Age and Racial Variation in Central Corneal Thickness of Preschool and School-aged Children

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ABSTRACT

**Purpose:** The purpose of this study was to determine variations in central corneal thickness (CCT) of preschool and school-aged African American and white children. Secondary aims were to assess possible correlations between CCT measurements and gender, axial length, intraocular pressure (IOP), family history of glaucoma, or history of prematurity.

**Methods:** Contact ultrasound was used to measure CCT and axial length in 76 white and 60 African American children between the ages of 7 months and 18 years. A questionnaire was completed by the parents or guardians, including medical and family history. Statistically significant associations and differences were assessed using the independent t test, analysis of variance, and linear regression. All associations were defined as significant when the alpha value was less than 0.05 (two-tailed).

**Results:** Mean CCT was thinner in African American children (535 ± 35 µm) compared to white children (559 ± 38 µm) ($P < .001$). The corneal thickness in children ages 10 to 18 years was significantly higher than in all other age groups in both African American ($P = .03$) and white ($P < .005$) children. No association was found between CCT and gender, axial length, IOP, or family history of glaucoma. Premature children had thinner CCT (536 ± 40 µm) than full-term children (552 ± 38 µm) ($P = .009$).

**Conclusions:** African American children have a thinner CCT compared to white children at all ages. Children of both racial groups have an increasing value of CCT with increasing age after approximately age 10 years. Children born prematurely have a thinner CCT than full-term children.

INTRODUCTION

Several recent studies have focused on how central corneal thickness (CCT) affects intraocular pressure (IOP) measurements and subsequent diagnosis and management of glaucoma in adults. Some researchers believe that a thin CCT leads to an underestimate of IOP and may delay the diagnosis of glaucoma. As a result, many clinicians have used the reported effect of CCT on measured IOP with the goal of obtaining a better estimate of actual IOP. Other researchers hypothesize that a thinner CCT is a surrogate marker for an abnormal sclera or...
laminar thickness, which may predispose for glaucomatous damage.\textsuperscript{10}

There have been several studies of CCT in children.\textsuperscript{11-18} Racial variations, change of mean thickness with age, and relation to IOP remain poorly understood. To our knowledge, no study has examined a large number of African American children and provided statistical data of CCT in children younger than 5 years segregated by race.

The purpose of this study was to determine age variations in the CCT of preschool and school-aged African American and white children. Secondary aims were to assess possible correlations between CCT measurements and gender, axial length, intraocular pressure, family history of glaucoma, or history of prematurity.

\textbf{PATIENTS AND METHODS}

The CCT of African American and white children from age 0 months to 18 years was prospectively studied. Age groups were defined as younger than 2 years of age, 2 to 4 years of age, 5 to 9 years of age, and 10 to 18 years of age to allow results to be compared with previous pediatric studies on CCT.\textsuperscript{11-13,17} Both Institutional Review Board approval and informed consent were obtained. Patients were recruited from the pediatric ophthalmology clinic and from children undergoing same-day surgery for ocular and non-ocular indications. Exclusion criteria included prior intraocular surgery, ocular trauma, contact lens use within the past week, any abnormal intraocular health, and documented interracial history.

Contact ultrasound (Nidek US-1800; Nidek, Fremont, CA) (ultrasound speed of 1,640 meters/second) was used to obtain 3 to 10 CCT measurements and axial length measurements on 137 children. IOP was measured by Tono-Pen (Reichert, Inc., Depew, NY). Measurements were made immediately after induction of anesthesia in the operating room or after 1 drop of 0.5\% proparacaine ophthalmic solution in the clinic. Parents completed a questionnaire regarding age, race, medical history, birth history, and family history of glaucoma (parents, siblings, grandparents, uncles, and aunts). Charts were reviewed for medical and ocular history.

The lowest pachymetry value was chosen for analysis because this likely represents the most central and direct path through the cornea. This method was also chosen to allow for comparison with previous pediatric studies on CCT.\textsuperscript{11} Right and left eyes were included in analysis. Subject characteristics were assessed using frequencies (\%) and measures of central tendency and variability (standard deviation).

The independent samples \textit{t} test was used to determine whether statistically significant differences in CCT measurements were evident between gender, racial groups, family history of glaucoma, and history of prematurity. Analysis of variance was used to identify whether significant differences existed in CCT measurements between four age groups of preschool and school-age subjects. The linear association between axial length and IOP with CCT was assessed using the Pearson correlation coefficient. A loess smoothed curve was used to demonstrate the pattern of CCT thickness with age. Nonparametric alternatives were used when assumptions for parametric methods were violated. All analyses were defined as statistically significant when the alpha value was less than 0.05 (two-tailed). SPSS version 11.5 software (SPSS, Inc., Chicago, IL) was used for all analyses.

\textbf{RESULTS}

One-hundred thirty-five patients and 269 eyes were included in the study. The average age of patients was 7 years (range: 7 months to 18 years). The study included 71 males (53\%) and 64 females (47\%). Seventy-six (56\%) children were white and 59 (44\%) were African American (Table). Three eyes were excluded from the study, two for a history of glaucoma and one for a history of intraocular surgery.

Mean CCT in all eyes and all patient groups was 549 ± 39 µm in both the right and left eyes. Mean CCT for males was slightly higher than for females, but not significantly ($P = .21$) (Table). White children in all age groups had a greater mean CCT compared with African American children. CCT in white children aged 10 to 18 years was significantly greater than in white children in all other age groups (Fig. 1). A similar finding was noted among African American children aged 10 to 18 years compared with children younger than 2 years.

A positive association between age and CCT is illustrated in Figure 2. The loess curve, illustrating the mean CCT per age in months, remains generally stable in both races before age 10 years (120 months). After approximately age 10 years, the thickness of the cornea increases with age. The increase in CCT
measurements with increasing age is slightly greater for white children compared to the increase in CCT with the same increase in age of African American children when viewing the loess curve.

As would be expected, significant variability was found in axial length depending on the age and refractive error of the child. Controlling for age, no correlation between axial length and mean CCT was found (R = 0.23, Pearson correlation coefficient).

Average IOP was the same among white (15 ± 4 mm Hg) and African American (16 ± 4 mm Hg) children (P = .09). No statistically significant relationship was found between mean CCT and IOP in white (R = 0.18, Pearson correlation) or African American (R = 0.24) children.

Thirty-five percent of children had a positive family history of glaucoma, whereas 65% denied a family history of glaucoma (Table). No significant difference in IOP was found between a positive (14.4 ± 4.3 μm) or negative (15.5 ± 3.4 μm) family history of glaucoma (P = .10). No statistical difference was found when race was an independent variable.

One hundred six children were born full-term and 23 were born prematurely. Mean CCT was statistically greater in full-term children than in premature children (Table). When divided into age groups, the mean CCT in full-term children was 540 ± 34 μm for those younger than 2 years, 568 ± 39 μm for those 2 to 4 years, 540 ± 22 μm for those 5 to 9 years, and 559 ± 43 μm for those 10 to 18 years. Mean CCT in premature children was 530 ± 26 μm for those younger than 2 years, 513 ± 20 μm for those 2 to 4 years, 518 ± 36 μm for those 5 to 9 years, and 568 ± 37 μm for those 10 to 18 years.

**DISCUSSION**

Recent studies have focused on how CCT affects diagnosis and management of glaucoma.1-8 A thin CCT may lead to an underestimate of IOP.
and could potentially delay the diagnosis of glaucoma. Other researchers hypothesize that CCT is a surrogate marker for an abnormal sclera or laminar thickness and possibly an independent marker for glaucoma. Although the exact relation of CCT to glaucoma is not fully understood, it is clear that variations in CCT in adults have been found among different racial groups. Corneas of African American adults are thinner than those of whites, Latinos, or Chinese, with no significant difference between the latter groups, but data are limited.

Prospective studies of children with significant power to analyze differences among subpopulations of race are few. Two recent articles compared CCT with racial variation in children, but had insufficient numbers of patients to be statistically significant. However, Dai and Gunderson found that corneas of African American children were thinner (523 ± 40 µm) than those of white children (563 ± 36 µm) (P < .001). Although statistically significant, their study only included 23 African American children, with the overwhelming majority being older than 5 years. More recently, Muir et al. showed that 35 African American children had a lower mean CCT (543 ± 37 µm) compared to white children (562 ± 35 µm) (P = .0002). Our study confirmed those results, noting that the mean CCT in African American preschool and school-aged children (535 ± 35 µm) was significantly less than that of white children (559 ± 38 µm) (P < .001). This difference supports the theory that there may be a structural difference between the two racial groups.

The relationship of CCT to increasing age is still incompletely understood. Several studies have found a thinner mean CCT with increasing age among non-white adults. Other studies have also found no decline in CCT with increasing age among white adults. Although this relationship appears to be divided along racial lines, Muir et al. has been the only statistically significant prospective study of CCT in children segregated by race (African American and white.). However, their study did not include analysis of CCT with age. To our knowledge, no other study has examined the CCT of African American and white children with respect to age.

Ehlers et al. were the first to study the relationship of mean CCT in children with increasing age. They evaluated 61 northern European children in five age groups (premature infants, full-term infants, and children 2 to 4 years, 5 to 9 years, and 10 to 14 years). Their results showed CCT measurements in both premature and full-term infants to be approximately 550 µm. All other age groups had CCT measurements of approximately 520 µm, suggesting stability of CCT in children older than 2 to 4 years. Of note, pachymetry measurements were obtained optically and are now known to produce a lower value than those obtained by contact ultrasound.

Hussein et al. found mean CCT values to increase with increasing age, reaching adult thickness at age 5 to 9 years. This study averaged all racial groups in its analysis, with nearly 88% of patients being white or Hispanic. Muir et al. found no increase in CCT during a 1- to 2-year period in children between the ages of 3 and 14 years. Their study included children with aniridia, aphakia, pseudoph-
kia, and cataracts. Nearly 60% were white. These results may represent a different population of patients compared with children without intraocular disease. A subsequent study by Muir et al. found no relationship between CCT and age in healthy children, but the exact data were not shown.\(^{18}\)

In the current study, mean CCT increased from all age groups younger than 10 years to 10 to 18 years in white children \((P < .001)\), whereas that of African Americans children increased from younger than 2 years to 10 to 18 years \((P < .013)\). However, there is a decrease in mean CCT between the 2 to 4 years and 5 to 9 years age groups. Because this could represent a grouping error, the CCT of children was compared directly to their age (Fig. 2). The loess curve (best-fit curve) remained stable in both white and African American children until approximately age 10 years, at which time CCT progressively increased with age. White children appear to have a greater increase in CCT with increasing age compared with the loess curve in African American children. Although there is a large amount of variability seen with individual CCT values, this trend of increasing thickening of mean CCT approaching the age of 18 years has not been previously reported.

This is also suggested when noting that the mean CCT in the 10 to 18 years age group in both African American and white children is closer in value to that found in the Ocular Hypertension Treatment Study trial \((\text{African American} = 555.7 \pm 40 \text{ µm}, \text{white} = 579 \pm 37 \text{ µm})\) than the overall mean CCT for all age groups. Although this could be affected by sampling size and sampling error, it does question prior results of stabilization during the 2 to 4 years or 5 to 9 years age groups. Further, we anticipate that the CCT of whites will plateau at some age because two studies suggest stability of CCT in white adults with age.\(^{9,25}\) African Americans also demonstrate an increase in thickness of CCT approaching the age of 18 years, but at a much slower rate.

Several recent studies have suggested a decrease in CCT with increasing age once adulthood is reached.\(^{11,13,14,20-22}\) This difference in the pattern of CCT with age of healthy children may support the theory that African Americans have a structural difference that leads to an increased risk for the development of glaucoma. We recommend a study with more power to further identify the association of CCT with increasing age.

Although there is no clear agreement in the literature regarding mean CCT differences between adult males and females, Dai and Gunderson found no significant difference in male and female children.\(^{15}\) Our study also found equivocal differences between males and females, although both studies may be underpowered to determine any difference.

Patients with myopia are at an increased risk for the development of glaucoma compared with non-myopic patients.\(^{26}\) Myopic eyes are generally longer eyes with a thinner posterior sclera. Some believe this may make myopic eyes more susceptible to damage from increased IOP. Several studies have compared CCT to axial length. Although at least one study found a positive correlation,\(^{19}\) other studies have not found this relationship.\(^{10,27}\) Our study compared CCT with the axial length of each eye. No relationship was found using the Pearson correlation \((R = 0.23)\).

Many studies have defined a relationship between IOP and CCT in adults.\(^{9}\) Two studies have found a relationship in children. Muir et al. evaluated 53 children (normal controls and patients with ocular hypertension) and found that IOP increased with increasing CCT.\(^{12}\) A second study of healthy controls found that for every 100-µm increase in CCT, there was a 2.2 ± 0.6 mm Hg in IOP.\(^{18}\) We did not find a correlation between IOP and CCT. It might be that there is not enough variation in normal IOP among our population of healthy preschool children to establish a correlation. All children in our study had IOP obtained by the use of a Tono-Pen to maintain consistency. This may introduce some error because applanation is the gold standard. Furthermore, many children had the IOP taken after induction of anesthesia. This may introduce enough error to negate any comparison to CCT.

CCT has been found to be related to a history of glaucoma in adults. Patients with normal tension glaucoma have thinner CCT than controls despite having normal IOP measurements.\(^{28-31}\) Also, patients with ocular hypertension have thicker CCT values when compared to controls.\(^{29,32-35}\) With children, it is unknown whether CCT is related to family history of glaucoma. In our study, there was no difference in the CCT of children with or without a family history of glaucoma. This was unchanged when race was an independent factor (Table). These findings are limited by the self-reported nature of the data. Further analysis suggests that more pa-
tients would be needed to produce enough power to suggest a correlation.

An unexpected finding was the lower value of CCT in children who were premature compared to children who were full term. This difference was not seen in the Ehlers et al. study.\textsuperscript{16} The strength of this relationship may be limited by the low number of children who were premature included in our study and the self-reported nature of the data. Further, CCT values in the premature groups may be biased by the majority of children in this category being African American, who are already thought to have lower CCT measurements. Still, this finding conflicts with the results reported by Ehlers et al. in which there was no difference in the mean CCT in premature and full-term children. Further study with greater power is necessary.

One limitation to this study is the inclusion of an African American child with Down syndrome. Previous reports have suggested that children with Down syndrome have thinner CCT than the normal control population.\textsuperscript{36} Although this could potentially decrease the mean, we did not believe this significantly altered the data because this child had CCT values of 513 and 515 µm in the right and left eye, respectively, both within the 95% confidence interval of the child’s age and ethnic group.

An additional limitation was failing to record the time the child had been awake before measuring the CCT and IOP. Hamilton et al. recently determined that the CCT and IOP of healthy adults significantly decreased during the first 2 hours the participants were awake.\textsuperscript{37} Although other reports have found little variation in diurnal IOP and CCT variation, these studies did not include multiple data points during the first 2 waking hours.\textsuperscript{38,39} It is unknown what impact this had on our data because most younger children were examined in the operating room in the early waking hours.

Our study confirms that the mean CCT of white children is thicker than the mean CCT of African American preschool and school-aged children. This finding supports the idea that a structural difference exists between African American and white eyes. This study questions the conventional wisdom that the cornea reaches its adult thickness between the ages of 2 and 4 years or 5 and 9 years.\textsuperscript{11,16} When comparing CCT to individual age, there is suggestion of increasing CCT values with increasing age after age 10 years. Our findings also suggest that children who are born prematurely have thinner CCT than children who are full term. Additional studies are needed to further define associations between CCT and age, history of prematurity, and family history of glaucoma. This will help define the natural history of CCT with age for both whites and African Americans.

**REFERENCES**

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