Epidemiology of Myopia

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Abstract: Myopia is not a simple refractive error, but an eyesight-threatening disease. There is a high prevalence of myopia, 80% to 90%, in young adults in East Asia; myopia has become the leading cause of blindness in this area. As the myopic population increases globally, the severity of its impact is predicted. Approximately one fifth of the myopic population has high myopia (≥−6 diopters), which results in irreversible vision loss such as retinal detachment, choroidal neovascularization, cataracts, glaucoma, and macular atrophy. The increasing prevalence of school myopia in the past few decades may be a result of gene-environment interactions. However, earlier school myopia onset would accompany faster myopia progression and greater risk of high myopia later in life. Recently, there have been effective interventions to delay the onset of myopia, such as outdoor activity and decreasing the duration of near work. Hyperopia (≤0.5 diopters) is a predictor of myopia. Pharmacological agents and optic interventions such as low-concentration atropine and orthokeratology may slow progression in myopic children. Novel surgeries and anti–vascular endothelial growth factor drugs could deal with some myopic complications. From available evidence, the prevention, control, and treatment of myopia seem to be promising. However, to reduce the impact of myopia in future decades, more work and effort are still needed, including that by governments and intercountry eye health organizations.

Key Words: epidemiology, myopia

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Myopia is a very common refractive error in the general population. Most people look at it as a simple refractive error that can be corrected by spectacles or refractive surgeries. In fact, myopia is an ocular disease characterized by an abnormally elongated eyeball, which cannot be rescued by optical lenses or refractive surgeries. Its severity can even result in blindness. The prevalence of myopia is increasing and has become an important issue in public health.[1–3] In Taiwan and Singapore, the prevalence of myopia is 20% to 30% among 6 to 7 year olds and as high as 84% in high school students in Taiwan.[2,4] The myopia progression rate in East Asian children is high [nearly −1 diopter (D) per year], and approximately 24% of the myopic population become high myopes as adults.[2,5–7]

Recently, myopia has become a significant public health problem. One of the complications of myopia, myopia maculopathy, has become a leading cause of untreatable visual loss in East Asia.[8–10] It is also the third cause of blindness in Copenhagen, Rotterdam, and the Latino population in Los Angeles. High myopia is mostly defined as refraction greater than −6 D. Because of ocular elongation resulting in ocular tissue thinning and degeneration, it is highly associated with sight-threatening conditions. The complications of myopia include presenile cataracts, glaucoma, retinal detachment, myopic choroidal neovascularization (CNV), foveoschisis, staphyloma, macular atrophy, and blindness.[11–13] Studies have shown that myopia progresses faster when children present with myopia at a younger age.[14,15] Once myopia occurs in school-aged children, it progresses quickly until early adulthood, when it slows down.[16–18] Early onset of myopia in childhood is associated with high myopia in adult life.[19–21] Therefore, it is very important to stop or control myopia progression in myopic children from a young age.

Myopia has a great impact on public health and socioeconomic well-being.[22,23] It is a condition of social, educational, and economic consequences. Blindness caused by myopia is a burden for patients, their families, and society. It is important to develop public policies and interventions to prevent patients from developing high myopia and associated visual impairment.

Myopia is the increase in axial length and the thinning of the sclera that may be due to both reduced collagen synthesis and increased collagen degradation.[24,25] Animal studies in chickens, tree shrews, marmosets, rhesus monkeys, and guinea pigs revealed that blurred vision is caused by form deprivation, minus lens rearing, and peripheral refraction with hyperopic defocus resulting in myopic development.[26,27] Animal studies not only can develop possible treatments for myopia but also can help to clarify the findings from epidemiological studies, such as light with outdoor activity and peripheral refraction with orthokeratology.[27–29]

BASIS AND DEFINITION OF MYOPIA

The normal development of emmetropization is hyperopia approximately +2 D in newborns and infants. The hyperopia decreases rapidly to approximately +1 D during the first 2 years.[30,31] During the period of 2 to 14 years of age, the hyperopia decreases slowly to emmetropia. The eyeball grows rapidly in early childhood from 18 mm of axial length at birth to 23 mm at 3 years of age.[32] Because of a 1-mm increase in axial length being correlated with a 2- to 3-D myopic shift, the refraction during this period is compensated by corneal flatting and thinning of the lens. The mean axial length of adults is 24 mm; therefore, there is only a 1-mm increase during the period from 3 to 13 years of age. Axial length has a very strong correlation with refractive status. Myopia usually results from an eye with longer axial length mostly due to the elongated vitreal chamber.[33] Myopia is an abnormal condition breaking the emmetropization process.[34] The myopic refraction will progress rapidly during onset from an early age and continue progression until early adulthood.

The most common definition of myopia is spherical equivalence −0.5 D or greater. The criterion standard for measurement of refractive error is cycloplegic refraction,[35–37] especially in children. Children have strong accommodative responses leading to "pseudomyopia" during examination.[38] However, if there is no cycloplegic examination for children, the refraction might be overestimated by approximately −1 to −2 D.[39,40] High myopia is commonly defined as refraction of −6 D or greater. Some studies define high myopia as −5 D or greater.[23,33] Myopia could also be

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defined as having an axial length greater than 24 mm, and high myopia defined as greater than 26 mm.[41,42]

PREVALENCE OF MYOPIA IN CHILDREN

The prevalence of myopia in children varies in different areas and countries. The myopia onset during childhood can be roughly calculated from the prevalence of different age populations. The higher prevalence of younger age groups would lead to a greater burden and severity of myopia in adulthood due to myopia progression in childhood leading to high myopia.

Asian Populations

In Taiwan from 1983 to 2000, the prevalence of myopia in 7 year olds increased from 5.8% to 21.0%. Among 12 year olds, the prevalence increased from 36.7% to 61.0%. Among 15 year olds, the prevalence increased from 64.2% to 81.0%. Among 16 to 18 year olds, the prevalence increased from 74% to 84% in 2000.[43] The difference in prevalence may reflect secular trends over time. In Singapore, the prevalence of myopia was 11.0% in Chinese children aged 6 to 72 months,[44] 29.0% in 7 year olds, 34.7% in 8 year olds, and 53.1% in 9 year olds.[4] In Hong Kong, the myopia prevalence was 17.0% in children younger than 7 years, which increased to 37.5% in 8 year olds and 53.1% in children older than 11 years.[45] In Korea, the prevalence of myopia by age group was 50% in 5 to 11 year olds, 78% in 12 to 18 year olds, and 45.7% in high school students.[46] In China, the prevalence of myopia in urban children ranged from 5.7% in 5 year olds, 30.1% in 10 year olds, and increased to 78.4% in 15 year olds.[47] In rural children, almost no 5 year olds, 36.8% of 13 year olds, 43.0% of 15 year olds, and 53.9% of 17 year olds were found to be myopic.[48,49] In India, urban children had a myopia prevalence of 4.7%, 7.0%, and 10.8% in 5, 10, and 15 year olds, respectively. In rural children, it was 2.8%, 4.1%, and 6.7% in 7, 10, and 15 year olds, respectively.[50,51] In Nepal, urban children had a myopia prevalence of 10.9%, 16.5%, and 27.3% in 10, 12, and 15 year olds. In rural children, it was 1.2% in 5 to 15 year olds.[52,53]

Non-Asian Populations

In Australia, the myopia prevalence was 1.4% among 6 year olds.[54] Among 12-year-old children, the overall myopia prevalence was 11.9%, which was lower among white European children (4.6%) and Middle Eastern children (6.1%) and higher among East Asian (39.5%) and South Asian (31.5%) children.[55] In the United States, the prevalence of myopia was 4.5% in 6 to 7 year olds and 28% in 12 year olds in a predominantly white population.[56] In another study, Asians had the highest prevalence (18.5%), followed by Hispanics (13.2%) in 5 to 17 year olds. African Americans (6.6%) and whites (4.4%) had the lowest.[57] In Chile, the prevalence of myopia was 3.4% in 5 year olds and 19.4% and 14.7% in 15-year-old boys and girls, respectively.[58] In England, the prevalence of myopia was 2.8% in 6 to 7 year olds and 17.7% in 12 to 13 year olds.[59] In Sweden, the prevalence of myopia was 49.7% in 12 to 13 year olds.[60] In Greece and Bulgaria, the prevalence of myopia (noncycloplegic) was 37.2% and 13.5% in 10 to 15 year olds, respectively.[61] In South Africa, the prevalence of myopia was 3% to 4% in 5 to 13 year olds, 6.3% in 14 year olds, and 9.6% in 15 year olds.[62]

INCIDENCE OF MYOPIA IN CHILDREN

In China, the annual incidence of myopia in 7-year-old children was approximately 10% to 14%.[63] In Taiwan, the annual incidence of myopia in 7 to 12 year olds was 8% to 18%.[64] In Australia, the annual incidence of myopia in 12 and 17 year olds was 2.2% and 4.1%, respectively.[65] The annual incidence rates of myopia in East Asian children were much higher than those in white European children.

PREVALENCE OF MYOPIA IN ADULTHOOD

The prevalence of myopia in adulthood is more stable because myopia onset is far less than that of childhood. However, the prevalence in the senior population could be overestimated because of lenticular cataracts inducing refractive myopia.

In Taiwan, a study of male military conscripts aged 18 to 24 years reported that the prevalence of myopia was 86.1%.[66] The Shihpai Eye Study in Taiwanese adults older than 65 years found a myopia prevalence of only 19.4%.[67] In China, the prevalence of myopia was 22.9% in the Beijing Eye Study (aged 40–90 years).[68] In Japan, the prevalence was 41.8% for myopia in younger adults.[69] In India, the prevalence was 34.6% in those 40 years or older.[70] In Singapore, the prevalence rates in Singaporean Chinese, Malay, and Indian adults older than 40 years were 38.7%, 26.2%, and 28.0%, respectively.[7,71,72] The difference in the prevalence reflects interethnic variation. In Bangladeshi and Pakistani adults older than 30 years, the prevalence of myopia was 23.8% and 36.5%, respectively.[73,74] In Indonesia, the prevalence was 48.1% in adults older than 21 years.[75] In Mongolia, the prevalence was 17.2% in adults older than 40 years.[76]

In the United States, the prevalence of myopia was 33.1% in adults 20 years or older.[77] In the United Kingdom, the prevalence was 49% in adults aged 44 years. In Norway, the prevalence was 35.0% in adults aged 20 to 25 years.[78] In Australia, the prevalence was 15.0% in adults aged 40 to 97 years.[79]

Prevalence of High Myopia

The prevalence of high myopia can be estimated at approximately 20% to 24% of the myopia prevalence in adults.[23,43] Early onset of myopia is the most important predictor of high myopia later in life.[80] Myopia prevalence is considerably high, especially in Asian countries with myopia epidemics. In college freshmen in Taiwan, high myopia increased from 26% among all types of myopia in 1988 to 40% in 2005.[81] According to a national investigation, the prevalence of high myopia (>−6 D) in those 18 years of age increased from 10.9% in 1983 to 21% in 2000.[11] A review estimated that in 2050 half of the global population (5 billion people) would be myopic, and one fifth of those (1 billion) would be considered highly myopic (>−5 D).[8]

PROGRESSION OF MYOPIA

After myopia onset, progression is fast in children. Younger children have greater myopia progression, and younger age is a significant risk factor for high myopia in the future.[14,15] In general, myopia progression in Asian children is faster than in Western children.[82] Previous studies showed progression of nearly −1 D per year in myopic Asian schoolchildren.[5,6] In Finland, the myopia progression rate was −0.93 D annually in 8 year olds and −0.52 D in 13 year olds.[83] Myopia progression declines with age and stabilizes after puberty.[84] However, for adults with high myopia, because of the thin sclera, myopia will still progress with axial length elongated.[85]

RISK FACTORS

Decades ago, myopia prevalence was low, and it was primarily considered to be due to genetic factors, such as a very young child having high myopia within a highly myopic family showing the inheritance of myopia.[86] Recently, because of myopia prevalence rapidly increasing in schools, there is debate regarding whether the cause of myopia is due to genetic or environmental factors.[87,88] School myopia with low myopia onset is considered to be mainly determined by environmental risk factors.[89] There might be some interaction between the 2 components. Myopia is also considered as a genetic susceptibility to environmental risk factors, meaning the genes responsible for growth of ocular components may be influenced by the environment in a person with low myopia.[90,91]

Genetics

There are 2 groups of myopia. One is congenital myopia or infantile-onset myopia, and the other is school myopia or juvenile-onset myopia. According to evolution, children with congenital or infantile poor vision could not survive in ancient times alongside the children with congenital myopia. Therefore, the genes for congenital myopia were not widely inherited, and the prevalence of congenital myopia is low, approximately 4% to 6%.[92] The low prevalence in the global population is similar to other diseases of poor vision in early childhood, such as amblyopia and strabismus.

School myopia might not be caused mainly by genetics. In Taiwan between 1983 and 2000, the myopia prevalence of 7 year olds increased up to 7 times, and that for 12 year olds increased up to 2.4 times.[43] A similar trend was reported in the United States between 1971 and 2004; over 30 years, the myopia prevalence in 12 to 17 year olds increased 2.6 times (from 12% to 31.2%).[3] In Finland over 20 years, the prevalence rate almost doubled in 14 to 15 year olds.[93] In Hong Kong, the odds of having myopia in grandparents' are far less than for parents' and children's generations (0.06, 0.26, and 0.35, respectively). The genome change of a certain population would not be as quick as within several decades. A dramatic increase in the prevalence of myopia in the generation of Alaskan Eskimos first exposed to compulsory education and a "Westernized" environment during their childhood was observed.[94,95] This suggests that environmental factors might contribute more in the development of myopia. However, the distribution of myopia differs among races and ethnic groups, and studies on parents with myopia and comparative studies in twins also support the notion that hereditary factors partly influence juvenile myopia development.[96,97] Therefore, regarding the increase in myopia prevalence worldwide, the theory of gene-environment interaction suggests that a certain number of individuals may be genetically susceptible to myopia if exposed to certain environmental factors.

Previously, molecular genetic studies were obtained predominantly from family linkage analyses, families with 2 or more individuals with 6 D or more of myopia, and candidate gene studies.[98,99] Recently genome-wide association studies and whole-exome sequencing studies have been conducted.[100–103] Some genetic associations have been successfully replicated in populations, but some have not. More than 20 chromosomal loci and 100 gene variants have been reported to be associated with myopia.

Near Work

Near work activities, such as reading, writing, and computer use, have been suggested to be possibly responsible for the remarkable increase in the prevalence of myopia.[104,105] Cohort studies showed that schoolchildren with incident myopia performed significantly more near work and had a greater increase in axial length.[106,107] A meta-analysis shows that more time spent on near work activities was associated with higher odds of myopia. The odds of myopia increased by 2% for every 1 diopter-hour more of near work per week.[108] Therefore, near work is a strong important risk factor of myopia. The severity of risk is according to the intensity, such as duration of continued reading and distance to the near objects.[109] Because near work is inevitable for learning, breaks of certain durations and preventing close reading may reduce the risk of near work.

Screens of Computers and Handheld Devices

There has been a dramatic increase in the use of computers and mobile phones in recent years. Increased screen time may be associated with the development of myopia.[66,110] Computer use induces asthenopia, but there is still no clear evidence of association with myopia development. Because of the long duration of looking at screens and blue light emission from LED screens, the risk of myopia development and blue light ocular hazards should be serious concerns, especially in children.[111]

Educational Stress

In the East, the educational system and stresses are different from the West. Eastern parents pay a lot of attention to the academic performance of children and encourage more time spent on near work. In contrast, Western parents pay more attention to physical education and encourage more outdoor activities. This difference might partly contribute to the high prevalence of myopia in the East.[112–114] Morgan and Rose[115] proposed that the extensive use of after-school tutorials and increasing educational loads are associated with high prevalence rates of myopia. An association with additional tutorial classes has also been reported in Singapore and Taiwan.[116–118]

PROTECTIVE FACTORS

Outdoor Activity

Outdoor activity has recently been recognized as a protective factor for myopia.[119] It may even overcome the risk factor of myopic parents if children spend enough time outdoors per week.[120] A meta-analysis showed that more time spent on outdoor activities was associated with lower odds of myopia. The odds of myopia decreased by 2% for every additional hour of time spent outdoors per week.[121]

The mechanism through which outdoor activity can help prevent the onset of myopia is still unclear. Brighter light might be a possible mechanism to protect against myopia.[122,123] The "light-dopamine" theory is accepted as a possible mechanism. Increased light intensity during time spent outdoors can stimulate the retina to release dopamine, which could inhibit axial elongation of the eyeball.[124–126] Myopia protection seems to be mainly from visible light, not UV light. Therefore, myopia prevention from time spent outdoors should be compatible with avoidance of UV exposure.

The outdoor activity, effective duration, frequency, and light intensity are still under investigation. There may be a threshold of 10 to 14 hours spent outdoors per week to prevent myopia onset.[120,127] Intermittent bright light suppresses myopia more than continuous bright light in chickens.[128] A randomized trial of schoolchildren in China showed that 40 minutes per day of outdoor activity decreased myopia onset by 9% after 3 years. In Taiwan, an interventional study showed that 80 minutes per day of intermittent outdoor activity decreased myopia onset by 9% after 1 year.

Hyperopia

One of the best ways to predict future myopia is based on cycloplegic refractive error. Children with +0.75 D (or more) of hyperopia are less likely to become myopic.[129,130] After myopia onset, the myopic shift is triggered, and the progression rate is approximately −1 D per year. Therefore, +0.75 D hyperopia or more might indicate less risk of myopia onset in the next year. A small study in Taiwan showed that 54% of premyopic children become myopic after 1 year.[131]

SUGGESTIONS TO ELIMINATE THE IMPACT OF MYOPIA

Prevention of Myopia Onset

For nonmyopic children, an annual cycloplegic refraction examination is suggested to monitor the baseline hyperopia refraction before myopia onset. Children should be encouraged to develop habits to reduce environmental risk factors, such as decreasing nonnecessary near work or increasing near work breaks, and strengthen protective factors, such as daily outdoor activities up to 2 hours per day. By delaying myopia onset as late as possible to the end of adolescence, high myopia status should seldom occur in adulthood.

Controlling Myopia Progression

For myopic children, progression is fast, and controlling myopia progression is important to prevent high myopia later in life. Annual cycloplegic refraction should be performed to determine the effect of myopia control. During this period, maintaining good lifestyle habits is not enough to slow myopia progression. Near work and outdoor activities had little meaningful clinical effects on the rate of myopia progression.[64,132,133] In addition, the optic correction of spectacles can assist only temporarily in clearing vision in children. However, the manipulations of optic correction in spectacles, including undercorrection, full correction, multifocal or bifocal, are all unable to inhibit myopia progression.[84,134,135]

A meta-analysis shows that only atropine or orthokeratology can significantly slow myopia progression.[135] Bifocal soft contact lenses might have potential but are still under investigation. However, the adverse effects of the 2 proven effective treatments should be decreased as much as possible. For atropine treatment, the concern of phototoxicity from pupil dilation can be solved by using low-concentration atropine, which achieves similar myopia-controlling effects as high concentrations.[136–138] For orthokeratology treatment, the greatest concern is microbial infection, inducing corneal ulcers.[139–142] During initial wearing of the corneal reshaping lens, superficial keratitis is common. Frequent prompt follow-up and topical antibiotics are often necessary. Hygienic care of orthokeratology lenses and the storage case to decrease microbial load are important.[143–146] Because of corneal reshaping resulting in difficulty of accurate refraction detection, annual axial length measurement to monitor myopia control is necessary.

Treatment for Complications

There have been recent advances in the treatment of complications of myopia. In presenile cataracts of myopia, phacoemulsification or femtosecond laser–assisted cataract surgery can achieve good results.[147] Nonetheless, myopia is a significant risk factor for complications such as posterior capsule rupture and development of retinal detachment after cataract or Nd:YAG capsulotomy.[148–150] Myopia is a known risk factor for glaucoma. A meta-analysis found myopia as a risk factor for glaucoma, with a pooled odds ratio of 1.92 and concluded that progressively higher myopia increases the likelihood of glaucoma.[151] However, the diagnosis of glaucoma is still challenging.[152,153] Early detection with prevention is important but is often overlooked.

Myopic CNV is the leading cause of CNV in young adults and results in poor visual outcomes after long-term follow-up.[154] Recently, intravitreal injection of anti–vascular endothelial growth factor has become the first-line therapy for myopic CNV and overall achieves good visual outcomes.[155] Myopia is a well-known risk factor for retinal detachment. It often presents with severe forms of retinal detachment, such as macular hole retinal detachment (MHRD) or giant retinal tears. Aside from traditional surgeries such as scleral buckling and/or vitrectomy for MHRD, there are several novel methods to assist in retinal attachment, such as inverted internal limiting membrane insertion, lens capsule flap, and internal limiting membrane reposition covered by autologous blood.[156–159] For myopic staphyloma–accompanied complications such as foveoschisis or fovea detachment, vitrectomy and/or macular buckling might achieve certain positive results.[160]

Macular atrophy in myopia often develops in cases of extremely high myopia or myopia with older age. Because of retinal and choroidal degeneration, there is still no good way to treat or prevent this development. However, there is a new international classification to facilitate communication, which helps compare findings from clinical trials and epidemiological studies, to accelerate the development of possible treatments.[161]

CONCLUSIONS

The tide of myopia is coming along with the consequences it will bring. Not only is the treatment of myopia complicated, but also prevention is more important. Although the mystery of myopia is still shrouded, evidence-based medicine helps us more clearly identify the risk factors, protectors, and treatments. Outdoor activity is a simple, free, and effective method to prevent myopia onset. Widespread outdoor activity is recommended to overcome the large amount of near work in the coming era of handheld devices. Low-concentration atropine and orthokeratology make school myopia controllable. Anti–vascular endothelial growth factor is becoming the choice for myopic CNV treatment. However, there are still many incurable myopia complications. Epidemiology shows us that myopia has become the leading irreversible cause of blindness in East Asian countries, and it will be in more countries in the future. Intercountry organizations for eye health, such as the World Health Organization or Asia-Pacific Academy of Ophthalmology, are encouraged to raise awareness of the threat of myopia and organize committees to establish guidelines for myopia prevention and treatment.

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The best and most beautiful things in the world cannot be seen or even touched – they must be felt with the heart.
— Helen Keller