REVIEW ARTICLE

The role of axial length and keratometry in the follow-up of myopic children

María Marta Galán[a], Jan Willem Lodewijk Tideman[b], Rafael Iribarren[c]

[a] *Ex Head of Children's Hospital Ophthalmology Dept. (HIGA), La Plata, Argentina.*

[b] *Department of Ophthalmology, Erasmus Medical Centre, Rotterdam, The Netherlands.*

[c] *Drs. Iribarren Eye Consultants, Buenos Aires, Argentina.*

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Corresponding author
Dr. Rafael Iribarren
Drs. Iribarren Eye Consultants
Arenales 981
1061 Buenos Aires City, Argentina
+54-911-5147-9312
Erafairibarren@gmail.com

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Abstract

Since increased rates of axial elongation are the primary cause of school myopia, following up axial length changes may be valuable in clinical practice. Recently developed curves of ocular growth for schoolchildren allow us to know in which percentile of normal growth is a particular child under follow up. As girls have shorter eyes with more curved corneas than boys, the published axial growth curves were split by gender. Corneal power is also a determinant of refraction. Keratometry is normally distributed in the myopic population around a mean of 43.00D. Some myopic eyes have flat corneas and others have steep corneas. Longer eyes are more prone to developing myopic maculopathy in adult years. If a mild myopic child has flat corneas near 40.00D, one can assume that these eyes may be 1 mm longer than usual by previous emmetropization mechanisms acting in the first years of life, well before myopia developed. In clinical practice, after subjective and cycloplegic refractive error has been evaluated, keratometry and axial length measurements are most necessary to know how any given eye has achieved its particular refractive error. We suggest that, alongside monitoring axial growth changes, keratometry is also considered at the first visit of a myopic patient to determine whether the cornea is either normal, or unusually flat or steep.

Key words: axial length, keratometry, myopia, children, refraction errors, follow up.

El rol de la longitud axial y la queratometría en el seguimiento de niños miopes

Resumen

Dado que el aumento de la tasa de elongación axial es la causa principal de la miopía escolar, el seguimiento de los cambios en la longitud axial puede ser valioso en la práctica clínica. Las curvas de crecimiento ocular desarrolladas recientemente para los niños de edad escolar permiten saber en qué percentil de crecimiento normal se encuentra un determinado niño en seguimiento. Como las niñas tienen ojos más cortos y córneas más curvas que los niños, las curvas de crecimiento axial publicadas se han dividido por género. El poder de la córnea también es un determinante de la refracción. La queratometría se distribuye normalmente en la población miope en torno a una media de 43,00D. Algunos ojos miopes tienen córneas planas y otros tienen córneas más curvas. Los ojos más largos son más propensos a desarrollar una maculopatía miópica en la edad adulta. Si un niño con miopía leve tiene córneas planas cercanas a 40,00D, se puede suponer que estos ojos pueden ser 1 mm más largos de lo habitual por mecanismos de emetropización previos que actuaron en los primeros años de vida, mucho antes de que se desarrollara la miopía. En la práctica clínica, después de evaluar el error de refracción subjetivo y ciclopléjico, la queratometría y las mediciones de la longitud axial son necesarias para saber cómo ha alcanzado un ojo determinado su error refractivo particular. Sugerimos que, junto con el seguimiento de los cambios en el crecimiento axial, se considere también la queratometría en la primera visita de un paciente miope para determinar si la córnea es normal o inusualmente plana o muy curva.

Palabras clave: largo axial, queratometría, miopía, niños, errores de refracción, seguimiento.

O papel do comprimento axial e da ceratometria no acompanhamento de crianças miopes

Resumo

Uma vez que o aumento da taxa de alongamento axial é a principal causa da miopia escolar, monitorar as mudanças no comprimento axial pode ser valioso na prática clínica. As curvas de crescimento ocular desenvolvidas recentemente para crianças em idade escolar nos permitem saber em que porcentagem do crescimento normal uma determinada criança está sendo monitorada. Como as meninas têm olhos mais curtos e córneas mais curvas do que os meninos, as curvas de crescimento axial publicadas foram divididas por gênero. O poder da córnea também é um determinante da refração. A ceratometria é normalmente distribuída na população míope em torno de uma média de 43,00D. Alguns olhos míopes têm córneas planas e outros, córneas mais curvas. Olhos mais longos têm maior probabilidade de desenvolver maculopatia miópica na idade adulta. Se uma criança com miopia leve tiver córneas planas perto de 40,00D, pode-se supor que esses olhos podem ser 1 mm mais longos que o normal devido a mecanismos de emetropização anteriores que atuaram nos primeiros anos de vida, muito antes de desenvolverem. Na prática clínica, após avaliar o erro refrativo subjetivo e cicloplégico, a ceratometria e as medidas do comprimento axial são necessárias para determinar como um olho específico atingiu seu erro refrativo específico.

Sugerimos que, junto com o monitoramento das mudanças no crescimento axial, a ceratometria também seja considerada na primeira visita de um paciente miópico para determinar se a córnea é normal ou anormalmente plana ou altamente curva.

Palavras chave: comprimento axial, ceratometria, miopia, crianças, erros de refração, acompanhamento

The International Myopia Institute (IMI) classifies myopia according to age of onset, rate of progression, amount of correction, and refractive or axial etiology[1-3]. Examples of refractive myopia would be those forms caused by nuclear cataract, keratoconus or lenticonus, while axial myopia can be attributed to excessive elongation of the globe[1]. The latter can also have undesirable consequences in the form of posterior pole lesions, such as staphyloma and myopic maculopathy[4]. Since axial elongation is the primary cause of school myopia, following up axial length changes may be valuable in clinical practice to detect children at risk of developing myopia or assess the effect of therapeutic modalities. The IMI suggests that, if possible, biometric changes should be recorded throughout the treatment period, while tracking axial length is considered essential in clinical and animal studies on myopia[2-3]. The goal would be early detection of children prone to high myopia, arresting their progression and thus avoiding the complication of myopic maculopathy, which is becoming a leading cause of vision impairment in working age population[5].

Measuring axial length

Traditionally, axial length is measured using ultrasound biometry, where a transducer that is in contact with the cornea emits ultrasound waves (typically 10 MHz), records the echoes of these waves reflected by the ocular structures and analyses the time delay between these echoes according to the mean speed of sound in the eye. These measurements can be done with a transducer in direct contact with the cornea or through immersion. In the first case, readings may be lower due to the corneal flattening resulting from excessive pressure on the eye by the operator that can lead to up to 0.30 mm of difference between successive measurements. Moreover, these measures can be difficult to obtain in children and are highly operator-dependent.

Most problems of the ultrasound systems were solved by optical Partial Coherence Interferometry, which provides non-contact axial length measurements using two partially coherent laser beams. These beams are directed into the eye, reflected by the intraocular tissues, and finally made to interfere with one another. The distances between the peaks of the interference pattern then correspond to the geometric distances the optical surfaces of the eye after a simple conversion[6]. Note that laser interferometry uses a slightly different definition of axial length as ultrasound because the former considers it the distance between the anterior cornea and the pigment epithelium, while the latter defines it using the internal limiting membrane. Consequently, some devices automatically subtract the 200 *μm* of foveolar retinal thickness, to ensure that old intraocular lens power calculation formulas would still work, as these were originally developed for ultrasound biometry[7-8].

Although partial coherence laser interferometry may slightly overestimate axial length in case of accommodation and may not be reliable in the presence of lens or corneal opacities, its measurements are overall more precise, repeatable, easier to align and quite tolerant to motion, thus making it ideal in a pediatric population. This is therefore the method of choice for clinical studies on myopia[2-3]. Most devices on the market today also incorporate measures for refraction and corneal curvature, while some offer special modules to monitor myopia (e.g. Topcon Aladdin) based on the eye growth tables developed by Tideman *et al*[9].

Eye growth

Between birth and adulthood the eye grows from 17 mm to 24 mm, while maintaining stable refractions through a local self-regulating retinal process guided by the image plane at the retina[10-11]. During the first *3* years of life, there is a delicate balance between the loss of lens and corneal power (from 45D to 26D and from 50D to 43D, respectively), while the axial length continues to grow proportionally at a mean rate of about 0.19 mm/year between 5 and 10 years and 0.10 mm/year between the ages of 10 and 14 years[10, 12-13]. Hence, the final refraction will result from the balance between corneal or lens power loss and axial growth, where, in older eyes, an axial length increase of 1 mm without compensation of the other components corresponds with a refractive change of –2.50D to –3.00D[14].

Once the axial length increases beyond the focal point, the eye will be myopic. The seeds of myopia may already be present early in childhood, as 6-year-olds that will later develop the condition often already have less hypermetropia than expected for their age, near plano instead of +1.25D for 6 years old and +0.75D for the 9 years old[9, 15]. A spherical equivalent of –6.00D generally corresponds to an axial length greater than 26 mm, which may lead to myopic maculopathy in middle adulthood[4]. Besides axial length measurement, keratometry is also very important because in clinical practice myopic adults with only –3.00D myopia can still develop a typical myopic maculopathy due to an excessive axial length compensated by flat corneas (personal observation, RI).

Tracking axial growth

Recently, Brennan & Cheng presented the first meta-analysis on axial length that indicated that Asian children have about 40% more rate of axial elongation than Caucasian children, probably due to environmental reasons[16-17]. Simultaneously, Tideman *et al.* generated axial growth charts based on European children up to adulthood based on a very large cross-sectional cohort, calculating the risk of myopia in percentiles[9]. The mean axial length was 22.36 ± 0.75 mm at 6 years, 23.10 ± 0.84 mm at 9 years, 23.41 ± 0.86 mm at 15 years, and 23.67 ± 1.26 mm in adulthood[9]. As seen, the eye grows 1.31 mm between 6 years and adulthood, which would represent a myopic change of 4–5D if no adequate compensation was present in the form of lens power loss due to structural changes[10]. A total of 354 children experienced accelerated axial growth and increased by more than 10 percentiles between 6 and 9 years. Of these, 162 (45.8%) were myopic at 9 years, compared to 4.8% (85/1781) whose axial length did not increase by more than 10 percentiles[9].

These observations confirm that following up axial growth could help in making clinical decisions. For example, if two children have the same refraction but one has a normal axial length and the other a length close to 25 mm, it is advisable to be cautious with the latter patient and provide appropriate treatment as he or she surely presents a greater risk of retinal issues in adult life. Meanwhile, children that experience a rapid axial growth at least one year before the diagnosis of myopia, recently called "emerging myopes", present an opportunity to preventively control this development though behavioral modification or more frequent exams[1, 18]. But this can only be achieved through the regular screening of all children with a certain risk factor, such as family history of high myopia, intense reading habits, and low outdoor exposure[17]. This type of detection may not be affordable as biometric devices and screening programs are not cheap.

Corneal power

As said, the ocular growth curves show that between the ages of 5 and 15 years stable, emmetropic eyes grow at about 0.19 mm/year from 5 to 10 years of age and 0.10 mm/year in children older than 10 years[13, 19] while myopizing eyes can experience speeds of up to 0.34 mm/year[9, 18, 20]. During this period the lens also loses several diopters of power to compensates for axial growth in stable emmetropes, but not enough in those with excessive growth that become myopic[18]. The corneal power is normally distributed in the population, with a mean power of 43.00D. Corneal power reaches adult values during the first 2–3 years of life[21]. Hence, in absence of abnormalities in the crystalline lens power, eyes with flat corneas are usually longer than normal (e.g. 1 mm longer for a keratometry of 40.00D), and eyes with steep corneas are shorter to maintain a balanced growth (e.g. 1 mm shorter for a keratometry of 46.00D)[22]. This should be kept in mind when using ocular growth curves[9] in clinical practice to follow the evolution of myopia as these curves were developed for eyes with an average cornea of 43.00D and each diopter of change in the corneal power corresponds with about 0.30 mm of axial length change to maintain a balanced refraction[14].

The main restrictions to the proposed method are the variations between ethnic populations, gender, keratometry and crystalline lens power, as well as the stature, all of which may affect a child's axial length. Axial length usually correlates with the spherical equivalent refraction, but there are some issues to consider when interpreting its results. Axial length is longer in Asians, taller individuals, and males[22]. Hence, Tideman's curves also consider that girls' eyes are shorter and with more curved corneas, and more powerful crystalline lenses, than those of boys[20, 22], by developing separate growth charts for boys and girls[9]. This is especially important since the axial length threshold for those at risk of myopic maculopathy is lower for women than for men (25.30 mm vs. 25.90 mm)[5, 23-24].

Clinical use

In the clinical management guidelines, the IMI advices including the axial length measurements as a standard procedure. Axial length is sometimes not available due to economic, financial or logistic reasons. If axial length is not available, keratometry may be performed to identify high- and low-powered corneas (keratoconus and potentially longer eyes prone to maculopathy, respectively). If only myopic cycloplegic refractive error is available, the information about corneal power gives the eyecare practitioner an idea about the eye being longer or shorter than the mean for the given refractive error. And extra care should be taken when finding a low or high myopic child with lower corneal power than usual, because those eyes are often longer and probably more prone to myopic maculopathy, assuming a normal crystalline lens power. However, axial length measurements remains the best method to measure myopia progression. To optimize myopic care, more widely and better affordable equipment to measure axial length is required.

Children who have an early onset, family history of high myopia, intense reading habits or who stay indoors with artificial illumination most of their time, are most at risk of developing progressive myopia and high myopia[25]. These children could be treated preventively though early lifestyle changes. At younger ages the gold standard would be treatment with diluted atropine[26]. As they get older, depending on their progression rate and preference, different dosages of atropine, defocus spectacles or special contact lenses could be prescribed along with or instead of diluted atropine drops[26]. More research is needed in this clinical area to compare cost effectiveness and compliance of the different treatment options and its combinations. Since most studies were performed in Asia, Europe and North America, and although most myopia seems environmental, similar prevalence and treatment studies must be performed in Latin America and Africa to exclude the influence of important local differences in progression and risk factors. For example, the strict confinement in Argentina during the COVID-19 pandemic (Picotti et al. *in preparation*) caused some myopic children who were previously stable for some years since 2017 with daily atropine drops, to progress again in 2020, despite good compliance (RI *personal clinical observation*). This could mean that before confinement outdoor exposure was helping these atropine treated children in arresting their progression.

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