Patient information - myopia (near-sightedness)

Prof. Dr. rer. nat. Frank Schaeffel, Ophthalmic Research Institute, University of Tübingen

Prof. Dr. med. Focke Ziemssen, Department of Ophthalmology, University of Tübingen

What is myopia?

The eye is build like a small camera that projects the image of the environment on its inner wall. Instead of an electronic chip that captures the image, a light sensitive tissue layer covers the eye inside like a wall paper. It contains a dense array of photoreceptor cells which respond to light with an electrical signal. To see sharply, the projected image must be in good focus. This condition is achieved by matching eye length and the focal length of the optics with an impressive precision of around 0.1 mm. In myopia, the eye grows too long so that the focused image is slightly in front of the retina. One can no longer see sharply at a distance. An elongation of the eye by only one millimeter, from 24 to 25 mm, causes about 2.7 diopters (D) myopia (Figure 1).

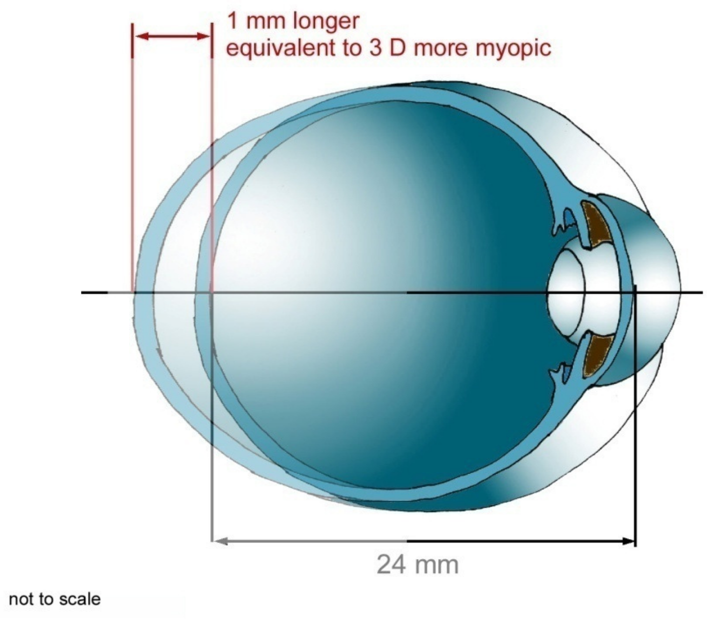

Figure 1. On average, the eye of adult human subjects is about 24 mm long. If it elongates by only 1 millimeter, it is already almost 3 diopters myopic. The most distant letter that still can be seen sharply, is then only about 30 cm away.

At which age does myopia develop?

At the end of the Kindergarten time, most children are still normal-sighted (emmetropic) or even slightly far-sighted (hyperopic). The most common type of myopia develops during the school years. It is therefore called „school myopia“. The typical age range is 8 to 15 years. The earlier myopia develops, the higher are typically the final values.

Can myopia disappear later in life?

Once the eye became too long, it does not regress. Myopia remains present for life time. It rather tends to progress further. The higher myopia, the faster it tends to progress in young people. With age, progression typically slows down and in most cases myopia develops towards a final value.

What types of myopia are known?

The most frequent type (about 90 percent of the cases) is “school myopia”. It typically reaches refractions between -3 bis -6 D in adulthood, sometimes more and may then become sight-threatening. There are also exclusively inherited versions of myopia which are already present in childhood. In these cases, normal-sightedness is never achieved. This type reaches often high refractive errors values of 20 D or more.

High myopia (defined as more than 6 D) affects 2-5 of hundred in Europe and the USA, and up to 20 of hundred in South East Asia.

Is myopia dangerous?

With increasing myopia, the risk of degenerative processes in the tissue layers in the back of the eye (the “fundus”) increases. The retina and the underlying layer, the choroid which is heavily blood perfused and supplies nutrition and oxygen for the retina, start thinning. In high myopia, the choroid becomes translucent and very thin. This increases the risk of retinal detachment and degeneration. Furthermore, the risk of clouding of the lens increases (“cataract“) and the intraocular pressure tends to increase (glaucoma). Therefore, it is recommended that highly myopic patient have their fundus checked by an ophthalmologist at least once a year.

With myopia above about -6D – with an equivalent eye length of about 26 mm – there is an elevated risk that alterations develop in the area of sharpest vision, the macula. Formation of new blood vessels in the macular area (macular degeneration) can compromise reading and working. On the other hand, a considerable number of highly myopic people have no visual deficits. There seems to be a considerable variability, perhaps predetermined by hereditary factors.

How frequent is myopia?

Myopia is correlated with the degree of education in all countries – the longer the time of studies, the more myopia. In Germany, the prevalence of myopia in the total population is around 35 percent. After high school (Gymnasium) about 50 percent are myopic. In countries with particularly competitive education, the prevalence of myopia may reach 90 percent or even more (big cities in China, Taiwan, Singapore). A recent analysis performed by the Brian Holden Institute in Australia concludes that more than 50 percent of the world population will be myopic by 2050.

Is myopia inherited?

The probability for a child of becoming myopic increases with the number of myopic parents. Myopia is often similar in two monozygotic twins. These observations provide evidence for an inherited mode of myopia.

On the other hand, many children are myopic even though their parents are emmetropic. Furthermore, myopia has increased tremendously in some countries within only few generations which cannot be explained by genetics. It must be concluded that the major part of myopia in the industrial nations has environmental reasons and must trace back to changes in the visual environment.

Which possibilities exist to block the development and progression of myopia?

Unfortunately there is no chance to reverse an already existing myopia but there are some options for retarding its progression so that critical levels are less likely to develop.

(1) ambient illuminance / light levels

In 2007, high ambient illuminances (as they are typical outdoors at daytime) were re-discovered as possible inhibitors of myopia. An effect of light on myopia progression was already described by Hermann Cohn in 1890. Epidemiological studies show that children develop the less myopia the longer they stay outdoors (example: Figure 2). Another study has shown that staying outdoors for only additional 45 minutes after school reduced myopia in school children in Guangzhou, China, by 25 percent. A study in Taiwan has shown that formation of new myopia was reduced by even 50 percent when pupils had their lunch outside instead of inside the school building. Even elevating the illuminances in the classrooms had some effects - though less so than the bright light outside. It is known that bright light increases the release of dopamine from the retina which, in turn, was known since about 1990 to inhibit the axial elongation of the eye.

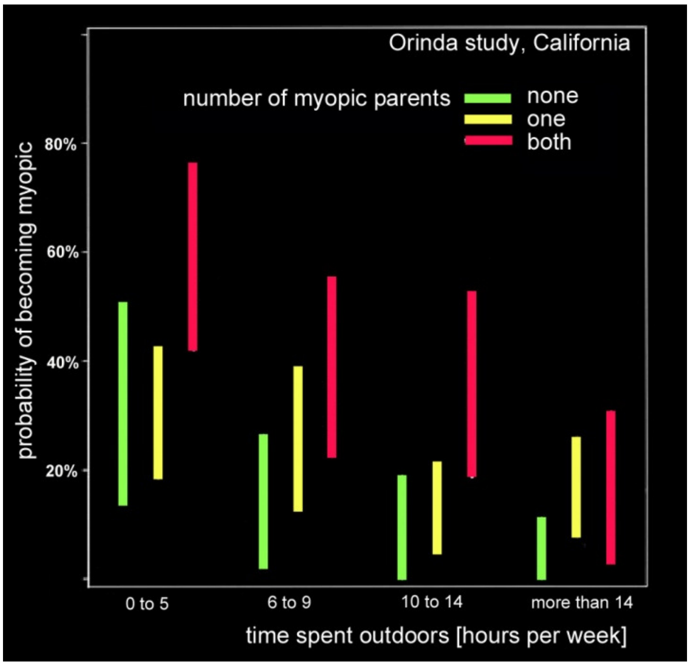

Figure 2. Children in California were the less myopic the longer they were outdoors. Furthermore, they were less myopic, if none or only one of the parents was myopic (adapted from Jones et al., Investigative Ophthalmology and Visual Science, 2007).

Based on such data, the minister of education (MOE) in Taiwan has started a "school children vision care program" in 2012. According to this program, children have to be outside for 120 minutes per day. Furthermore, a "3010" rule was established that pupils have to interrupt reading activities every 30 minutes for the following 10 minutes. The heights of the desks were adjusted to increase reading distances. After these rules were established, the prevalence of myopia in first grade was said to be reduced from 50 percent to about 45 percent since 2012 after it had been increasing continuously before for a number of years (presented at the 15th International Myopia Conference in Wenzhou in 2015). This simple way of reducing the incidence and progression of myopia might be useful also in other countries.

(2) Reading time and reading distance

A correlation between reading time and increase in myopia was found in most, but not in all of the studies. However, a recent review presenting a meta-analysis of published work on this topic concluded that every "diopter hour" (reading distance in diopters x reading time) per week increases the odd of becoming myopic by 2 percent.

In animal models, myopia can be induced by placing negative lenses or diffusers in front of the eyes. If the goggles are removed for only half an hour per day, myopia is reduced to half. Wallman (2002) concluded that regular interruptions of reading should be beneficial - a conclusion that was already drawn by Cohn in 1890 and applied in Taiwan in 2012 (see above). Some studies showed that more myopia develops if reading distances are short. Therefore it is advisable to do near work with a reasonable viewing distance (30 cm or more) - a conclusion that was, again, already drawn by Cohn in 1890. A large computer screen is helpful to increase the viewing distance to 50 cm or more.

(3) Correction of myopia with lenses

Animal experiments have shown that the retina is able to distinguish whether the plane of focus is in front of or behind the photoreceptor layer in the retina. It has also been shown that biochemical signals released by the retina control the growth rates of the back of the eye. An important finding was that the retina control eye growth at each position in the back of the globe and not only in the center where visual acuity is best.
Conventional spectacle lenses often overcorrect myopia in the periphery, imposing hyperopic refractive errors. It was found in rhesus monkeys that peripheral hyperopia may stimulate axial eye growth even if the center of vision, the fovea, is in good focus. Therefore, a new type of spectacle lenses was tested in children, which leaves the periphery slightly more myopic, but provides full correction in the center. However, these lenses did not reduce myopia progression more than regular progressive addition lenses (reading glasses) so that this approach requires further improvement. In contrast, old fashion bifocals with a near addition in the lower half of the lens were reasonably effective in children in Ontario, Canada, and inhibited progression of myopia by about half. A problem here is that these lenses may look quite "uncool" and may be difficult to sell to the children. Figure 3 shows a comparison of the effects of different optical corrections on myopia progression.

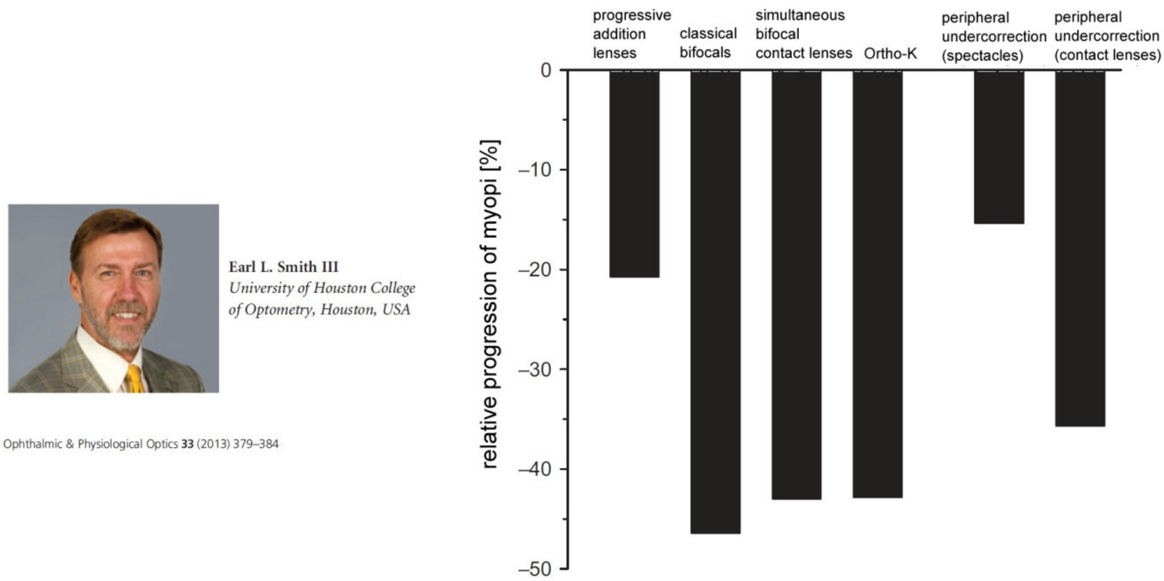

Figure 3. Effect of different optical corrections on myopia progression in children. Progressive addition lenses (reading glasses) show an inhibition by 20 percent, classical bifocals of 47 percent, multifocal contact lenses by 43 percent, ortho-k-lenses also by 43 percent, and spectacle lenses which leave the periphery more myopic by 15 percent. Contact lenses with similar optical effect in the periphery inhibited by 35 percent (adapted from Smith and Campbell, Ophthalmic and Physiological Optics 2013).

(4) Contact lenses

(A) Hard contact lenses reduce the refractive power of the eye by flattening the cornea (the frontal surface of the eye). That flattening of the cornea has a large optical effect can be demonstrated when one pulls the eye lid laterally and, even though the optics becomes poor because the cornea is irregularly distorted, myopic people without correcting lenses may see sharper at a distance. For the same reason, myopia appears reduced when the rigid contact lenses are taken off, but a major part of the effect is just corneal while the back of the eye does not become shorter. Typically, the cornea returns to its previous shape when contact lenses are not worn for a couple of days. This also goes along with an apparent increase of myopia.

Mainly the United States and China, the so-called “ortho-K” contact lenses are advocated against myopia. They are worn over night and their shape is optimized to flatten the cornea mechanically. When they are taken off in the morning, the flattened cornea allows for better distance vision. The mechanical effect of the ortho-K lenses accumulates over several nights of wearing. Also, the change in corneal shape persists longer when they are taken off. It is assumed that they can even inhibit axial eye growth on the long term because they flatten the cornea mainly in the center, leaving the periphery of the cornea steeper and the refraction in peripheral visual field more myopic - a condition that is already known to inhibit eye growth. However, only few data are available at present to support this assumption.

(B) The retina is able to determine the plane of best focus and controls eye growth to achieve the best match between focal length and eye length. Interestingly, even with multifocal lenses which generate two different focal planes on top of each other (with respective lower image contrast in each of them), eye growth adapts to the "average of the two focal planes". This can be used to inhibit myopia by adding a near vision plane to the distance correction. In some cases, multifocal contact lenses were surprisingly effective.

An advantage of optical intervention is that there is no known rebound effect which means that the effect of the treatment does not disappear when the treatment is terminated.

(5) Undercorrection of myopia, or no correction at all

Positive lenses with converging light rays induce more myopic refractions when placed in front of the eye trigger a compensatory growth response of the eye in animal models. To adapt to the lens, the eye of young animals remains shorter and becomes hyperopic. For a long time it was thought that undercorrection, giving too weak correction to myopic children, should do the same and generate more hyperopic (less myopic) refractions. Surprisingly, this was not the case in two much-cited studies. The most likely explanation for the lack of a positive effect of undercorrection is that accommodation, an active mechanism of the eye to focus on near objects by deforming the lens, relaxes. Since the undercorrected eye is already focused at closer distances, one can read with little accommodation. In this case, the retinal image is in good focus again, and there is no need for the retina to generate an inhibitory signal for eye growth which means no difference in myopia progression. The same seem applicable if progressing myopia is not corrected at all.

Even though the eye has the mechanisms to control its growth to achieve best focus, myopia does not limit itself. The apparent contradiction could be resolved by considering the role of accommodation as described above. In addition, refractive errors in the periphery of the visual field, which depend on an individual eye shape, play an important role during "emmetropization" (the process of growing into best focus).

In summary, there is no rationale to actively undercorrect myopia. Most myopic people are somewhat under-corrected anyway because small rates in myopia progression are not immediately followed by changes in optical correction.

(6) Drugs

A number of substances have been identified in animal models which inhibit the development of myopia that can be experimentally induced by placing negative lenses or diffusers in front of their eyes. Only three of them have been tested in clinical studies with children.

(A) a substance that enhances the release of dopamine (the adenosine antagonist 7-methylxanthine). This substance is administered in tablet form in the morning evening, and, after promising results of an initial study, is further studied by a Danish research group (Klaus Trier and colleagues).

(B) a substance that inhibits the transmitter acetylcholine with high specificity through the M1 receptor (Pirenzepin). It has been administered as a gel into the eye. However, the beneficial effect on myopia development was only temporary and high doses were necessary. Therefore, it is currently not further studied.

(C) atropine, which is well known since long because it dilates the pupils and paralyzes accommodation. It is extracted from Atropa belladonna, a plant that is common in the central European forests (Figure 4).

Figure 4. Atropa belladonna, common in central European forests. Its berries contain atropine, a muscarinic antagonist that highly effectively inhibits the parasympathetic nervous system. It also dilates the pupil and paralyzes accommodation. It is toxic at high doses: about twelve berries are said to be deadly to humans.

Atropine blocks the receptors of the neurotransmitter acetylcholine. It is typically applied as eye drops with 1% concentration. Atropine was already recognized to inhibit myopia progression 50 years ago. The interest in it declined however when it became clear that its effects wear out over time when atropine was given daily for a year. Despite the treatment, myopia started to progress again. When the treatment was finally terminated, progression accelerated and after 1-2 further years, myopia reached the level in the control group. Moreover, the side effects are inconvenient: because the pupil is always maximally dilated, photophobia and glare are typical. Since accommodation is not functional, the children need reading glasses. Also, tear production is inhibited which may cause dry eyes.

The interest in atropine treatment against myopia increased again after it was found that also very low doses of 0.01 percent solution, one eye drop every evening, were also effective. At these low doses there were almost no side effects observed. After termination of the treatment, myopia remained lower than in the control group. In a study in Singapore, myopia was reduced to half after a 3 year "wash-out" phase (Figure 5).
It must be noted that, in about 12 percent of the children, atropine had no clear effect. It is not known why atropine did not work in these cases. Furthermore, there are a few data suggesting that it is more effective in Asian children. In Taiwan, atropine is regularly used against myopia progression in children. About half of the myopic children are treated. In Germany, there is no special approval of atropine for this purpose. The 0.01 percent solution is not officially available through pharmacies. Only eyes drops with the 1 percent solution can be purchased for the purpose of diagnostic pupil dilatation and accommodation paralysis. Furthermore, the 1 percent solution is occasionally used in amblyopia therapy in children. However, physicians can order the low concentration atropine solution according to their own discretion. More details are available in the related **information sheet.**

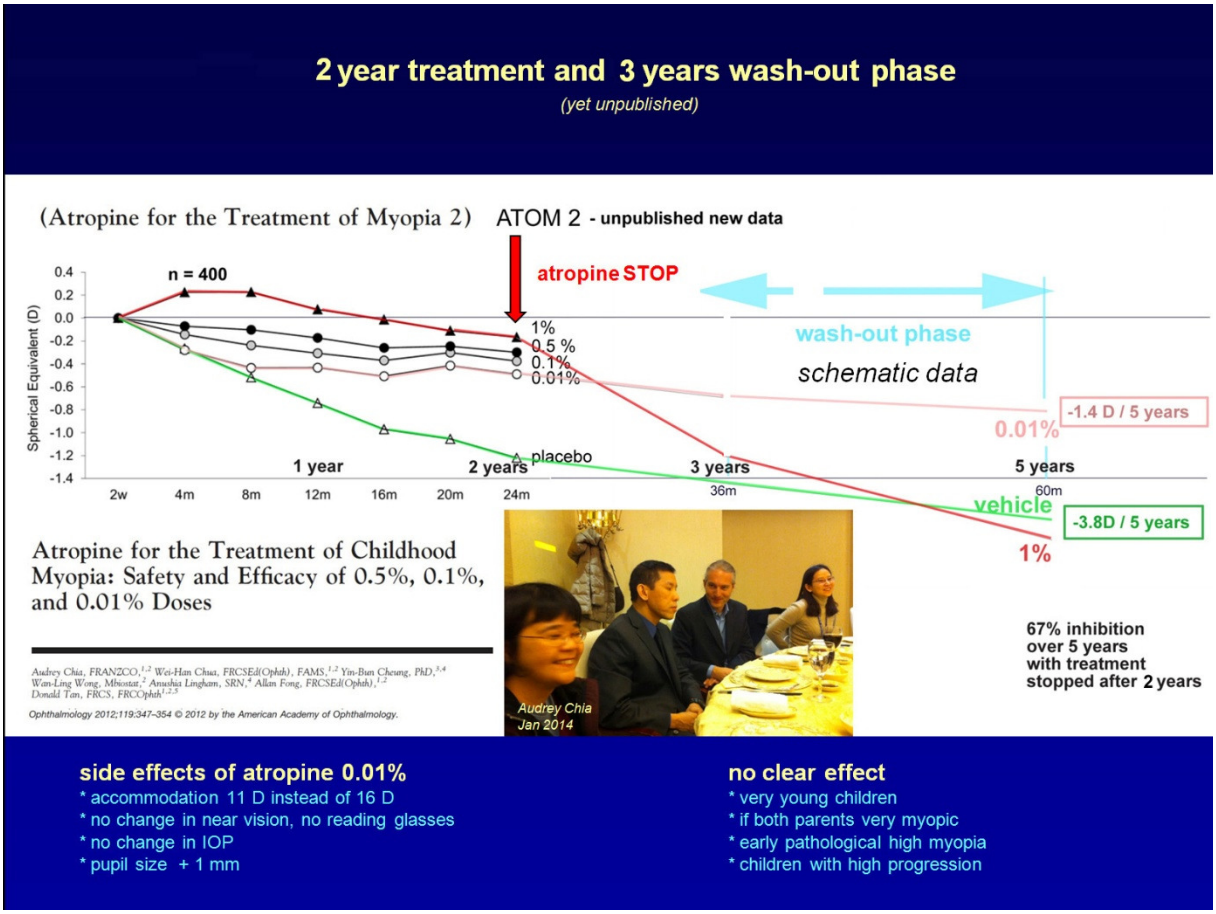

Figure 5. Inhibition of myopia progression with various dosages of atropine eye drops, given every evening over a period of 2 years. After termination of the treatment, myopia progression accelerates in the case of treatment with the one percent solution (dark red line). With the 0.01 percent solution, there is no acceleration of the progression when the treatment is terminated. Even after 3 years without further treatment, there was only about half of the myopia (after Chia et al, Am J Ophthalmology 2014; Ophthalmology 2015).

What else can be done against myopia?

Other than correcting myopia with spectacle lenses or contact lenses there are other options to correct the optics of the eye. Surgical interventions may be of interest to patients who cannot tolerate spectacles of contact lenses. With increasing optical power, such lenses induce optical aberrations, i.e. the retinal images are distorted if one does not look straight through the center of the lens. Also negative lenses cause demagnification of the image. Since these changes to the optics are permanent, it must be confirmed that myopia is no longer progressing because there is little chance for a second operation. It is clear that stable myopia is not typical in young people.

1) The refractive power of the cornea can be changed by removing tissue inside the cornea with a **Laser**. This can be done directly on the surface (LASEK) as well as within the corneal tissue (LASIK, SMILE). Therefore, the thickness of the cornea is an important variable which limits how much tissue may be removed and how much optical correction can be achieved. The higher the correction, the more disturbing optical side effects may appear like seeing halos

around light sources and reduced contrast sensitivity. In some cases, driving may become difficult particularly at night or under dim light conditions when the pupil is large.

2) Another option is surgical implantation of an additional intraocular lens (phakic IOL) or, in cases of very high myopia, replacement of the natural lens with a weaker artificial lens (clear lens exchange). A side effect is the increased rate of retinal detachment which may occur several years later and can permanently reduce vision.
   If the natural clear lens is replaced with a plastic lens, accommodation is lost. In this case one can consider implanting multifocal lenses which focus in different planes at a time. A disadvantage is that contrast is divided into different planes of focus, reducing contrast sensitivity of the patient.

All these options have in common that the length of the eye ball remains unchanged. The patient continues to have myopic eyes - independently from the lack of spectacles. Therefore, these eyes are still at risk for those complication that are typically associated with long eyes, like retinal holes and detachment, elevated intraocular pressure (glaucoma) and degenerative processes in retina and choroid. Therefore, control examinations by an ophthalmologist can detect degenerative changes. Any of the surgical interventions should not be considered when a retinal disease is already present.