Transient Axial Length Change during the Accommodation Response in Young Adults

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PURPOSE. To measure the degree of transient axial elongation during the accommodation response in emmetropic and myopic young adults. To evaluate the effect of refractive error and accommodative demand on transient axial elongation of the eye.

METHODS. Axial length of the right eye was measured in 30 emmetropes and 30 myopes, by using the IOLMaster (Carl Zeiss Meditec, Inc., Dublin, CA), while accommodative stimuli of 0, 2, 4 and 6 D were presented with a Badal optometer.

RESULTS. Axial length increased in both emmetropic and myopic subjects during short periods of accommodative stimulation. Greater transient increases in axial length were observed in myopic than in emmetropic subjects. The mean axial elongation with a 6-D stimulus to accommodation was 0.037 mm in emmetropes and 0.058 mm in myopes (P = 0.02). The degree of transient axial elongation correlated well with the stimulus to accommodation in emmetropes and myopes. Anterior chamber depth decreased, on average, by 0.19 mm in emmetropes and 0.18 mm in myopes when observing a 6-D stimulus to accommodation.

CONCLUSIONS. During relatively short periods of accommodative stimulation, axial length increases in both emmetropic and myopic young adults. At higher levels of accommodative stimulation, a significantly greater transient increase in axial length is observed in myopic subjects than in their emmetropic counterparts. (*Invest Ophthalmol Vis Sci. 2006;47:1251–1254*

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The increase in the prevalence of myopia has fueled debate on the environmental based risk factors that may be involved in the development of this condition.1-2 Evidence has suggested that genetic influences play an important role in the development of juvenile-onset myopia.3-4 The factors that may contribute to the onset of myopia in young adults are less clear. Several studies have shown that intense near-work tasks, particularly those with high levels of cognitive demand, may lead to episodes of transient myopia5 and the development of permanent myopia.6 Although the exact combination of factors leading to the development of myopia is not certain, what is clear is that elongation of the vitreous chamber is the principal structural correlate of myopia in both children and adults.7,8

Partial coherence laser interferometry (PCI) has been developed in recent years, principally as a high-precision ocular biometric technique for use before cataract surgery and intraocular lens implantation.10 In axial length measurements, it can offer a level of precision of 0.01 mm. An order of magnitude increase in precision compared with A-scan ultrasonography. Stone et al.11 have used PCI to monitor small (~27 μm) diurnal fluctuations in axial length. A commercially available PCI instrument, the IOLMaster (Carl Zeiss Meditec, Inc., Dublin, CA), has been shown to produce valid and repeatable measurements of axial length and anterior chamber depth,11,12 and has great utility in studies of the relationship between refractive error and ocular biometry. Axial length measurements are given in millimeters, to a precision of 0.01 mm. Further advantages of this instrument are its noncontact method of operation, fast measurement time (approximately 1.5 seconds for axial length measurement), and facility for measurement of anterior chamber depth, which is obtained by image analysis of an optical section formed through the anterior segment of the eye at 38° from the visual axis and provides a measure of anterior chamber depth to a precision of 0.01 mm.12

Drexler et al.13 used PCI to investigate the effect of accommodation on axial length in emmetropic and myopic subjects. Transient increases in axial length were observed when the subjects fixated on a closed-loop accommodative target at a distance equivalent to their individual amplitude of accommodation (mean of 5.1 ± 1.2 D for the emmetropic group and 4.1 ± 2.0 D for the myopic group). The greatest elongation was observed in emmetropic eyes (mean, 12.7 μm), with myopic eyes elongating by a significantly smaller amount (mean, 5.2 μm). A further experiment in the emmetropic group showed a level of elongation smaller than that at the near point when a target at a distance of 33 cm was observed. The purpose of this study was to compare the extent of transient axial length elongation in a cohort of emmetropic and myopic young adult subjects, who are well matched in age and amplitude of accommodation. A further purpose of this work was to determine whether the incremental stages of transient elongation in emmetropic eyes as the accommodative demand is increased, as noted by Drexler et al.,13 are evident in myopic eyes.

METHODS

Sixty subjects were recruited from the undergraduate students at the Department of Optometry, University of Bradford. Subjects were screened to exclude those with a history of ocular and systemic diseases and refractive surgery. All investigations and measurements performed as part of this study adhered to the tenets of the Declaration of Helsinki. All subjects gave informed consent to take part after a full explanation of the nature and possible consequences of the study.

The refractive error of all subjects was measured under noncycloplegic conditions with a infrared autorefractor (average of three readings; model SRW-5000; Shin-Nippon, Tokyo, Japan).14 Subjects were classified into two groups according to their spectacle refraction: emmetropes had spherical equivalent refraction (SER) not exceeding 0.50 DS of myopia or hypermetropia, and astigmatism less than 0.50 DC; myopes had SER at least 2.00 DS of myopia and astigmatism < 0.50 DC. All myopic subjects were early-onset myopes, with myopic pro-
Accommodation was stimulated in the right eye for 20 seconds at four discrete levels (0, 2, 4, and 6 D) using a 90% contrast Maltese cross target that subtended 10 minutes of arc within a ±1.20 D Badal optometer, viewed through a 50/50 beamsplitter. The subject’s left eye was occluded during this section of the experiment. Figure 1 shows a schematic diagram of the fixation target and accommodative stimulation apparatus. Three axial length measurements of the right eye were made and averaged at each accommodation stimulus level. An index of the quality of axial length measurements is given by the IOLMaster in the form of a signal-to-noise ratio, which is determined by calculating the ratio between the highest peak in the PCI trace and the average of the baseline noise level. Axial length measurements with a signal-to-noise ratio of less than 2.0 were rejected and the measurement repeated. The accommodation stimulus levels were presented at random for each subject. Subjects observed an internally illuminated fixation target at 6 m for 2 minutes between accommodative stimulus levels to allow accommodation to relax. A pilot study showed that inclusion of the beamsplitter in the optical path of the IOLMaster did not have a significant effect on the validity or repeatability of axial length measurements. The Badal optometer was used to correct the refractive error of the myopic subjects, as well as to stimulate accommodation. Thus, the stimulus to accommodation was equivalent between all subjects in both refractive error groups. Ambient room illumination was extinguished during all measurements, to optimize the contrast of the Maltese cross target as seen via the beamsplitter. The accommodation response to the Badal stimulus was measured at all accommodative levels (i.e., 0, 2, 4, and 6 D) in a separate trial with an open-view infrared autorefractor (SRW-5000; Shin-Nippon). The anterior chamber depth of the right eye was measured with the IOLMaster, while accommodative stimuli of 0 and 6 D were presented to the left eye with the Badal optometer. Contralateral accommodative stimulation was needed for this measurement, as the beamsplitter caused an underestimation of anterior chamber depth reduction when the ipsilateral eye was stimulated. Contact lens–wearing subjects were asked to refrain from lens wear during the 24-hour period immediately preceding the measurements.

### Table 1. Dataset for Emmetropes and Myopes

<table>
<thead>
<tr>
<th></th>
<th>Emmetropes</th>
<th>Myopes</th>
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</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>21.4 ± 2.0</td>
<td>21.5 ± 2.1</td>
</tr>
<tr>
<td>Right eye SER (D)</td>
<td>−0.07 ± 0.23</td>
<td>−3.59 ± 0.75*</td>
</tr>
<tr>
<td>Amplitude of accommodation (D)</td>
<td>8.06 ± 1.26</td>
<td>8.33 ± 1.13</td>
</tr>
<tr>
<td>AL at 0 D accommodation (mm)</td>
<td>23.25 ± 0.66</td>
<td>25.39 ± 1.03*</td>
</tr>
<tr>
<td>AL change at 2 D accommodation (mm)</td>
<td>0.014 ± 0.019</td>
<td>0.019 ± 0.020</td>
</tr>
<tr>
<td>AL change at 4 D accommodation (mm)</td>
<td>0.026 ± 0.021</td>
<td>0.037 ± 0.026</td>
</tr>
<tr>
<td>AL change at 6 D accommodation (mm)</td>
<td>0.037 ± 0.027</td>
<td>0.058 ± 0.037*</td>
</tr>
<tr>
<td>ACD at 0 D accommodation (mm)</td>
<td>3.66 ± 0.31</td>
<td>3.59 ± 0.41</td>
</tr>
<tr>
<td>ACD change at 6 D accommodation (mm)</td>
<td>−0.19 ± 0.05</td>
<td>−0.18 ± 0.03</td>
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Data are mean ± SD. AL, axial length; ACD, anterior chamber depth.

*Significantly different (P < 0.05).

### RESULTS

Table 1 shows baseline and accommodation-induced changes in axial length and anterior chamber depth in the emmetropes and myopes. Ethnic origin did not have a significant effect on baseline axial length or SER in the emmetropic or myopic subjects. The Pearson product moment correlation coefficient between axial length and SER was −0.85, in keeping with previous studies of similar groups of young adult subjects.15 Figure 2 shows a plot of mean elongation of axial length from baseline against accommodative stimulus level in the emmetropic and myopic subject groups. Error bars show the SEM. One-way ANOVA showed that the difference in axial elongation between the emmetropes and myopes was not significant at 2 D (P = 0.27) or 4 D (P = 0.08), but was significant with the 6-D stimulus to accommodation (P = 0.02). Dioptric equivalence of axial elongation with the 6-D stimulus to accommodation, as calculated from the Bennett-Rabbits schematic eye was, on average, −0.10 D in the emmetropes and −0.15 D in myopes.16 A reduction in anterior chamber depth was observed in both the emmetropes and myopes when accommodation was stimulated from 0 to 6 D. This change in anterior chamber depth was not significantly different between the emmetropes and myopes.
In keeping with the findings of Drexler et al., we observed a transient elongation in axial length during the accommodation response. In contrast to Drexler et al. the greatest elongation was seen in myopic eyes, with emmetropic eyes elongating significantly less at higher levels of accommodative demand. We concur with the assertion of Drexler et al. that this transient elongation is due to the effect of contraction of ciliary smooth muscle applying an inward pull force to a region of the choroid and sclera adjacent to the ciliary body. This effect requires a rearward displacement of the posterior portion of the globe to maintain a constant ocular volume, which results in a transient increase in axial length. Recently, Yasuda and Yamaguchi have shown that contraction of ciliary smooth muscle induced by pilocarpine can cause a steepening of the central area of the cornea, indicating potential for transient biometric change of the eye during the near vision response. We suggest that the greater elongation observed in myopic eyes in our study may be due to reduced ocular rigidity and a more efficient transmission of ciliary muscle force to the choroid and sclera in these subjects. We note, however, the work of Schmid et al. who found no difference in ocular rigidity between emmetropic and myopic children. Ocular rigidity is a worthy subject for further investigation, particularly in young adult emmetropes who may be at risk of the development of latent onset myopia due to occupational near vision demands. The subject cohort used in our study was younger and had a higher amplitude of accommodation than did the cohort used by Drexler et al., which may have influence on the results. Our emmetropic and myopic groups were closely matched for amplitude of accommodation. Furthermore, accommodation stimulus levels used in our study were equivalent in all subjects in both refractive groups (i.e., 2, 4, and 6 D above baseline), rather than the maximum accommodative effort at the near point. Because the accommodation of the myopic subjects in Drexler et al. was stimulated to a lesser extent than the accommodation of the emmetropes (mean values of 4.1 D for myopes and 5.1 D for emmetropes), it may be that the transient axial elongation of the myopic subjects was underestimated in the experiment presented in the current report were within the achievable accommodative range of all subjects, thus avoiding potential ceiling effects that may occur (e.g., an open-loop response) if the stimulus exceeds the available amplitude of accommodation. The work presented herein has also shown that the degree of transient axial elongation correlates well with the level of accommodative stimulation, as shown by Drexler et al. in emmetropes. The amount of transient axial length elongation increased systematically as the stimulus to accommodation was increased. Further, we can state that this effect also occurs in the myopic eye, and indeed this effect was more pronounced in these subjects. A statistically significant correlation was not found between baseline axial length and transient elongation, or between SER and transient elongation. The fact that a significant difference in elongation was detected at 6 D accommodative stimulus supports the notion that there is an inherent difference in the structural makeup of the myopic eye and that myopic eyes are more amenable to transient biometric change during high levels of accommodation than are their emmetropic counterparts.

Because the difference in axial length elongation was not observed until higher levels of accommodative stimulation, outside the normal range for tasks such as reading or visual display unit use, it seems unlikely that this effect plays a significant role in the development of myopia in adults. This effect could play a role in the refractive development of children as their reading distance is generally closer than that of adults. The COMET study has shown that progressive-addition spectacle lenses may be more beneficial in slowing the progression of myopia in children adopting closer reading distances. Hyperopic defocus occurring as a result of lag of accommodation during near vision has been shown to be a potential factor in myopia. Transient axial elongation during sustained accommodative effort may actually reduce the degree of hyperopic blur occurring due to accommodative lag by a small amount—this effect being greater in myopes than in emmetropes, but probably not of clinical significance. These findings do, however, indicate that there may be differences in the structure of the eye in the region of the ciliary body between emmetropes and myopes, causing forces from the ciliary muscle to be transmitted differentially to the choroid and sclera in these two refractive groups. Further investigations should now take place to measure the axial expandability of the eyes of premyopic children during the accommodation response. It may be that ocular expandability serves as a pre-

Figure 3 compares the transient axial elongation found with the 6-D stimulus to accommodation against baseline axial length in the emmetropic and myopic subjects. The Pearson product moment correlation coefficient (r) between axial elongation and baseline axial length was 0.22 in the emmetropes and 0.26 in the myopes. These correlations were not statistically significant in either refractive group (P > 0.05). Pearson product moment correlation coefficient between amount of axial elongation at 6 D of accommodation and SER was not significant in either group (emmetropes: r = 0.01, P > 0.05; myopes: r = 0.10, P > 0.05). Pearson product moment correlation coefficients between accommodation stimulus level and degree of transient elongation were calculated for each subject. Group-averaged correlation coefficients were 0.91 ± 0.04 for the emmetropes and 0.95 ± 0.02 for the myopes. Correlation coefficients were highly significant (P < 0.0005) for the emmetropic and myopic subjects.

Accommodation response measurements with the open-view infrared optometer (SRW-5000; Shin-Nippon) showed that the myopic subjects accommodated slightly less than the emmetropic subjects at each accommodative stimulus level. These differences were not statistically significant at any accommodative stimulus level.

**DISCUSSION**

In keeping with the findings of Drexler et al., we observed a transient elongation in axial length during the accommodation response. In contrast to Drexler et al. the greatest elongation was seen in myopic eyes, with emmetropic eyes elongating significantly less at higher levels of accommodative demand. We concur with the assertion of Drexler et al. that this transient elongation may be due to the effect of contraction of ciliary smooth muscle applying an inward pull force to a region of the choroid and sclera adjacent to the ciliary body. This effect requires a rearward displacement of the posterior portion of the globe to maintain a constant ocular volume, which results in a transient increase in axial length. Recently, Yasuda and Yamaguchi have shown that contraction of ciliary smooth muscle induced by pilocarpine can cause a steepening of the central area of the cornea, indicating potential for transient biometric change of the eye during the near vision response. We suggest that the greater elongation observed in myopic eyes in our study may be due to reduced ocular rigidity and a more efficient transmission of ciliary muscle force to the choroid and sclera in these subjects. We note, however, the work of Schmid et al. who found no difference in ocular rigidity between emmetropic and myopic children. Ocular rigidity is a worthy subject for further investigation, particularly in young adult emmetropes who may be at risk of the development of late-onset myopia due to occupational near vision demands. The subject cohort used in our study was younger and had a higher amplitude of accommodation than did the cohort used by Drexler et al., which may have influence on the results. Our emmetropic and myopic groups were closely matched for amplitude of accommodation. Furthermore, accommodation stimulus levels used in our study were equivalent in all subjects in both refractive groups (i.e., 2, 4, and 6 D above baseline), rather than the maximum accommodative effort at the near point. Because the accommodation of the myopic subjects in Drexler et al. was stimulated to a lesser extent than the accommodation of the emmetropes (mean values of 4.1 D for myopes and 5.1 D for emmetropes), it may be that the transient axial elongation of the myopic subjects was underestimated slightly. The accommodative stimulus levels selected in the experiment presented in the current report were within the achievable accommodative range of all subjects, thus avoiding potential ceiling effects that may occur (e.g., an open-loop response) if the stimulus exceeds the available amplitude of accommodation. The work presented herein has also shown that the degree of transient axial elongation correlates well with the level of accommodative stimulation, as shown by Drexler et al. in emmetropes. The amount of transient axial length elongation increased systematically as the stimulus to accommodation was increased. Further, we can state that this effect also occurs in the myopic eye, and indeed this effect was more pronounced in these subjects. A statistically significant correlation was not found between baseline axial length and transient elongation, or between SER and transient elongation. The fact that a significant difference in elongation was detected at 6 D accommodative stimulus supports the notion that there is an inherent difference in the structural makeup of the myopic eye and that myopic eyes are more amenable to transient biometric change during high levels of accommodation than are their emmetropic counterparts.

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cursor to and therefore a predictor of the onset of myopia. This information would be most useful in the development of therapeutic approaches to the control of myopia onset and progression and in the selection of suitable subjects for clinical trials of myopia control programs.

In our study, we saw greater levels of transient axial elongation than those noted by Drexler et al. Our results are comparable to those of Uozato et al. (IOVS 2003;44:ARVO E-Abstract 4O80), who found transient accommodation-induced elongations of −0.06 mm with a stimulus level of 10 D, again using the IOLMaster. To calculate axial length from the optical path length, the IOLMaster uses an average refractive index for the eye, and therefore may be susceptible to an overestimation of up to 0.02 mm in axial length for an eye accommodating to a 10-D stimulus when compared with PCI methods that use individual refractive indices for the ocular components. Atchison and Smith have shown that the action of accommodation may induce errors in the measurement of axial length obtained from the IOLMaster. The source of this potential error is the increase in optical path length (i.e., the product of the linear dimension of a given optical medium and the refractive index of that medium) that occurs when the anterior vertex of the crystalline lens moves forward into the anterior chamber and crystalline lens thickness increases during the accommodation response. During this response, the higher refractive index material of the anterior portion of the crystalline lens (n′ = 1.386) displaces a portion of the lower refractive index aqueous humor (n′ = 1.336), leading to an increase in optical path length. In our experiment, the level of reduction in anterior chamber depth during the accommodation response was found to be in agreement with previous studies, but was not significantly different between emmetropic and myopic subjects. Because the refractive index of aqueous humor and crystalline lens are likely to be equivalent between emmetropes and myopes of similar age, we are confident that the statistical significance of the difference in axial elongation noted during the accommodation response between these refractive groups is not an artifact of the measurement technique. We therefore conclude that, although the axial elongation resulting from the accommodation response may be exaggerated by the IOLMaster, the eyes of myopic individuals undergo a greater degree of transient axial elongation than do the eyes of emmetropes at higher levels of accommodative demand.

References


