Original Article

# Axial Length to Corneal Radius of Curvature Ratio and Refractive Errors

**Hassan Hashemi[1,2], MD; Mehdi Khabazkhoob[1], MS; Mohammad Miraftab[1], MD**
**Mohammad Hassan Emamian[3], MD; Mohammad Shariati[4], MD**
**Tahereh Abdolahi-nia[1,5]; Akbar Fotouhi[6], MD, PhD**

[1]*Noor Ophthalmology Research Center, Noor Eye Hospital, Tehran, Iran*
[2]*Farabi Eye Hospital, Tehran University of Medical Sciences, Tehran, Iran*
[3]*Shahroud University of Medical Sciences, Shahroud, Iran*
[4]*Education Development Center, Tehran University of Medical Sciences, Tehran, Iran*
[5]*Department of Optometry, Tehran University of Medical Sciences, Tehran, Iran*
[6]*Department of Epidemiology and Biostatistics, School of Public Health, Tehran University of Medical Sciences, Tehran, Iran*

**Purpose:** To determine the distribution of axial length (AL) to corneal radius of curvature (CRC) ratio and to evaluate its association with refractive errors in an Iranian population.
**Methods:** In this cross sectional study, multistage cluster sampling was used to select subjects 40-64 years of age residing in Shahroud, northern Iran. All subjects underwent manifest and cycloplegic refraction, and biometry using the Allegro Biograph (WaveLight AG, Erlangen, Germany). Individuals with a history of intraocular surgery, extensive pterygia and ocular trauma were excluded.
**Results:** Of a total of 6,311 patients, 5190 (82.2%) participated in the study. We excluded 247 patients to adhere with study criteria and 132 patients due to missing data. Mean AL/CRC was 3.034 [95% confidence interval (CI), 3.031–3.037]. AL/CRC was 3.028 and 3.042 in female and male subjects, respectively ($P<0.001$). The $R^2$ coefficients between spherical equivalent (SE) refractive error and AL/CRC, AL, CRC, lens thickness, and anterior chamber depth were 0.607, 0.351, 0.012, 0.038, and 0.091, respectively. Linear regression showed a 12.1 diopter (D) shift towards myopia with every 1 unit increase in AL/CRC ($P<0.001$). Mean AL/CRC was 3.472 among myopes with SE less than -5.0D; this value decreased linearly and was as low as 2.690 among hyperopes with SE more than 5.0D. $R^2$ coefficients for AL/CRC with spherical and cylindrical power were 0.560 and 0.071, respectively.
**Conclusions:** Minimal changes in AL/CRC lead to large changes in refractive error. The correlation between refractive errors was significantly stronger with the AL/CRC ratio than with AL and CRC alone.

**Keywords:** Axial Length; Corneal Radius of Curvature; Refractive Errors

*J Ophthalmic Vis Res* 2013; 8 (3): 220-226.

**Correspondence to:** Akbar Fotouhi, MD, PhD. Epidemiology and Biostatistics Department, School of Public Health, Tehran University of Medical Sciences, Tehran, Iran; Tel: +98 21 8898 7381-2, Fax: +98 21 8898 9664; email: afotouhi@tums.ac.ir

**Received:** December 09, 2012 **Accepted:** May 22, 2013

## INTRODUCTION

Ocular biometrics are among the most important factors affecting refractive errors.[1-3] Most studies suggest axial length (AL) is the most important determinant of refractive errors.[2-6] However, current knowledge on emmetropization indicates that individual biometric components are not important by themselves and that emmetropization is a result of a balance among these components.[7]

Changes in AL and corneal radius of curvature (CRC) are important biometric factors affecting refractive errors.[8-10] AL has a larger effect on inducing refractive errors as compared to CRC.[2,3] However, the process of emmetropization seems to indicate a compensating association between these two components. For example, Grosvenor et al[8] demonstrated a more important role for the AL/CRC ratio than for AL alone, and the correlation between spherical equivalent (SE) refractive error and this variable was stronger than that with each of its components alone. Subsequently, other studies have shown that the AL/CRC ratio was the most important biometric factor in myopia, especially high myopia.[10,11]

AL/CRC was first studied by Emsley and later addressed in other studies.[8] However, AL/CRC has been less extensively studied than other biometric parameters. The average values reported for AL/CRC range from 2.90 to 3.10.[2,3,12,13]

Some reports have indicated that AL is smaller in some races despite a higher prevalence of myopia. This observation indicates that AL/CRC may be a more important factor than AL or CRC alone. Few studies have studied this index in the Middle East.[3,12,14] Although in some areas of the world, this index can be derived from studies on AL and CRC, reports concerning AL/CRC are scarce.

Herein, we report the AL/CRC ratio in an Iranian population. In addition, we examine the correlation between this index and other ocular biometric components and their association with refractive errors.

## METHODS

The first phase of Shahroud Cohort Eye Study (ShECS) was a cross-sectional study in 2009. Details of the sampling strategy and methodology have been published elsewhere.[15]

Briefly, multistage sampling was performed to select subjects from the 40-64 year old population of Shahroud. Three hundred clusters were randomly selected from 9 strata (health care centers). From each cluster, 200 people were for complete eye examinations. After signing informed consent forms, the participants were interviewed to collect data on demographics, economic status, occupation, smoking habits, and ophthalmic and general medical history.

Near and distance visual acuity was measured in all participants using a LogMAR chart with and without correction. Refraction was first performed with the Topcon AR 8800 autorefractometer (Topcon Corporation, Tokyo, Japan) and results were then refined by objective (Heine BETA 200 Retinoscope, Germany) and subjective refraction. If no contraindication existed, participants underwent cycloplegic refraction induced with cyclopentolate 1%. Ophthalmic tests included slit lamp biomicroscopy (Haag-Streit BM 900 Basic Slit Lamp, USA) and fundus examination.

For the current study, we excluded data from participants with history of intraocular surgery. Patients with a history of ocular trauma requiring hospitalization, and patients with extensive pterygia (grade 3) were also excluded.

Biometric measurements were completed after testing for visual acuity and before ophthalmic examinations and cycloplegia. All eyes were measured using the Allegro Biograph (WaveLight AG, Erlangen, Germany) and for the purpose of this study, AL and CRC readings were extracted.

The ratio of AL to CRC was the main variable of interest. An SE of -0.5 diopter (D) or less was defined as myopia and an SE of 0.5D or more was considered as hyperopia. To show correlations between refractive errors and the AL/CRC ratio, we created SE categories. Mean and 95% confidence intervals (CIs) for AL/CRC were determined in the total population and in different age and gender groups. The effect of cluster sampling was adjusted for determining CIs. For AL/CRC, we calculated the distribution and variation, and to show associations and correlations with other variables we used Pearson correlation and linear regressions. $R^2$ was calculated using linear regression analysis, and the regression coefficient (95% CI) was reported. To compare AL/CRC in different age groups, we used the Generalized Linear Model

(GLM) to consider the impact of clusters. In this model, age was considered as a fixed factor.

All participants received detailed information about the study before being enrolled and were required to sign informed consent prior to participation. The study was approved by the Ethics Committee at Shahroud University of Medical Sciences.

## RESULTS

Of the 6,311 eligible subjects, 5,190 individuals (82.2%) agreed to participate. For the purpose of the current study, we eliminated data from 247 individuals who did not fulfill the study criteria, and 123 more individuals who had missing data. Eventually, analysis was performed on data from 4,820 individuals. Considering the high correlation between fellow eyes in terms of AL (r=0.912) and CRC (r=0.948), only data from right eyes are presented.

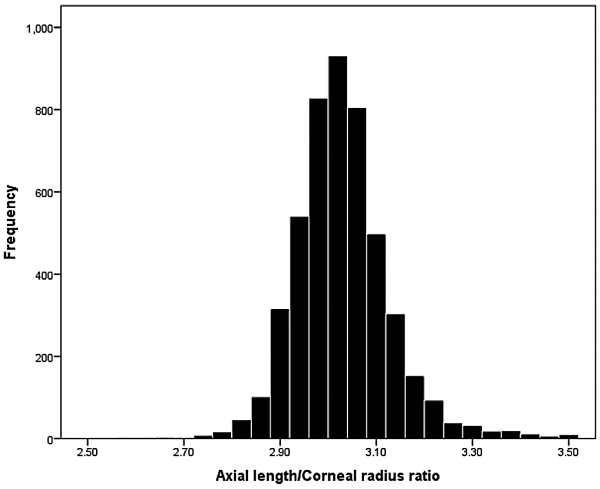


**Figure 1.** Distribution of axial length/corneal radius of curvature in an Iranian cohort.

Mean AL/CRC was 3.034 (95% CI, 3.031 to 3.037), and the 25th, 50th, 75th, and 95th percentiles were 2.97, 3.02, 3.08, and 3.21, respectively. Figure 1 shows the distribution of AL/CRC. Skewness, kurtosis, and the interquartile range for AL/CRC were 2.04, 12.437, and 0.111, respectively. Mean AL/CRC was 3.01 in emmetropic eyes (SE less than 0.5D) and the normal range (mean ± 2 standard deviations) was 2.87 to 3.15.

Table 1 shows mean AL/CRC values in different age groups and in either gender; GLM analysis showed no significant difference among different age groups (P=0.658). After adjusting for age, AL/CRC was 3.028 (95% CI, 3.024 to 3.032) and 3.042 (95% CI, 3.037 to 3.048) in female and male subjects, respectively (P<0.001). AL/CRC had a direct and significant correlation with AL ($R^2$=0.358), and an inverse correlation with CRC ($R^2$=0.124). Intraocular pressure had a weak but significant association with AL/CRC ($R^2$=0.02, P=0.045).

AL/CRC showed the strongest correlation with SE refractive error. $R^2$ coefficients for SE and AL/CRC, AL, CRC, lens thickness, and anterior chamber depth were 0.607, 0.351, 0.012, 0.038, and 0.091, respectively. The relationship between the study variables and SE was evaluated using simple linear regression analysis and the results are summarized in Table 2.

Figure 2 demonstrates the correlation between SE and AL/CRC, AL, and CRC; the highest and lowest AL/CRC values were seen in eyes with high myopia and high hyperopia, respectively (Fig. 3). Mean AL/CRC was 3.472 in eyes with myopia greater than -5.0D; this value decreased linearly and reached a minimum of

**Table 1.** Distribution of axial length/corneal radius of curvature by age and gender

| | Mean (95% Confidence interval) | 5th percentile | Median | 95th percentile |
|---|---|---|---|---|
| Age (years) | | | | |
| 40-44 | 3.037 (3.031-3.043) | 2.900 | 3.025 | 3.201 |
| 45-49 | 3.032 (3.026-3.037) | 2.889 | 3.024 | 3.208 |
| 50-54 | 3.036 (3.029-3.043) | 2.887 | 3.027 | 3.205 |
| 55-59 | 3.033 (3.025-3.041) | 2.886 | 3.024 | 3.204 |
| 60-64 | 3.031 (3.021-3.041) | 2.873 | 3.020 | 3.218 |
| Gender | | | | |
| Female | 3.028 (3.024-3.032) | 2.886 | 3.016 | 3.201 |
| Male | 3.042 (3.037-3.048) | 2.892 | 3.035 | 3.212 |
| Total | 3.034 (3.031-3.037) | 2.887 | 3.025 | 3.206 |

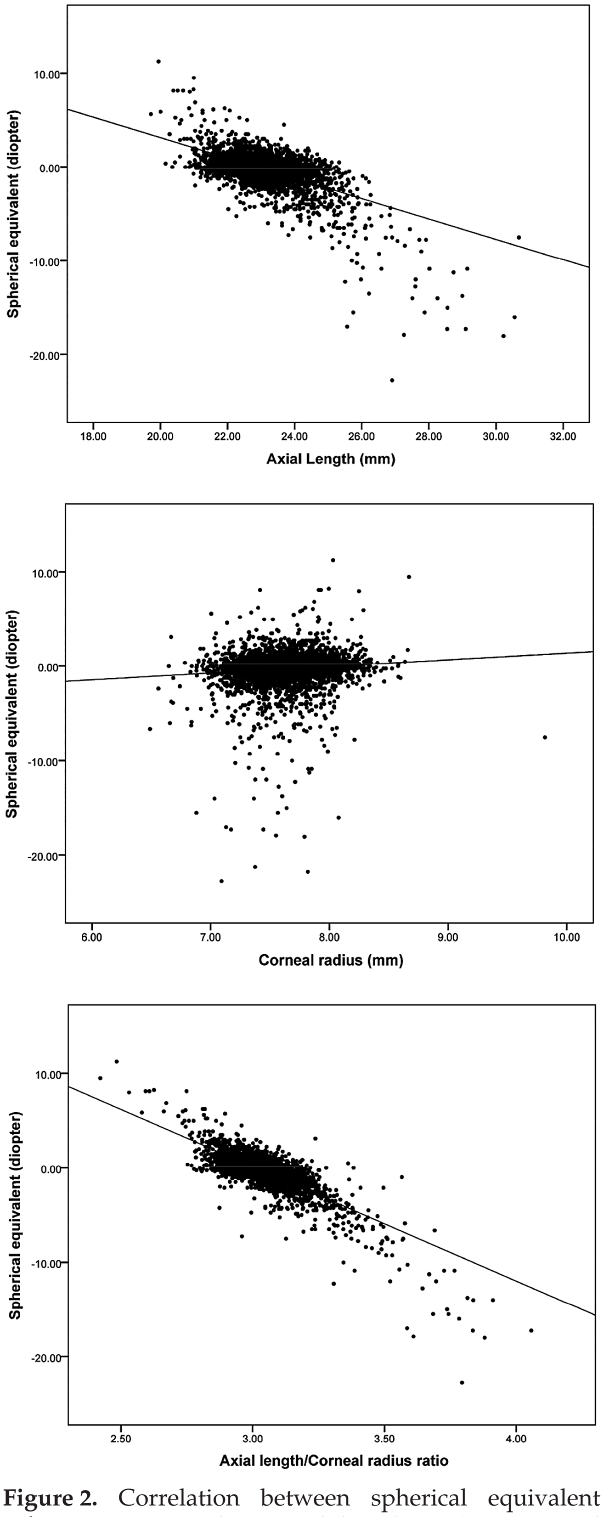


**Figure 2.** Correlation between spherical equivalent refractive error and A, axial length (AL); B, corneal radius of curvature (CRC); C, AL/CRC.

2.690 in cases with hyperopia more than 5.0D. Linear regression showed a shift of 12.1D in SE refractive error towards myopia with every 1

**Table 2.** Simple linear regressions between spherical equivalent (diopter) and the studied variables

| Variables | Coefficient (95%CI) | p-value |
|---|---|---|
| Axial length/corneal radius | -12.13 (-12.89 to -11.36) | <0.001 |
| Axial length (mm) | -1.09 (-1.19 to -0.98) | <0.001 |
| Corneal radius (mm) | 0.71 (0.47 to 0.95) | <0.001 |
| Lens thickness (mm) | 1.18 (1.02 to 1.35) | <0.001 |
| Anterior chamber depth (mm) | -1.64 (-1.82 to -1.47) | <0.001 |

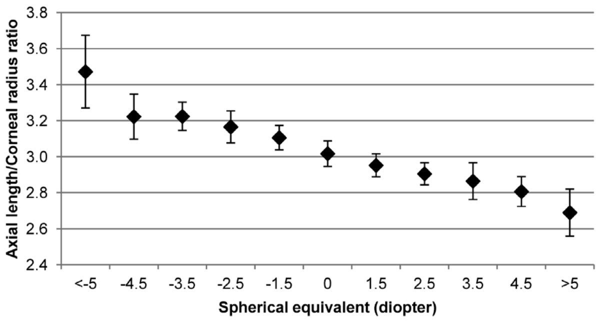


**Figure 3.** Correlation between axial length/corneal radius of curvature and spherical equivalent categories.

unit increase in AL/CRC (P<0.001). As for the association between refractive error components and AL/CRC, the spherical component showed a stronger correlation as compared to the cylindrical component; $R^2$ coefficients were 0.560 and 0.071, respectively.

## DISCUSSION

The distribution of AL/CRC has been reported in different populations and age groups.[1,3,10,16] All of these studies have provided AL/CRC values along with other biometric components. In the current study we focused on the AL/CRC ratio and reported its association with refractive errors. A summary of other studies is presented in Table 3. In some studies, AL/CRC has been reported directly; for others we used raw AL and CRC data to calculate the ratio. The reported mean values in different studies range from 2.9 to 3.1. These results revealed some interesting insights. First, the AL/CRC ratio shows no significant variation among different races. Second, the minimum value was seen among young Australian children[13] and the maximum was reported in the 17-30 year-old age group in the UK[16].

**Table 3.** Studies reporting axial length (AL), corneal radius of curvature (CRC), and AL/CRC

| Origin | n | Age (years) | AL/CRC | AL | CRC |
|---|---|---|---|---|---|
| Singapore[21] | 1,004 | 40 to 81 | 3.04 | 23.23 | 7.65 |
| Myanmar [3] | 444 | 40-49 | 2.99 | 22.75 | 7.61 |
| Myanmar [3] | 463 | 50-59 | 2.99 | 22.74 | 7.61 |
| Myanmar [3] | 342 | 60-69 | 2.99 | 22.75 | 7.61 |
| Myanmar [3] | 249 | >70 | 2.97 | 22.73 | 7.65 |
| Myanmar [3] | 1,498 | 40+ | 2.99 | 22.76 | 7.62 |
| Mashhad, Iran [2] | 269 | 21-60 | 3.10 | 23.60 | 7.6 |
| Australia[13] | 1,765 | 5.5 to 8.4 | 2.906 | - | - |
| UK[15] | 373 | 17-30 | 3.10 | - | - |
| Spain[10] | 583 | 20.32±2.82 | 3.05 | - | - |
| Jordan[1] | 1,093 | 17-40 | 3.00 | - | - |
| Saudi Arabia[16] | 152 | 16-50 | 3.00 | - | - |
| Current study | 4,820 | 40-64 | 3.033 | 23.14 | 7.63 |

Few studies have studied the intergender difference in AL/CRC.[1,10] We found this ration to be 0.015 units greater in male subjects as compared to female counterparts. This difference may seem small, but considering the limited range of AL/CRC, it may explain much of the intergender difference in refractive errors. Ojaimi et al,[13] Gonzales et al,[10] Mallen et al,[1] and Osubeni[17] have also reported higher AL/CRC in men. This difference could be due to anthropometric differences between men and women. Of note, most studies have reported a higher prevalence of hyperopia among female and myopia in male subjects.[1,3,18,19] This could be one of the most important results of the intergender difference in AL/CRC as discussed above.

We found no significant association between AL/CRC and age. The greatest changes in ocular biometrics towards emmetropization occur before the age of 20 years[20] which was not evaluated in the current study. It seems that emmetropization may have long ceased in our subjects prior to the study. Another explanation for the lack of significant change in AL/CRC ratio with age may be that some other refractive component, such as the lens, is in balance to control refractive errors.

Grosvenor[8] was the first to suggest an association between AL/CRC and refractive errors[8]; he pointed out the importance of this index, especially in myopes as in several other reports.[10,11,21] Our findings further confirm Grosvenor's hypothesis; we found a linear increase in AL/CRC from high hyperopia toward high myopia. Every 0.1 unit of increase in AL/CRC was associated with approximately 1D of myopic shift. This finding has been confirmed by other investigators.[8] The association between SE and AL/CRC was stronger than that with AL or CRC alone; this finding has been previously reported by Grosvenor.[8]

Our findings indicate that refractive errors are a function of changes in AL and CRC. Major changes in each component can change the ratio and manifest as high refractive errors. For example in high myopia, high AL is present and since emmetropization is disrupted, the cornea cannot compensate for changes in AL. As expected, the AL/CRC ratio stays relatively stable after the fifth decade of life and thus, we expect additional factors to be responsible for refractive errors. This is especially true when we see myopia in older subjects which can be attributable to opacities in the crystalline lens, or low myopia due to structural changes of the lens nucleus.

Overall, in light of results from different studies,[8,10,11,12] chances of emmetropia are highest when the AL/CRC ratio is close to 3. Any disturbance in this ratio, in any age group, can be interpreted as a sign portending refractive errors. In children, in particular, a ratio that differs from 3 can be indicative of disruption in the emmetropization process, and therefore assessment for amblyopia and anisometropia become important. Although emmetropization is a slower process in adults, the fact that the AL/

CRC ratio remains constant becomes important in interpreting the pathogenesis of pathologic conditions. Although clinical application of the ratio fades in the presence of advanced clinical tests such as electrophysiologic tests, retinal imaging, optical nerve head imaging, and optical coherence imaging, it is still an important predictive index for children at risk of progressive myopia and adults at risk of primary open angle glaucoma. Based on our hypothesis, one major clinical application would be in refractive and cataract surgery; corrections should be designed to keep this ratio near 3 to achieve emmetropia. Naturally, using this in practice requires knowledge of the normal range in the population because it may vary by demographics of different populations.

Attention to the range of AL/CRC in normal populations is necessary. The index has the strongest correlation with refractive error as compared to other biometric components. The association between AL/CRC and refraction is linear; the ratio is highest in high myopia and lowest in high hyperopia. Studying the index in normal populations can help determine the standards for use in refractive surgery.

## Conflicts of Interest

None.

## *REFERENCES*


1. Mallen EA, Gammoh Y, Al-Bdour M, Sayegh FN. Refractive error and ocular biometry in Jordanian adults. *Ophthalmic Physiol Opt* 2005;25:302-309.
2. Yekta A, Fotouhi A, Hashemi H, Ostadi Moghaddam H, Heravian J, Heydarian S, et al. Relationship between refractive errors and ocular biometry components in carpet weavers. *Iran J Ophthalmol* 2010;22:45-54.
3. Warrier S, Wu HM, Newland HS, Muecke J, Selva D, Aung T, et al. Ocular biometry and determinants of refractive error in rural Myanmar: the Meiktila Eye Study. *Br J Ophthalmol* 2008;92:1591-1594.
4. Foster PJ, Broadway DC, Hayat S, Luben R, Dalzell N, Bingham S, et al. Refractive error, axial length and anterior chamber depth of the eye in British adults: the EPIC-Norfolk Eye Study. *Br J Ophthalmol* 2010;94:827-830.
5. Wickremasinghe S, Foster PJ, Uranchimeg D, Lee PS, Devereux JG, Alsbirk PH, et al. Ocular biometry and refraction in Mongolian adults. *Invest Ophthalmol Vis Sci* 2004;45:776-783.
6. Shufelt C, Fraser-Bell S, Ying-Lai M, Torres M, Varma R. Refractive error, ocular biometry, and lens opalescence in an adult population: the Los Angeles Latino Eye Study. *Invest Ophthalmol Vis Sci* 2005;46:4450-4460.
7. Ooi CS, Grosvenor T. Mechanisms of emmetropization in the aging eye. *Optom Vis Sci* 1995;72:60-66.
8. Grosvenor T, Scott R. Role of the axial length/corneal radius ratio in determining the refractive state of the eye. *Optom Vis Sci* 1994;71:573-579.
9. Wu HM, Gupta A, Newland HS, Selva D, Aung T, Casson RJ. Association between stature, ocular biometry and refraction in an adult population in rural Myanmar: the Meiktila eye study. *Clin Experiment Ophthalmol* 2007;35:834-839.
10. González Blanco F, Sanz Fernández JC, Muńoz Sanz MA. Axial length, corneal radius, and age of myopia onset. *Optom Vis Sci* 2008;85:89-96.
11. Goss DA, Jackson TW. Clinical findings before the onset of myopia in youth. I. Ocular optical components. *Optom Vis Sci* 1995;72:870-878.
12. Wong TY, Foster PJ, Ng TP, Tielsch JM, Johnson GJ, Seah SK. Variations in ocular biometry in an adult Chinese population in Singapore: the Tanjong Pagar Survey. *Invest Ophthalmol Vis Sci* 2001;42:73-80.
13. Ojaimi E, Rose KA, Morgan IG, Smith W, Martin FJ, Kifley A, et al. Distribution of ocular biometric parameters and refraction in a population-based study of Australian children. *Invest Ophthalmol Vis Sci* 2005;46:2748-2754.
14. He M, Huang W, Li Y, Zheng Y, Yin Q, Foster PJ. Refractive error and biometry in older Chinese adults: the Liwan eye study. *Invest Ophthalmol Vis Sci* 2009;50:5130-5136.
15. Fotouhi A, Hashemi H, Shariati M, Emamian MH, Yazdani K, Jafarzadehpur E, et al. Cohort Profile: Shahroud Eye Cohort Study. *Int J Epidemiol* 2013 Apr 22. [Epub ahead of print].
16. Logan NS, Davies LN, Mallen EA, Gilmartin B. Ametropia and ocular biometry in a U.K. university student population. *Optom Vis Sci* 2005;82:261-266.
17. Osuobeni EP. Ocular components values and their intercorrelations in Saudi Arabians. *Ophthalmic Physiol Opt* 1999;19:489-497.
18. Yekta AA, Fotouhi A, KhabazKhoob M, Hashemi H, Ostadimoghaddam H, Heravian J, et al. The prevalence of refractive errors and its determinants in the elderly population of Mashhad, Iran.

*Ophthalmic Epidemiol* 2009;16:198-203.

19. Eysteinsson T, Jonasson F, Arnarsson A, Sasaki H, Sasaki K. Relationships between ocular dimensions and adult stature among participants in the Reykjavik Eye Study. *Acta Ophthalmol Scand* 2005;83:734-738.
20. Zadnik K, Mutti DO, Mitchell GL, Jones LA, Burr D, Moeschberger ML. Normal eye growth in emmetropic schoolchildren. *Optom Vis Sci* 2004;81:819-828.
21. Lin JT. Analysis of refractive state ratios and the onset of myopia. *Ophthalmic Physiol Opt* 2006;26:97-105.