Effect of Stature and Other Anthropometric Parameters on Eye Size and Refraction in a Population-Based Study of Australian Children

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PURPOSE. To determine the effect of anthropometric parameters on refraction and ocular biometry.

METHODS. Noncontact methods were used to examine ocular dimensions and cycloplegic refraction in a stratified random cluster sample of year-1 Sydney school students (mean age, 6 years; n = 1765). Height, body weight, and waist circumference were measured according to a standardized protocol. Body mass index (BMI) was subsequently calculated. The percentage of body fat was measured with leg-leg bioelectrical impedance analysis. Associations between parameters were analyzed by multiple linear regression.

RESULTS. After adjustment for age in weeks, height was found to be strongly associated with axial length and corneal radius. Children in the 1st quintile for height had axial length of 22.39 ± 0.04 mm compared with 22.76 ± 0.04 mm in children in the 5th quintile. Other anthropometric parameters were not associated with axial length or corneal radius. Height was not associated with anterior chamber depth after adjustment for weight. Increases in weight, BMI, and waist circumference were associated with a deeper anterior chamber after adjustment for height. No associations were found between the measured anthropometric parameters and refraction or axial length–corneal radius ratio.

CONCLUSIONS. This study found a strong association between height and axial length and corneal radius, but not spherical equivalent refraction. The findings may demonstrate the effectiveness of emmetropization in the presence of normal physiological influences. (Invest Ophthalmol Vis Sci. 2005;46: 4424–4429) DOI:10.1167/iovs.05-0077

Axial length appears to be a major determinant of refractive error. Myopic refractive errors are associated with longer eyes,1 and hyperopic errors are associated with shorter eyes.2 Higher, potentially pathologic, myopia is associated with even longer eyes.3 However the simple equation of axial length with refractive error is misleading, since normal eye development in fact involves matching between components, which tends to bring the refraction toward emmetropia, irrespective of axial length.4 At the same time, certain unknown factors appear to produce excessive axial elongation that is not compensated for by other biometric components, thus contributing to myopic refractive errors.5

These complex interactions during the development of the eye can be examined in a variety of ways. Boys are generally taller than girls and tend to have longer eyes.1,6–11 A simple view would be that boys tend to be more myopic than girls. The relation of refractive error and ocular biometry with gender has been examined in several studies.7–14 Although boys have been consistently shown to have larger eyes, there appears to be no systematic relationship between gender and refractive error. Some recent studies suggest no difference,15 whereas other studies suggest that girls are more myopic than boys.16–18

Although most attention has been focused on the effect of education and urbanization on myopia, Cordain et al.17 have argued on anthropological grounds that changing dietary patterns may contribute to the increasing prevalence of myopia in many parts of the world. Specifically, this study argued that consumption of high glycemic index and load diets, common in more economically developed societies, may be associated with the secular increases in height in many societies and may deregulate the control of eye growth, therefore suggesting that myopes are typically taller, heavier, and have a higher body mass index (BMI).17

In several studies, investigators have examined the relationship between refractive error and height.18–27 In many studies, greater height has been associated with more myopic refractions,18–22,27,28 but the pattern is not consistent, and several studies have found no relationship.24,25 Recent Asian population studies in adults26 and children27 showed strong associations between height and axial length and corneal curvature. However, height was associated with more myopic refractions in children only.27

In this study, we examined the relationship between refractive error, ocular biometry (axial length, corneal curvature, and anterior chamber depth) and anthropometry, including height, weight, BMI, waist circumference, and body fat percentage, in a population of year-1 students examined in schools in the Sydney Metropolitan Area.

METHODS

The Sydney Myopia Study is a survey of refractive errors and other eye diseases in a large stratified random cluster sample of year-1 (6- to 7-year-old) and year-7 (12- to 13-year-old) schoolchildren. The study...
was approved by the Human Ethics Committee of the University of Sydney and by the New South Wales Department of Education. Written, informed consent was obtained from parents, and participants provided verbal consent on the day of the examination. The research adhered to the tenets of the Declaration of Helsinki. Details of survey methods are described elsewhere. In brief, 34 primary schools across the Sydney Metropolitan region were selected using random cluster sampling, based on socioeconomic status, to provide a representative sample of children in Sydney schools. A proportional mix of public and private or religious schools was included.

Procedures included a 193-item questionnaire for parents, asking for estimates of time spent by each child engaging in close-up activities and distance activities. Sociodemographic information, including ethnicity, country of birth, education, occupations, age of parents, and type of current housing were collected, in addition to the mother’s obstetric history, child’s birth history, past and current medical history, and a detailed family history of eye disorders. The examination included a detailed assessment of visual acuity, identification of amblyopia and strabismus, cycloplegia using cyclopentolate, autorefraction, and keratometry (Canon RK-F1 autorefractor; Canon Inc., USA, Lake Success, NY) and ocular biometry (axial length, anterior chamber depth, corneal radius of curvature; IOLMaster, Carl Zeiss Meditec AG, Jena, Germany).

The eye drop protocol included amethocaine hydrochloride 0.5% (Minims; Chauvin Pharmaceuticals Ltd., Romford, UK) which was instilled into each eye to provide anesthesia and enhance the absorption of the subsequent eye drops, and two cycles of cyclopentolate 1% (1 drop) and tropicamide 1% (1 drop) applied 5 minutes apart, after corneal anesthesia. The autorefractor was set to generate five valid readings of refraction in each eye automatically, taking place 20 to 30 minutes after instillation of the eye drops. Cycloplegia was considered full when the pupil was fixed and ≥6 mm in diameter. The average refraction was used for analysis.

The ocular biomter (IOLMaster; Carl Zeiss Meditec AG) was used to measure five valid readings of axial length and anterior chamber depth and three keratometry readings. Measures were taken on the entire cohort before the instillation of eye drops and on a subsample after pupil dilatation. Predilation measurements for ocular biometry are reported in this study. Anterior chamber depth refers to predilation and not to pupil dilation. Data were analyzed on computer (Statistical Analysis System software, ver. 8.2; SAS Institute, Cary, NC). The correlation coefficients between the two eyes for the refractive and the biometric variables were high (spherical equivalent refraction, 0.87; axial length, 0.97; anterior chamber depth, 0.88; CR1, 0.98; and CR2, 0.97). Right and left eye data were analyzed, but only right eye data are reported due to comparable results. Mixed models were used to adjust for clustering within schools. Where cluster effects were not significant, t-tests and normal linear regression were used. Multiple linear regression models were constructed to evaluate the effects of height, weight, BMI, body fat percentage, waist circumference, and gender on refraction and ocular biometric parameters including axial length, anterior chamber depth, and corneal curvatures. Although height and weight correlated ($r = 0.74$), there was minor collinearity in the models that included both. All confidence intervals (CIs) are 95%.

### Definitions

Signals from the tear film and retinal pigment epithelium (RPE) are used by the biomter for axial length measurements. The system automatically adjusts for the distance difference between the inner limiting membrane and the RPE, so that the displayed axial length values are directly comparable to those obtained by immersion ultrasound. Light is relatively often reflected at the inner limiting membrane thus producing an interference signal. In this event, the measuring cursor was moved to the RPE peak. Anterior chamber depth was defined as the distance from the anterior corneal surface to the anterior lens surface. Corneal curvature was measured in two meridians, the greatest corneal radius of curvature (CR1) and the least corneal radius of curvature (CR2). The axial length–corneal radius (AL/CR) ratio was defined as the axial length divided by the mean corneal radius. Parental myopia was based on self-report of myopia and/or of wearing spectacles before age 30 years for difficulty with distance viewing.

The child’s weight and percentage of body fat (using leg-leg bioimpedance analysis) were measured. Height was measured with shoes off using a freestanding height rod, and BMI was subsequently calculated ($BMI = weight$ [in kilograms]/$height^2$ [in meters]). Waist circumference was measured and defined as the narrowest part of the child’s trunk.

### Statistical Analysis

Data were analyzed on computer (Statistical Analysis System software, ver. 8.2; SAS Institute, Cary, NC). The correlation coefficients between the two eyes for the refractive and the biometric variables were high (spherical equivalent refraction, 0.87; axial length, 0.97; anterior chamber depth, 0.88; CR1, 0.98; and CR2, 0.97). Right and left eye data were analyzed, but only right eye data are reported due to comparable results. Mixed models were used to adjust for clustering within schools. Where cluster effects were not significant, t-tests and normal linear regression were used. Multiple linear regression models were constructed to evaluate the effects of height, weight, BMI, body fat percentage, waist circumference, and gender on refraction and ocular biometric parameters including axial length, anterior chamber depth, and corneal curvatures. Although height and weight correlated ($r = 0.74$), there was minor collinearity in the models that included both. All confidence intervals (CIs) are 95%.

### Population Characteristics

Of 2238 eligible children, 1765 (79%) were given parental permission to participate in the study and questionnaire data were provided by parents. Of these 1765 children, 24 were not examined, as they were absent from school during the examination period and one 9-year-old child was excluded from the analysis. A total of 1740 children (859 girls, 881 boys) provided data for the analysis of examination findings. Mean age was 6.68 years in girls and 6.74 years in boys. This small difference was statistically significant ($P < 0.0001$). The ethnic distribution of this sample included 64.5% white (European), 17.2% East Asian, and 18.3% other.

### Table 1. Characteristics of Age and Anthropometry in Children

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Total</th>
<th>Girls</th>
<th>Boys</th>
<th>East Asian</th>
<th>White</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (wks)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean (SD)</td>
<td>348.6 (22)</td>
<td>347 (21.9)</td>
<td>350.2 (22.2)</td>
<td>340.0 (20.4)</td>
<td>351.0 (22.0)</td>
</tr>
<tr>
<td>Anthropometry</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Height (cm)</td>
<td>120.6 (5.7)</td>
<td>119.9 (5.7)</td>
<td>121.2 (5.6)</td>
<td>118.3 (5.7)</td>
<td>121.2 (5.2)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>23.7 (4.5)</td>
<td>23.5 (4.7)</td>
<td>23.9 (4.3)</td>
<td>22.1 (4.1)</td>
<td>24.0 (4.4)</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>16.2 (2.1)</td>
<td>16.2 (2.2)</td>
<td>16.2 (2.2)</td>
<td>15.7 (2.0)</td>
<td>16.2 (2.0)</td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>16.1 (6.2)</td>
<td>15.5 (7.4)</td>
<td>16.6 (4.7)</td>
<td>13.8 (6.1)</td>
<td>16.3 (5.9)</td>
</tr>
<tr>
<td>Waist (cm)</td>
<td>55.1 (5.1)</td>
<td>54.8 (5.2)</td>
<td>55.4 (5.0)</td>
<td>53.0 (5.0)</td>
<td>55.4 (4.8)</td>
</tr>
</tbody>
</table>

Probabilities refer to gender differences or ethnic differences, * $P < 0.0001$, † $P < 0.05$.
Asian, 4.9% Middle Eastern, 2.3% South Asian, 2.0% Oceanic and Indigenous Australian, 7.9% mixed, and 1.2% other ethnic groups. Anthropometric characteristics of the population are shown in Table 1.

RESULTS

The correlations of age, height, weight, BMI, body fat percentage, and waist circumference with ocular biometric parameters and spherical equivalent refraction are shown in Table 2. Height correlated positively with axial length, anterior chamber depth, and corneal radius of curvature. The correlation between height and AL/CR was low but statistically significant.

Figures 1A and 1B show the mean values of axial length and CR1 and CR2 among children categorized by quintiles of height. Significant trends by height quintiles were found only for axial length and corneal radii ($P < 0.0001$). There were no trends observed in spherical equivalent refraction or anterior chamber depth by quintiles of height. There were no significant trends in all ocular biometric parameters or spherical equivalent refraction by quintiles of weight, BMI, body fat percentage, or waist circumference. Increasing postcycloplegia anterior chamber depth was found with increasing BMI, a trend that was statistically significant ($P = 0.0048$). Figure 2 shows a scatterplot of axial length against height in all children (correlation coefficient, 0.251). The effect of height on axial length appears to taper in the tallest children, which could be suggestive of a more complex relationship.

Regression models are shown in Table 3. Each value in Table 3 represents the result of a separate regression model, with individual ocular biometric components or refraction as the dependent variable and the anthropometric parameter as the independent variable. In the final model of this table, a 10-cm taller child, after controlling for age in weeks, sex, weight and parental myopia, could be expected to have a 0.29-mm increase in axial length. In the same model, the same subject could be expected to have an $-0.11$-mm increase in CR1 and a $0.13$-mm increase in CR2. The same model also showed a small but significant increase in anterior chamber depth with weight, waist circumference, and BMI. These associations were also confirmed with postcycloplegia anterior chamber depth. The associations with anterior chamber depth were lost, however, when boys and girls were examined separately, and only the height-related associations remained. In the final model, there were no significant associations between anthropometric parameters and refraction.

DISCUSSION

In this study, we found no strong associations between height, weight, BMI, body fat percentage, waist circumference, and refraction or AL/CR ratio. Strong relations between height and axial length and corneal curvature were confirmed. Weight and BMI were associated with deeper anterior chambers, but this relation was lost when boys and girls were examined separately.

**TABLE 2. Correlation of Age and Anthropometric Parameters with Ocular Biometric Parameters and Refraction**

<table>
<thead>
<tr>
<th></th>
<th>Age (wk)</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>BMI (kg/m²)</th>
<th>Body Fat (%)</th>
<th>Waist (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AL (mm)</td>
<td>0.082*</td>
<td>0.252*</td>
<td>0.170*</td>
<td>0.067†</td>
<td>0.138*</td>
<td>0.131*</td>
</tr>
<tr>
<td>ACD (mm)</td>
<td>0.163*</td>
<td>0.159*</td>
<td>0.127*</td>
<td>0.072†</td>
<td>0.074†</td>
<td>0.098*</td>
</tr>
<tr>
<td>CR1 (mm)</td>
<td>-0.047†</td>
<td>0.179*</td>
<td>0.127*</td>
<td>0.056†</td>
<td>0.103*</td>
<td>0.085†</td>
</tr>
<tr>
<td>CR2 (mm)</td>
<td>-0.005</td>
<td>0.205*</td>
<td>0.119*</td>
<td>0.029</td>
<td>0.09†</td>
<td>0.068†</td>
</tr>
<tr>
<td>AL/CR</td>
<td>0.15*</td>
<td>0.060†</td>
<td>0.050†</td>
<td>0.030</td>
<td>0.042</td>
<td>0.065†</td>
</tr>
<tr>
<td>SE (D)</td>
<td>0.033</td>
<td>0.008</td>
<td>0.005</td>
<td>0.0007</td>
<td>-0.009</td>
<td>-0.022</td>
</tr>
</tbody>
</table>

Data are the Pearson correlation coefficient. AL, axial length; ACD, anterior chamber depth; CR1, greatest corneal radius of curvature; CR2, least corneal radius of curvature; AL/CR ratio, axial length–corneal radius ratio; SE, spherical equivalent refraction.

* $P < 0.0001$.
† $P < 0.05$.
Results in several studies have shown a relationship between myopia and greater height in adults\textsuperscript{19-23,32} and more recently with children\textsuperscript{27}. Findings in other studies have shown no relationship with myopia.\textsuperscript{24,25} Two recent Asian studies comprehensively evaluated the effect of height, weight, and BMI in children\textsuperscript{17} and adults.\textsuperscript{20} Wong et al.\textsuperscript{20} studied a Chinese population in Singapore aged 40 to 81 years and found a strong positive correlation between height and axial length, anterior

Each value represents a separate regression model, with the individual ocular biometric components or refraction as the dependent variable and height, weight, BMI, body fat percentage, and waist circumference as the independent variables adjusting for other covariates. Models for height are adjusted for weight and vice versa. Data in parentheses represent the 95% confidence interval. AL, axial length; ACD, anterior chamber depth; CR1, greatest corneal radius of curvature; CR2, least corneal radius of curvature; AL/CR, axial length/mean corneal radius ratio.

\textsuperscript{*} P < 0.0001.

\textsuperscript{†} P < 0.05.
chamber depth, corneal radius of curvature, a negative correlation with lens thickness, but no correlation with refraction. They found weight and BMI to be associated with a more hyperopic refraction. Saw et al. found a strong association between height and axial length in Chinese school children aged 7 to 9 years and found that taller children tended to have myopic refractions, particularly in girls. The inconsistent nature of the relationship suggests that the effects observed might have been mediated by other factors that independently affect stature and refractive status, such as the relationships between socioeconomic status, education and diet, rather than by a direct relationship between height and refraction. High socioeconomic status may be independently linked to better diet (increased height) and to increased education (greater myopia). Such an association would produce a correlation between height and myopia, without a causal link. These correlations would tend to be stronger in societies in which the educational and dietary disparities were greater.

The older studies were subject to sampling bias and used a variety of techniques in measuring refraction. Our study is the largest of the modern studies to examine the effect of anthropometry on refraction and ocular biometry. In addition, data were available in only 951 (55.4%) adults in the Tanjong Pagar Survey and 1449 (66%) children in the Singapore study, compared with more than 1700 children with refraction and biometry data in our study (77% of eligible children). The principal strength of our study was the sampling strategy and high participation rate, which was meant to overcome potential bias, and also the additional data on waist circumference and body fat percentage.

Strong evidence of an increase in myopia over the past few decades exists, probably related to an environmentally driven increase in axial length. It has been suggested that myopes are typically taller and heavier and have a higher BMI as a result of changing dietary patterns. This argument is plausible, given the increase in BMI and height reported over the past few decades and the strong relationship between height and axial length. Theoretically, the height-related increase in axial length could result in deregulation and consequent myopia. However, in our young, growing population with minimal skewness, there was no significant association between refraction and any of the measured anthropometric parameters. Height was strongly related to axial length and corneal radius, but it appears that height-related axial length and corneal radius increases proportionately compensate for each other, since the AL/CR ratio and spherical equivalent refraction data showed almost no correlation with height.

This study confirmed height-related increases in axial length and corneal radius of curvature but found AL/CR ratio and refraction to be unaffected. These findings demonstrate the eye’s ability to compensate for axial length differences in relation to height. The lack of association between measured anthropometric parameters and refraction contests previous theories of dietary change as a major contributor in the temporal increase in the prevalence of myopia.

References


