with glaucoma and controls had significantly thinner corneas than individuals with ocular hypertension.3,6,11 Thus, persons with OAG had mean CCT measurements ranging from 7 µm to 21.5 µm less than controls, while ocular hypertensive patients had thicker corneas, ranging from 16 to 43 µm greater than those found in controls. La Rosa et al reported a slightly higher (but nonsignificant) average CCT among 83 white participants with OAG (558.7 µm) as compared with controls (535.9 µm), and a significantly higher mean corneal thickness among those with ocular hypertension (574.5 µm). All of the preceding results, however, are based on predominantly white populations, as the data for black populations are limited. As far as we know, La Rosa et al have the only report to date concerning the relationship between diagnosis and CCT among individuals of African descent. The authors corroborate the presence of thinner corneas among 29 African Americans with OAG (529.5 µm) compared with 26 African American controls (533.8 µm); however, the study did not include for comparison any black participants with ocular hypertension. Results based on 1064 black BES participants support the findings that individuals with OAG (mean, 520.6 µm) have thinner corneas than controls (mean, 530.0 µm), as well as those with a diagnosis of ocular hypertension (mean, 533.2 µm).

Although IOP and glaucoma diagnosis status have attracted the most attention regarding a possible relationship with CCT, several other factors have been identified in recent years as being associated with corneal thickness. Most recently, results from the OHTS indicate that thinner CCT significantly predicted the development of OAG in multivariate analyses.32

AGE, DIABETES, AND REFRACTIVE ERROR

There have been inconsistent findings concerning the relationship between age and CCT. Some studies report no significant association,10,17,30,31 whereas the BES and others found a definite inverse relationship.1,4,5

Diabetes is highly prevalent in the BES, and individuals with a history of diabetes were found to have thicker corneas (P = 03) in this population (Table 3). This result is consistent with findings from the OHTS and is supported by the fact that changes in corneal endothelium have been documented in persons with early diabetes.5

The number of studies investigating the relationship between refraction and CCT are limited, and the findings have been inconsistent. Cho et al found no significant correlation in a study including 151 Hong Kong Chinese participants between 10 and 60 years of age. On the contrary, refraction (spherical equivalent) was independently associated with CCT (P = .001) in the OHTS, but not maintained in the multivariate mixed model.3 Alsibirk et al reported a significant association between refraction and CCT among 325 Greenland Eskimos 15 years of age and older, and Tanaka et al found that 46 highly myopic eyes (−9.0 to −25.5 diopters) in a Brazilian population had thinner corneas than 90 control eyes classified as low ametropic (−3 to +3.2 diopters). The ages of the participants were not specified in that study. Findings from the BES are based on individuals 50 years of age and older and are consistent with those reported by Alsibirk et al and Tanaka et al. Refractive error was positively correlated with CCT such that those with more negative spherical equivalents had significantly thinner corneas than those with less negative or more positive refractive errors (Table 3).

Although there appeared to be a modest, positive correlation between CCT and IOP among the study’s white participants, no association was found among individuals of African descent. Black participants in the BES tended to have thinner corneas and higher intraocular pressure than their white counterparts. Factors such as younger age, a history of diabetes, and more positive refractive errors were found to be associated with thicker corneas among persons of African descent. While Barbados’ black participants are known to have higher IOP than other populations, central corneal thickness is an unlikely explanation for such a finding. Likewise, there is no clear rationale for using CCT data to correct the IOP measurements of these individuals.

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A look at the past . . .

Hess has studied experimentally the subjective light sensations occurring with sneezing, hard pressing, and the like. The sensations are readily produced by bending the head forward and making an expiratory effort with mouth and nose closed. Moderate pressure upon the eyes with the hands sufficed to prevent the appearance of the sensations.