Lens Thickness Changes among Schoolchildren in Taiwan

Yung-Feng Shih, Ting-Hsuan Chiang, and Luke L.-K. Lin

PURPOSE. To explore the possible influence of ocular growth, refractive error and age on the crystalline lens in school-age children.

METHODS. A Taiwan nationwide survey of myopia performed in 2006 was used to determine the prevalence and severity of myopia and the changes in ocular components. A total of 11,656 students were enrolled, including 5,390 boys and 6,266 girls, with ages ranging from 7 to 18 years. Refractive status was measured with an autorefractometer with the subject under cycloplegia. Lens thickness, anterior chamber depth, and axial length were measured with biometric ultrasound.

RESULTS. Data revealed that the crystalline lens became thinner between the ages of 7 and 11. Subsequent increases in the lens thickness correlated with age and the stability of myopia. This phenomenon was found not only in myopic eyes, but also in emmetropic and hyperopic eyes. The changes in anterior chamber depth inversely correlated with the changes in the lens. In school-age children, the ratio of lens/axial length was found to be significant: ~0.147 in the emmetropic group. However the ratio was seen to increase with age. The ratio of anterior segment/axial length was found to be approximately 0.3 in emmetropic eyes among all age groups and less than 0.3 in the myopic eyes of schoolchildren.

CONCLUSIONS. Lens thinning appeared to be compensatory in nature with respect to the increased axial length of normal eye growth. Myopic eye growth induces the lens to compensate by becoming much thinner. The change in anterior chamber depth corresponded inversely with lens thickness. (Invest Ophtalmol Vis Sci. 2009;50:2637–2644) DOI:10.1167/iovs.08-3090

The cause of myopia is complex and remains obscure. The failure of clear visual input may result in a disturbance of emmetropization, leading to an abnormal elongation of the eyeball and myopia.1–5 In a previous study,6–9 we showed that emmetropization, leading to an abnormal elongation of the axial length closely corresponds with ocular refraction. We found to be significant: ~0.147 in the emmetropic group. However the ratio was seen to increase with age. Therefore, it is interesting and necessary to understand the meaning of these ocular component changes during ocular development.

Myopia can be induced by a hyperopic retinal defocus, due to inaccurate accommodation,10 lag of near accommodation,11 or transient myopia after sustained near vision.12 We know that the human crystalline lens accounts for almost 20% of ocular refractive power and plays an important role in accommodation. During accommodation, the lens diameter increases forward by 0.3 mm, and the posterior pole moves backward less than 0.1 mm. Lens central thickness increased by approximately 0.5 mm, and equatorial diameter decreased by 0.4 mm.13 If excess accommodation was one of the causes of myopia, LT should increase during myopic development. However, every diopter of excess accommodation produced only a 0.06-mm increase in LT. In addition, a reduced accommodative response has been found in myopia and progressing myopia.14 Myopic subjects are worse at detecting retinal defocus,15 thereby resulting in a less accurate accommodative response. Animal studies have shown that hyperopic retinal defocus can lead to the development of axial myopia.1–5 Thus, it is unclear whether lens thinning induces hyperopic retinal defocus followed by myopia production, or whether myopia production and progression cause the lens to become progressively thinner. The purpose of this study was to assess the role of crystalline lens changes influenced by ocular refraction, ocular growth, and age. We hoped to elucidate potential mechanisms of myopic pathogenesis by understanding the changes in ocular components during the ages at which myopia develops.

MATERIALS AND METHODS

This study used a nationwide survey of myopia performed in Taiwan in 2006. The survey was first stratified based on a grading of the developmental status of cities and then sampled with a probability proportional to their population size. The details of the methods were similar to those of the surveys of 19956 and 2000.7 The total population for the regions surveyed in this study included nearly 4 million schoolchildren in elementary, junior high, and senior high schools in Taiwan. In total, 11,656 students were enrolled, including 5,390 boys and 6,266 girls with ages ranging from 7 to 18 years. The data used for analysis included ocular refraction and biometric LT, anterior chamber depth (ACD), and axial length (AL) in the right eye (Table 1). The refractive error (REF) with cycloplegia and corneal curvature (K) were checked with an automated refractometer (RK-3000; Topcon, Tokyo, Japan) given in a spherical equivalent: spherical + 1⁄2 × signed cylindrical REF.

The definition of hyperopia was ≥ +0.5 D, emmetropia was between +0.25 and −0.25 D, and myopia was < −0.25 D. The biometric AL (including ACD, LT, and total AL) was measured by A-scan ultrasonography (model A-1500; Sonomed, Lake Success, NY). Three measurements were recorded for each procedure, and the mean ± SD was calculated from the three separate measurements.

Informed consent was obtained from the schoolchildren and their guardians, and the protocol adhered to the Declaration of Helsinki. The

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Supported by the Bureau of Health Promotion, Department of Health, Executive Yuan, Republic of China (Taiwan); and Grant DOH95-HP-1315 for Epidemiology Studies of the Refractive Status among 6- to 18-year-old Schoolchildren in Taiwan.

Submitted for publication October 31, 2008; revised December 11, 2008, and January 5, 2009; accepted April 17, 2009.

Disclosure: Y.-F. Shih, None; T.-H. Chiang, None; L.-K. Lin, None

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thus the severity of myopia increased in 2006 (Fig. 2B) gradually increased with age from 8 to 12 years, and lower after the age of 13 in 2006 (Fig. 1). AL (Fig. 2A) and ACD (Fig. 2C) showed a decrease with age from 7 to 11 and then remained stable. At the ages of 7 to 11, LT decreased very quickly from the age of 7 to 11 in myopic and emmetropic eyes. However, when we examined LT in different age groups, we found that LT decreased very quickly from the age of 7 to 11 in myopic and emmetropic eyes (Fig. 4).

The correlations between LT, age, K, ACD, AL, and REF were assessed by Pearson correlation. We found that LT significantly increased with age (r = 0.03, P < 0.0001) and REF (r = 0.202, P < 0.0001), but decreased with ACD (r = 0.164, P < 0.0001), AL (r = 0.052, P < 0.0001) and REF increased (r = 0.006, P < 0.0001) between ages 7 and 12. Then, if we separated the data into two age groups—7 to 11 and 12 to 18—LT showed a significant decrease with age (r = -0.17, P < 0.0001), AL (r = -0.17, P < 0.0001) and REF increased (r = 0.006, P < 0.0001) between ages 7 and 11, LT significantly increased with age (r = 0.202, P < 0.0001) and decreased with ACD (r = -0.358, P < 0.0001) and AL (r = -0.052, P < 0.0001) between the ages of 12 and 18. However, it does not correlate significantly with REF (r = 0.006, P < 0.0001).

The probabilities are significant, but the correlation coefficients are quite low. We thought this may be due to very small changes in LT and a large variance in REF. Therefore, we divided the ocular refraction into three groups: hyperopia (≥ +0.5 D), emmetropia (+0.25 to −0.25 D), and myopia (< −0.25 D). No significant difference in K was found among the three groups (Fig. 3A), but myopic eyes had deeper ACDs than did emmetropic and hyperopic eyes in all age groups (P < 0.001). All three groups showed increased ACD from the ages of 7 to 11 and then remained relatively stable. Myopic and emmetropic eyes showed more prominent changes than did hyperopic eyes (Fig. 3B; P < 0.001). LT in all three groups decreased from the ages of 7 to 11, but subsequently increased with age (Fig. 3C). LT in myopic eyes was found to be the least of the three groups (P < 0.001). The change in LT in hyperopic eyes was relatively smaller than in myopic or emmetropic eyes. AL in the myopia group showed a prominent increase with age from age 7 to 18. However, hyperopic and emmetropic eyes showed only slight increases in AL with age (Fig. 3D).

Most of the myopic groups showed a decrease in LT from the ages of 7 to 11, but a subsequent increase with age (Fig. 4). However, when we examined the changes in highly myopic (< −6.0 D) and moderately hyperopic (> +3.0 D) eyes, we found that LT decreased very quickly from the age of 7 to 11 in the latter, whereas the former showed continuous thickening of the lens from the age of 7 onward (Fig. 5).

When we examined LT in different age groups, we found that 18-year-olds had thicker lenses than the younger children had (P < 0.001), with no significant difference in LT between myopic refraction groups. At the age of 15, LT decreased from hyperopic refraction to emmetropia, and subsequently remained stable. At the ages of 8 and 12, LT decreased from
hyperopic refraction to emmetropia, and then continuously decreased with myopic refraction (Fig. 6). LT in hyperopic eyes was greater than in emmetropic eyes in these four age groups. According to the passive emmetropization model, these slopes should depend on how quickly hyperopia decreased. Younger age groups had a more rapidly decreasing slope from hyperopia to emmetropia than to myopia. However, the lenses were thinner in younger age groups. LT increased with age after the age of 12. We tested major ocular components and age on LT by regression analysis, and we found LT significantly decreased with age from age of 7 to 11 ($P < 0.0001$) and increased with age after 12 ($P < 0.0001$). Age was the most important factor for increasing LT.

Because a relationship was noted between ACD, LT, and AL, we examined the ratio of each ocular component to the AL, and the relationship of the ratio with ocular refraction and age. The mean ratio of ACD/AL did not significantly differ between myopic eyes and the other groups (Fig. 7A). However, the ratio of LT/AL appeared to be more stable with age in emmetropic and hyperopic eyes (Fig. 7B). Myopic eyes showed a decrease in the LT/AL ratio with age. The ratio was $<0.145$ in myopic eyes (Fig. 7B). In addition, the mean ratios of the anterior segment (ACD+LT)/AL among emmetropic and hyperopic eyes were very stable with age, but decreased with age in myopic eyes (Fig. 7C). The mean ratio of anterior segment/AL in myopic eyes was $<0.3$.

Table 2 shows the mean ocular component ratios for the different refractive groups. The mean ratio of LT/AL in schoolchildren was approximately 0.147 in the emmetropic group, 0.152 in the hyperopic group, and 0.139 in the myopic group, and the mean ratio of ACD/AL in schoolchildren was approximately 0.1537 in the emmetropic group, 0.1542 in the hyperopic group, and 0.152 in the myopic group. Still, the mean anterior segment/AL ratio was approximately 0.3 in the emmetropic group and 0.292 in the myopic group. We found that all ratios were highest in hyperopic eyes and lowest in myopic eyes. The mean ratio of LT/AL in emmetropic eyes was 0.147 and ACD/AL was 0.153 in emmetropic eyes for schoolchildren. We also compared the emmetropic eye data of adults with data of younger schoolchildren. We found the LT/AL ratio increased with age, whereas the ACD/AL ratio decreased with age (Table 3). However, the anterior segment/AL ratio was constant with age ($-0.3$; Table 4).

**DISCUSSION**

In our review of the previous three nationwide myopia surveys (1995, 2000, and 2006), we found that the mean prevalence of...
myopia increased from 1995 to 2000, was similar between 2000 and 2006, and was lower after the age of 13 in 2006. All our studies of the myopia survey showed similar results: AL increased with age and myopia and ACD increased from the age of 7 to 11 and then remained relatively stable after the age of 12. In contrast, mean LT decreased from the ages of 7 to 11, but increased with age after 12. Therefore, we analyzed the data of girls only (right eyes) in 2006 in this study.

In this study, we found that these changes in ACD and LT occurred not only in myopic but also in emmetropic and hyperopic eyes. Myopic eyes had deeper ACD than did emmetropic and hyperopic eyes. All three groups showed increased ACD from the ages of 7 to 11 and then remained relatively stable. LT of all three groups decreased from the ages of 7 to 11, and subsequently increased with age. Both myopia and emmetropia showed more prominent changes than hyperopia. LT of myopic eyes was found to be the least of the three groups. We believe that this thinning of the lens is compensatory with respect to increasing AL during normal eye development. The lens is a major optical component that compensates for axial elongation. In persons with emmetropia, the lens reduces in thickness and power to increase the focal length, in concert with increasing AL. This is supported by a longitudinal study by Zadnik et al. who showed evidence of crystalline lens thinning in children and proposed a passive mechanism of coordinated ocular growth. The ocular axis elongates with the thinning of the lens and the flattening of the cornea, which leads to emmetropia in children between the ages of 8 and 10 years. However, Mutti et al. suggested that the thinning and flattening of the crystalline lens is mechanically induced by the equatorial growth of the eye during childhood.

In our study, LT in myopic eyes was found to be the least of the three groups. Most of the myopic groups showed lens

**Figure 3.** Mean of ocular components of hyperopic (≥ +0.5 D), emmetropic (+0.25 to −0.25 D), and myopic (< −0.25 D) eyes in 2006. (A) No significant difference was found in mean K among the three groups. (B) Myopic eyes showed a deeper mean ACD than did emmetropic and hyperopic eyes. (C) Myopic eyes showed the least mean LT of the three groups. (D) Myopic eyes had the longest mean AL.
FIGURE 4. The mean LT among in each myopic refraction group showed decreased LT from age of 7 to 11, and subsequently increased with age.

FIGURE 5. LT in highly myopic eyes (< -6.0 D) increased with age and in moderately hyperopic eyes (> +3.0 D), decreased very quickly from age of 7 to 11, and then increased from 12 onward.
thinning from the ages of 7 to 11, followed by thickening with age, and no obvious difference was found between myopic groups. In persons with myopia who have excess axial elongation, the lens decreases its power and thickness further to compensate. In contrast, highly myopic (< -6.0 D) and moderately hyperopic (> +3.0 D) eyes showed a different pattern. We found lens thinning from the ages of 7 to 11 among moderately hyperopic eyes, whereas highly myopic eyes showed thickening from the age of 7 onward. The thickening of the lens in highly myopic eyes may be due to the few cases of high myopia found in younger children. In addition, the etiology or mechanism of neonatal high myopia may be different from that of school-age myopia.18

We also found that 18-year-olds had greater LT than younger children and that there was no significant difference in LT between the myopic refraction groups. LT in hyperopic eyes was greater than that in emmetropic or myopic eyes in each age group. However, hyperopic eye lenses at the age of 18 were thinner than average. This difference may also have been caused by the few cases of highly hyperopic eyes found in older children. At the age of 15, LT decreased from hyperopic refraction to emmetropia, and then remained stable. At the ages of 8 and 12, LT decreased from hyperopic refraction to emmetropia, and then continuously decreased with the myopic refraction. According to the passive emmetropization model, these slopes should depend on how quickly hyperopia decreased. Younger age groups have a more rapidly decreasing slope than older age from hyperopia to emmetropia to myopia. LT increased with age after 12. Age was the most important factor for increasing LT.

Moreover, lenses in hyperopic eyes were thicker than those in emmetropic or myopic eyes in each age group. However, myopic eyes had the thinnest lenses in all age groups. We believe that the lens becomes thinner as a process of normal eye growth between the ages of 7 to 11, to compensate for the increased AL in all eyes. Zadnik et al.19 found that upward trends of AL, ACD, and vitreous chamber depth in emmetropic schoolchildren reflected the continued growth of the eye from the ages of 6 to 15 years. In our study, myopic eyes went through more axial elongation during the ages of 7 to 11 (not only normal eye growth but also myopic eye growth), and the lens continuously thinned to compensate for the myopic elongated AL. Therefore, myopia was associated with the greatest lens thinning. After the age of 12, normal eye growth appeared to slow. Subsequently, LT began to increase with age. The longitudinal changes in LT observed in the COMET study (Norton TT, et al. IOVS 2008;49:ARVO E-Abstract 2603) also suggest that the lens may thin during the rapid progression of myopia and then thicken, with some variation by age, as the progression begins to slow. We also noted that the change in ACD correlated inversely with the changes in the lens. Myopic eyes had deeper ACDs than emmetropic and hyperopic eyes. In contrast, LT in myopic eyes was found to be the least of the three groups.

A major question that requires further exploration is how to predict the onset and progression of myopia.20 Axial length/corneal radius ratios have been shown to be approximately 3.0 in persons with emmetropia and significantly greater than 3.0 in persons with myopia.21 Mutti et al.22 have suggested that the difference in the rates of change of axial and lenticular components may act as longitudinal predictors of the onset of myopia. In our study, we found that the mean ratio of LT/AL in schoolchildren was approximately 0.147 in the emmetropic group, 0.152 in the hyperopic group, and 0.139 for the myopic group. And, the mean

![Figure 6](http://iovs.arvojournals.org/pdfaccess.ashx?url=/data/journals/iovs/932960/)
The ratio of ACD/AL in schoolchildren was approximately 0.1537 in the emmetropic group, 0.1542 in the hyperopic group, and 0.152 in the myopic group. Meanwhile, the mean ratio of anterior segment/AL was approximately 0.3 in the emmetropic group. Therefore, it appears that the ACD varied inversely with LT to maintain the ratio of anterior segment to AL. Besides, we noted that the LT/AL ratio increased with age, whereas the ACD/AL ratio decreased with age in adult eyes. At the same time, the anterior segment/AL ratio

Table 2. Mean Ocular Component Ratios

<table>
<thead>
<tr>
<th></th>
<th>Hyperopia</th>
<th>Emmetropia</th>
<th>Myopia</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACD/AL</td>
<td>0.1542</td>
<td>0.1537</td>
<td>0.152</td>
</tr>
<tr>
<td>LT/AL</td>
<td>0.152</td>
<td>0.147</td>
<td>0.139</td>
</tr>
<tr>
<td>Anterior Seg/AL</td>
<td>0.305</td>
<td>0.301</td>
<td>0.292</td>
</tr>
</tbody>
</table>

Age range, 7–18 years.

Table 3. Ratios in Emmetropic Eyes in the Different Age Groups

<table>
<thead>
<tr>
<th>Age Range (y)</th>
<th>LT/AL Ratio</th>
<th>ACD/AL Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Male</td>
<td>Female</td>
</tr>
<tr>
<td>7–18</td>
<td>0.150</td>
<td>0.144</td>
</tr>
<tr>
<td>21–30</td>
<td>0.164</td>
<td>0.160</td>
</tr>
<tr>
<td>31–40</td>
<td>0.175</td>
<td>0.176</td>
</tr>
<tr>
<td>41–50</td>
<td>0.183</td>
<td>0.181</td>
</tr>
<tr>
<td>51–60</td>
<td>0.187</td>
<td>0.186</td>
</tr>
<tr>
<td>61–70</td>
<td>0.191</td>
<td>0.198</td>
</tr>
<tr>
<td>Average</td>
<td>0.177</td>
<td>0.179</td>
</tr>
</tbody>
</table>

Data for the age ranges above 18 years were borrowed from Shih et al.9
remained approximately 0.3 in emmetropic eyes among all age groups. In addition, a LT/AL ratio less than 0.147 or an anterior segment/AL less than 0.3 may serve as predictive factors for myopia. When LT/AL < 0.147 was used to test the refractive status of right eyes among all students, the detection rate of myopia is 77.7%. If the anterior segment/AL < 0.3 was used as a probe, myopia was found with a frequency of 71.8%. Whether these ratios may serve as predictive factors for myopia production or progression should be explored in further studies.

**References**


**TABLE 4.** The Mean Anterior Segment (LT/ACD)/AL Ratios in Emmetropic Eyes by Age Group

<table>
<thead>
<tr>
<th>Age Range (y)</th>
<th>Male</th>
<th>Female</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>7–18</td>
<td>0.305</td>
<td>0.297</td>
<td>0.301</td>
</tr>
<tr>
<td>21–30</td>
<td>0.295</td>
<td>0.283</td>
<td>0.289</td>
</tr>
<tr>
<td>31–40</td>
<td>0.298</td>
<td>0.291</td>
<td>0.295</td>
</tr>
<tr>
<td>41–50</td>
<td>0.298</td>
<td>0.290</td>
<td>0.294</td>
</tr>
<tr>
<td>51–60</td>
<td>0.298</td>
<td>0.295</td>
<td>0.297</td>
</tr>
<tr>
<td>61–70</td>
<td>0.297</td>
<td>0.297</td>
<td>0.297</td>
</tr>
<tr>
<td>Average</td>
<td>0.297</td>
<td>0.295</td>
<td></td>
</tr>
</tbody>
</table>

Data for the age ranges above 18 years were borrowed from Shih et al.9