

Relations between Age, Weight, Refractive Error and Eye Shape by Computerized Tomography in Children

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Purpose: To investigate relationships between age, weight, refractive error, and morphologic changes in children's eyes by computerized tomography (CT).

Methods: Of the 772 eyes of 386 patients under the age of 20 years, who visited our Department of Ophthalmology between January 2005 to August 2006 and underwent CT of the orbit, 406 eyes of 354 patients with clear CT images and normal eyeball contour were enrolled in the present retrospective study. The axial lengths, widths, horizontal and vertical lengths, refractive errors, and body weight of eyes were measured, and relationship between these parameters were investigated.

Results: Axial length was found to correlate significantly with eye width ($r=0.914$), and in emmetropic eyes and myopic eyes, axial lengths and widths were found to increase as age and body weight increased. Axial lengths increased rapidly until age 10, and then increased slowly. In emmetropic eyes, widths / axial lengths increased with age, but in myopic eyes these decreased as age or severity of myopia increased. Moreover, as age increased, the myopic population and severity also increased.

Conclusions: The axial length was longer in case of myopia compared to emmetropia in all age groups and there was almost no difference in the increase rate of axial length by the age of myopia and emmetropia. However, the width was wider in case of myopia compared to emmetropia in all age groups and the increase rate of width in myopia by age was smaller than that of emmetropia. Myopia showed decreasing rate of width/axial length with increase of age, from 1.004 in 5 years to 0.971 in 20 years. However, emmetropia showed increasing rate of width/axial length with increase of age, from 0.990 in 5 years to 1.006 in 20 years.

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The tissue and organs of children grow with age and the rates of these growths are organ dependent. Scammon divided tissue and organs into four different types; general, neural, lymphoid, and genital.

Height and weight show rapid growth in infancy and puberty and show 'S-type' growth patterns, whereas brain, head circumference, and visual organs are of the neural type and grow up to 80% of the adult size by age 4. On the other hand, thymus and lymphatics, the 'lymphoid type' reach twice the adult size at age 12 and then regress gradually. The fourth tissue type, 'the genital type', includes genitalia, prostate, and others, and these grow rapidly from puberty and reach the

size at 16 to 18 years of age.¹ Eyeball or orbit size and volume might be expected based on the above to follow the growth pattern of the neural type.

Many computerized tomography (CT), magnetic resonance imaging (MRI) or ultrasonography (US) studies have investigated the morphologies of eyeball and orbit. However most of these studies have been conducted in adults only or in a few age groups.²⁻⁶ If the normal shape and size of eyeballs are known by age, then diverse diseases that present as eyeball developmental disorders, such as, intrauterine infection, hereditary diseases, fetal alcohol syndrome, congenital glaucoma, congenital developmental disorders, and amblyopia could be detected at early disease stages, and thus, vision prognoses could be improved.^{2,7-10}

In this study, we documented the eyeball shapes of children under the age of 20 years as determined by CT, and investigated the relations between eyeball shape and age, weight and refractive error. We tried to characterize eyeball morphological changes versus growth and to determine the effects of refractive error on this relation.

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Materials and Methods

By retrospectively checking medical records, we investigated 772 eyes of 386 people under the age of 20 years who had medical examination including fundus examination in our department of ophthalmology through visiting outpatient department or emergency department and underwent a CT exam of the orbit or face within a week for screening of bony or soft tissue injury, or who had visited department of plastic surgery after ophthalmologic examination and underwent a CT exam for examination. Four hundred six eyes of 354 patients were included, excluding candidates if there was eyelid swelling or eyeball injury which could cause deformity in eyeball contour, if CT images were not clear, if the cornea and approximate location of the macula did not appear in the same plane on images, or if there was a difference between measured values of > 0.3 mm by 3 different researchers or by a repeat exam by a single researcher, or if there was ophthalmologic diseases.

CT (Somatom Sensation 16, Siemens, Germany) scans were performed in axial and coronal views at a thickness of 3 mm. Marosis M-view (version 5.4) was used with a 1024 × 768 pixel resolution, a window level of 50 Hounsfield units (H), and a width of 350 H. Measured values were enlarged ten times to actual size and averaged values were measured twice by 3 researchers.

Axial length was defined as the distance through the visual axis from the posterior corneal surface to the posterior pole of the eye in axial view, and width was defined as the distance between temporal and nasal ends of the eye in axial

view. Horizontal length was defined as the distance between temporal and nasal ends of the eye in largest coronal view, and vertical length was defined as the distance between top and bottom ends of the eye (Fig. 1).

Refractive errors were subdivided, i.e., myopia ≤ -1.0 D, -1.00 < emmetropia < 1.00 D, hyperopia ≥ 1.00 D according to spherical equivalents.

Statistical analyses were performed using SPSS for Windows (version 12.0). Age, weight, spherical equivalent, axial length, width, width/axial length, horizontal and vertical lengths are presented as averages and standard deviations or as median values and ranges.

Pearson correlation coefficients determined using bivariate correlation analysis were used to compare factors, such as, axial length, width, horizontal length, vertical length, age, weight, spherical equivalent, and width/axial length.

Results

Distributions of myopia and emmetropia according to age, body weight, male/female ratio, left eye/right eye ratio, and spherical equivalents of refractive errors are presented in table (Table 1). Axial length, width, horizontal length, vertical length, width/axial length and vertical length/horizontal length of eyes are presented as averages and standard deviations with medians and ranges (Table 2).

Average axial length was 24.13 mm±1.03 mm (SD) in myopia and 23.08±0.91 mm (SD) in emmetropia, i.e., myopia was 1.05 mm longer than emmetropia on average. We compared relationships between axial length, width,

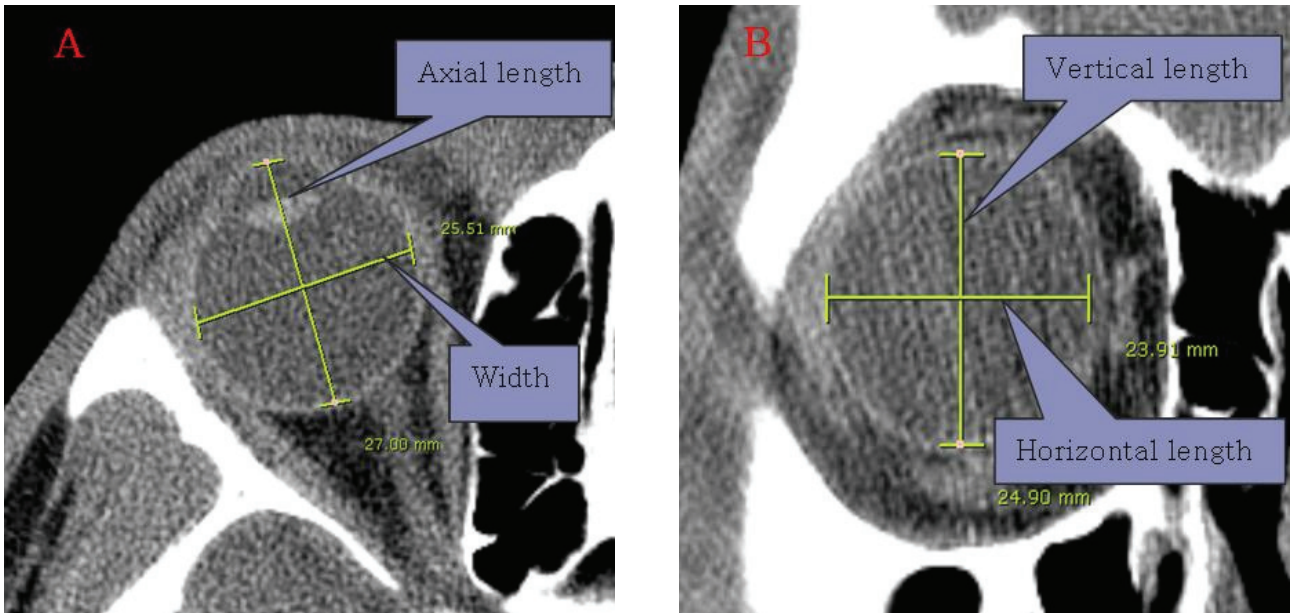


Fig. 1. Measurements of eye by computed tomography. (A) Axial length: The distance through the visual axis from the posterior corneal surface to the posterior pole of the eye in axial view. Width: The distance between temporal and nasal ends of the eye in axial view. (B) Horizontal length: The distance between temporal and nasal ends of the eye in the largest coronal view. Vertical length: The distance between top and bottom ends of the eye in the largest coronal view.

Table 1. Population characteristics

Classification	Total (N=406)	
	Mean±SD [†]	Median (Range)
Age (years)	9.5±6.2	8.0 (0.1~20)
Weight (kg)	23.7±14.1	19.5 (5.0~79.0)
Sex (Male)		301 eyes (75%)
Monocular		330 eyes (81%)
Right eye		201 eyes (50%)
Myopic eye* (Diopter) (44%)	-2.72±1.55	-2.125 (-1.0~-7.0)

* : Spherical equivalent.

†: Standard deviation.

Table 2. Eyeball measurements by computerized tomography

Classification	Myopia		Emmetropia		Total	
	Mean±SD*	Median	Mean±SD*	Median	Mean±SD*	Median (Range)
Axial length (mm)	24.13±1.03	24.26	23.08±0.91	23.11	22.70±1.44	22.71 (26.40~18.27)
Width (mm)	23.69±0.92	23.80	23.05±1.08	23.17	22.68±1.31	22.61 (19.08~25.93)
Vertical length (mm)	23.88±1.05	23.75	23.28±0.96	23.24	22.85±1.34	22.85 (17.58~26.37)
Horizontal length (mm)	23.57±1.09	23.57	22.76±1.07	22.88	22.34±1.37	22.26 (17.21~26.01)
Width/Axial length	0.982±0.018	0.979	0.999±0.021	0.998	1.000±0.026	0.999 (1.067~0.950)
Vertical length/Horizontal length	1.014±0.033	1.007	1.024±0.036	1.028	1.023±0.032	1.022 (1.111~0.918)

* : Standard deviation.

horizontal length, vertical length, age, body weight, and spherical equivalent of refractive error by separating them into various groups. Most of these relationships were statistically significant, but the relationships between vertical length/horizontal length and axial length, body weight and axial length in myopia, and relationships between body weight and width/axial length in both myopia and emmetropia were statistically insignificant (Table 3).

Axial length was found to be significantly associated with width, horizontal length and vertical length (correlation

coefficient $r > 0.8$ for all). Axial length showed proportional increase with age and weight and increased rapidly until age of 10 (Fig. 2). Axial length increased but width/axial length decreased as degree of myopia increased, and as age increased the degree and proportion of myopic eyes also increased (Fig. 3). Axial length in myopia was longer than in emmetropia in all age groups and increases in axial length were similar in myopia and emmetropia. Width in myopia was wider than in emmetropia in all age groups, but width in myopia increased less than in emmetropia. In myopia,

Table 3. 3-Dimensional information on eyeballs and correlations between various parameters

Classification	Relationship	Relationship coefficient r	Probability p
Width (x) ↔ AL* (y)	$y=1.006x-0.116$	$r=0.914$	$p<0.001$
HL [†] (x) ↔ AL* (y)	$y=0.964x+1.050$	$r=0.869$	$p<0.001$
VL [‡] (x) ↔ AL* (y)	$y=0.962x+0.634$	$r=0.847$	$p<0.001$
HL [†] (x) ↔ Width (y)	$y=0.918x+2.043$	$r=0.925$	$p<0.001$
VL [‡] (x) ↔ Width (y)	$y=0.860x+2.952$	$r=0.845$	$p<0.001$
VL [‡] (x) ↔ HL [†] (y)	$y=0.877x+2.318$	$r=0.863$	$p<0.001$
VL [‡] /HL [†] (x) ↔ AL* (y)	$y=-4.963x+27.801$	$r=-0.106$	$p=0.101$
(Myopia) Weight (x) ↔ AL* (y)	$y=0.025x+22.671$	$r=0.388$	$p=0.082$
(Emmetropia) Weight (x) ↔ AL* (y)	$y=0.038x+21.539$	$r=0.501$	$p=0.001$
(Myopia) Weight (x) ↔ Width/AL* (y)	$y=-0.000x+0.988$	$r=0.004$	$p=0.986$
(Emmetropia) Weight (x) ↔ Width/AL* (y)	$y=0.000x+0.992$	$r=0.025$	$p=0.876$

* : Axial length.

†: Horizontal length.

‡: Vertical length.

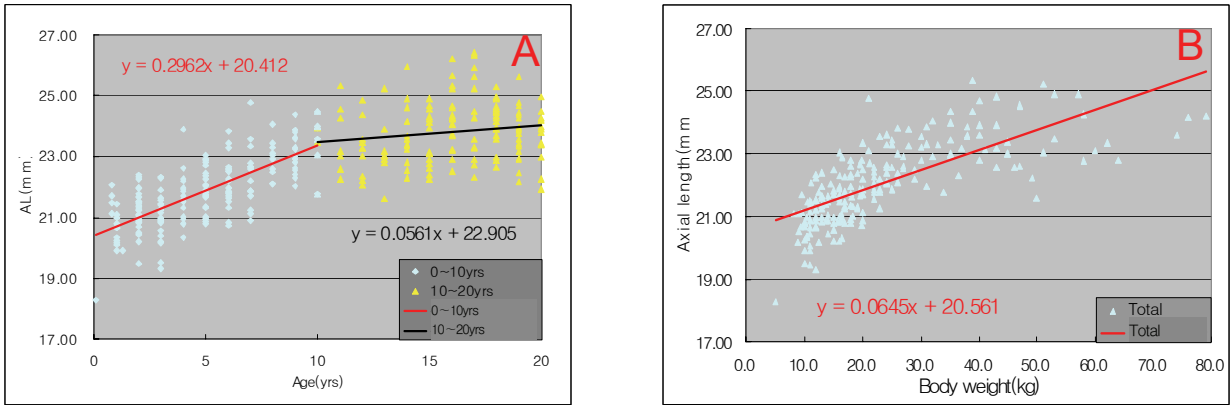


Fig. 2. Relationship between age and axial length, body weight and axial length.
 (A) Relationship between age and axial length in age 0~10 years ($r=0.725$, $p<0.001$) and 10~20 years ($r=0.166$, $p=0.043$).
 (B) Relationship between body weight and axial length ($r=0.723$, $p<0.001$).

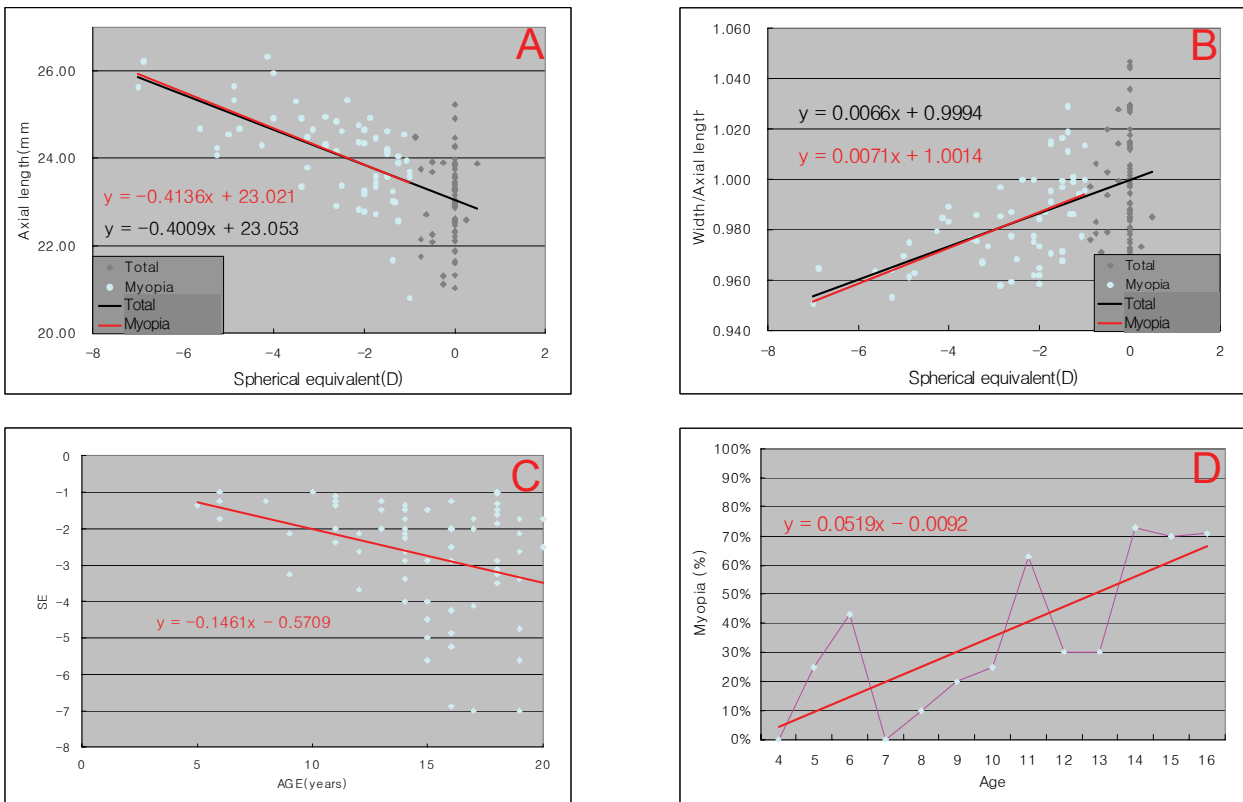


Fig. 3. Relationship between spherical equivalent and axial length, spherical equivalent and width/axial length.
 (A) Relationship between spherical equivalent and axial length in myopia ($r=-0.598$, $p<0.001$) and the total population ($r=-0.595$, $p<0.001$).
 (B) Relationship between spherical equivalent and width/axial length in myopia ($r=0.575$, $p<0.001$) and in the total population ($r=0.495$, $p<0.001$).
 (C) Relationship between age and spherical equivalent in myopia ($r=-0.335$, $p=0.004$).
 (D) Relationship between age and the proportion of myopic eyes in the total population ($r=0.634$, $p=0.002$).

width/axial length decreased with age, and was 1.004 at age 5 but decreased to 0.971 at age 20. However, in emmetropia, width/axial length increased with age. It was 0.990 at age 5 but increased to 1.006 at age 20 (Fig. 4).

Discussion

CT, MRI or US are used to investigate eyeball or orbit morphologies. Axial length can be measured relatively accurately by US but height and width cannot and it is

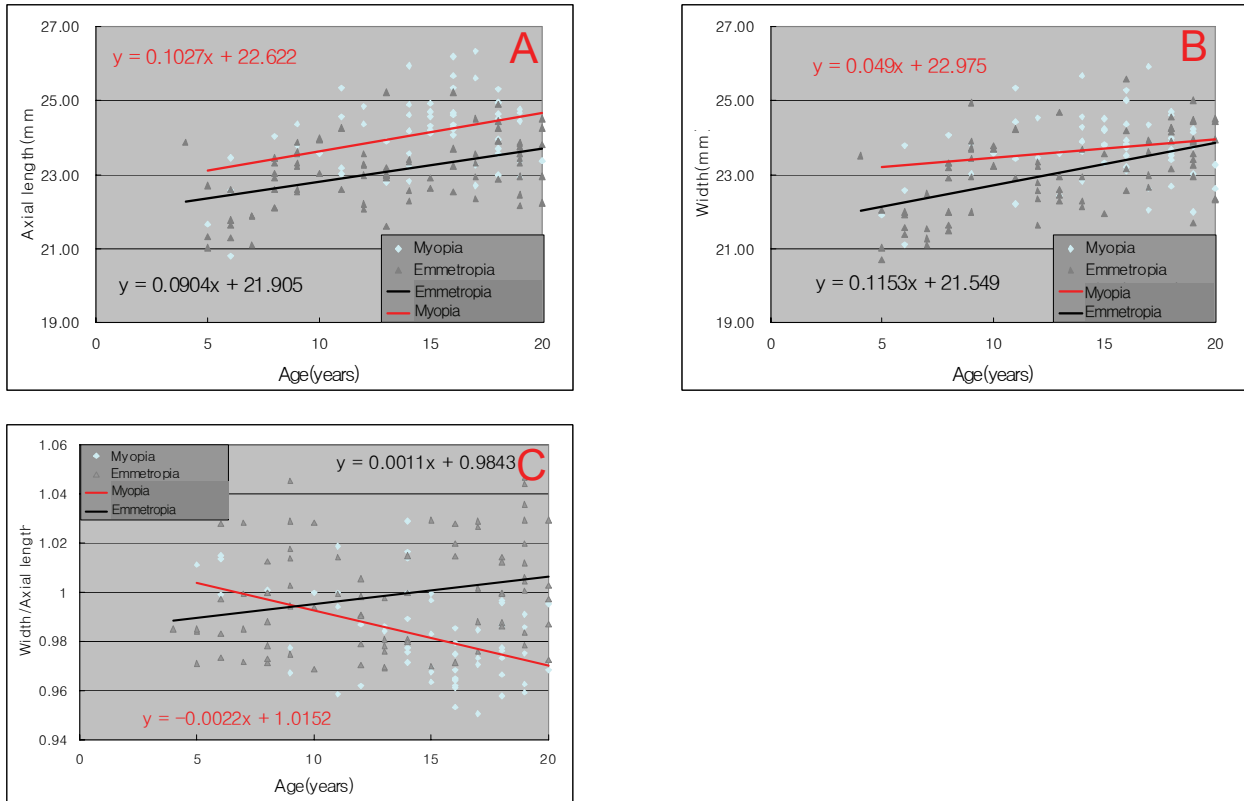


Fig. 4. Relationships between age and axial length, age and width, age and width/axial length in myopia and emmetropia. (A) Relationships between age and axial length in myopia ($r=0.372$, $p=0.003$) and emmetropia ($r=0.480$, $p<0.001$). (B) Relationships between age and width in myopia ($r=0.198$, $p=0.129$) and emmetropia ($r=0.517$, $p<0.001$). (C) Relationships between age and width/axial length in myopia ($r=-0.452$, $p<0.001$) and emmetropia ($r=0.250$, $p=0.025$).

difficult to determine exactly if there is some kind of substance in the eyeball, such as a silicone implant that might influence US findings. MRI is superior to CT in terms of image quality, but it is inaccurate for observing the orbit and due to its high cost and time requirements, is inferior to CT for clinical purposes.^{4,5,11-14}

Some studies have been conducted on axial length using US. In one study, axial length was estimated between 3 and 9 months after birth, average axial length was 19.03 ± 0.58 mm at 3 months and 20.23 ± 0.64 mm at 9 months, representing a growth of 1.20 ± 0.51 mm in axial length over 6 months. In another study of 6 to 16 year olds, axial length was found to be directly proportional to age (correlation coefficient $r=0.733\sim 0.761$), height (correlation coefficient $r=0.827\sim 0.872$) and weight (correlation coefficient $r=0.773\sim 0.820$) respectively. In addition, it has been reported that axial length in boys is greater than in girls in 6 to 14 year olds by about 0.32 mm, and another report on emmetropia found that axial length increases rapidly until 10.5 years and then increases slowly.^{8,15-18} In the present study, axial length increased as age and body weight increased. Axial length increases rapidly until age 10 and then slows, which resembles the neural type growth pattern of Scammon (Fig. 2).

The majority of studies reported to date involve measures

of axial length from the anterior corneal surface, but since eye shape is measured from internal surface of the eye, we measured axial length from the posterior corneal surface. When measuring axial length from the anterior corneal surface, measurement errors due to the eyelid in CT images can be reduced. Corneal thicknesses usually range between $450\sim 650$ μm , and age, sex, and refractive error have little influence.¹⁹⁻²²

In an MRI study of adult eyeball shapes (age 18 to 36), eyes were divided into 7 groups by refractive error and groups were then compared. It was concluded that there was no difference between eyeball height and width in emmetropia, but that eyeball height is greater than width in myopia. Axial length, eyeball height and width were longer in myopia than in emmetropia, and axial length was greater than eyeball height or width in myopia and emmetropia. Moreover, the greater the severity myopia, the more axial length (0.35 mm/D), eyeball height (0.19 mm/D) and width (0.10 mm/D) increased.¹⁴ However, in our study increments of eye width were greater than increments of axial length. These studies differ in terms of eye shape measurements. First, in the study using MRI, axial length was measured from the anterior corneal surface, and measured axial lengths were 500 μm longer on average. Second, widths were

measured in coronal view, which corresponds to horizontal length as defined in the present study, which is shorter than the width. Thus axial length was longer and eyeball width was shorter in the previous study than in our study, which accounts for these observed differences.

Several studies have been conducted on morphological changes of eye shape according to refractive error. In one study, those that developed myopia earlier, showed a greater degree of myopia, and as degree of myopia increased, axial length and eyeball volume also increased. Another study found that after 5 years of age, the prevalence and degree of myopia increased constantly until age 40, and as the spherical equivalent of myopia increased, axial length increased proportionally.^{13,23-25}

In our study the myopic population increased and the degree of myopia increased as age increased, which suggests that as age increases a new myopic population develops and myopic eyes become more myopic. Both emmetropic and myopic groups had a greater vertical than horizontal length, though width, horizontal length, and vertical length were all greater in myopia than in emmetropia. As degree of myopia increased in myopic eyes, axial length (0.414 mm/D), width (0.234 mm/D) and vertical length (0.273 mm/D) increased proportionally. Moreover, axial length in myopia was longer than width, horizontal length, and vertical length, which differentiated it from emmetropia.

Both axial length and width increased in emmetropia as age increased, but width increased faster than axial length, so at age 5 'width/axial length < 1' and this becomes 'width/axial length > 1' at age 20. However in myopia, both axial length and width increased with age, but axial length increases faster than width, so at age 5 'width/axial length > 1' and this becomes 'width/axial length < 1' at age 20. Thus, eye shape in emmetropia changes from oval, with a greater anterior to posterior diameter, to spherical shape during aging, but in myopia, eye shape changes from spherical (the anterior to posterior diameter was similar to the width of the eye) to an oval shape during aging (Fig 4). As axial length increases but axial width decreases in case of myopia, it can be indirectly identified that orbital volume does not increase as much as the axial length increases in case of myopia.

This study suggests that an understanding of eyeball growth patterns may facilitate the early detection of orbital diseases. The authors believe that such knowledge can improve prognoses among children.

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