Myopia: Unveiling the Efficacy of Treatment Options in Adults and Adolescents

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Myopia is a common ocular disorder affecting nearly 140 million people in the US. It causes difficulty in focusing on objects located at a far distance, rendering it "near-sightedness." Previously conducted research has asserted that the causes of myopia are multifactorial and only partially understood. To demonstrate that several medical and surgical management options exist for myopia in adults, and while the treatments are limited for adolescents ages 6-14 years old, this review describes the significant financial, social, and management challenges that come with the burden of myopia for these adolescents. The primary purpose of this review is to ascertain that there is compelling evidence and data that efforts were made to understand and evaluate the efficacy of management options, and preventative measures of myopia in adults and adolescents to provide acceptable treatments for patients of different ages. The review also aims to identify scientific gaps for future research that will immensely benefit the evolution of Myopia treatments. What became apparent in the process of this review was that it is important to understand and review subsidiary problems before evaluating the effectiveness of the various management options. The first of these problems is understanding the underlying causes and challenges of myopia in adults and adolescents. The second is identifying the list of available management options and how many are available for adults vs adolescents. The third problem is the evaluation methodology to be adopted to help us determine the effectiveness of the management options. Answering and solving these problems is essential before investigating whether there is compelling evidence to show the efficacy of these management options. This review was restricted to full-length articles published in English, and only peer-reviewed articles, systematic reviews, meta-analyses, clinical trials, and observational studies were included

Research Question: What are the management options and preventative measures of myopia in adults and adolescents, and what are the areas (scientific gaps) for possible future research?

Keywords: myopia, myopia causes, myopia challenges, myopia complications, myopia effects, myopia treatments, non-surgical myopia treatments, surgical myopia treatments

Introduction

Myopia, or nearsightedness, is a refractive error that makes far-off objects appear unclear, while closer objects appear distinct[1]. Myopia affects nearly 140 million people in the U.S.1 With the increasing prevalence of myopia worldwide, particularly among younger populations due to lifestyle factors such as increased screen time and reduced outdoor activity, early diagnosis and treatment are essential, as the condition can worsen every few months until the late teenage or early adulthood years[2]. People who develop high myopia have an increased risk of cataract, retinal detachment, myopic macular degeneration, and open-angle glaucoma, all of which have both personal and economic costs[3]. Myopia does not only affect educational outcomes; disadvantages arising from myopia also extend to quality of life and personal and psychological well-being[4]. Adolescents with myopia reported significantly lower quality of life and psychological and social functioning. Studies have also shown that myopia significantly affects the anxiety levels of adolescents, and low self-esteem among children has been linked to myopia[4]. Additionally, the largest contributing factor to the worsening of myopia is eye fatigue, which is a result of not wearing glasses[2]. This ultimately causes a greater burden on families compared to if it was caught and treated early[2]. Therefore, early diagnosis and treatment of myopia is crucial. Furthermore, understanding the underlying factors contributing to myopia progressions, such as genetic predisposition, environmental influences, and lifestyle habits, can inform targeted strategies for prevention and management, ultimately promoting better eye health and quality of life for individuals affected by myopia[5–10]. Fortunately, a wide array of treatments catering to myopia exists, encompassing both surgical interventions and nonsurgical modalities. This literature review will discuss the causes and challenges, evaluate both the safety and efficacy of the management options, along with preventative measures of myopia in adults and adolescents, as well as scientific gaps in the current literature and the areas for possible future research.

The eye has 2 components which focus images: the cornea and the lens[5]. The cornea is a clear dome-shaped front portion of the eye; the lens is a clear structure with a curved surface[3]. In order for a person to see, light must pass through the cornea onto the lens[3]. They refract light to focus it directly onto the retina, the nerve tissues, at the back of the eye[3]. The retina translates light into signals sent to the brain, enabling people to see images[3].Myopia is a refractive error, meaning the problem occurs when a misshapen cornea focuses light incorrectly as it enters the eye[6]. Myopia results from the shape of the eye being too long from front to back or oval-shaped[5]. It could also occur from the curve of the cornea being too steep[5]. As a result of these changes in the shape of the eye, light rays are focused in front of the retina, resulting in perceived blurriness[5]. When looking at nearby objects, the light rays do not converge as much since the objects are closer[7]. This allows the myopic eye to focus the light onto the retina more accurately, resulting in clearer vision for nearby objects compared to distant ones[6]. This comparison of light refraction between a normal eye and a myopic eye is further demonstrated in Figure 1 below.

Methods

Around 50-100 of the studies used for this review were from databases such as PubMed, Embase, Web of Science, and Cochrane Library and were searched from the database origin through January 3, 2024. Manuscripts included the causes, challenges, management options, and preventative measures of myopia in adults and adolescents. The review was restricted to full-length articles published in English. A comprehensive set of search terms was utilized to ensure inclusivity and relevance. These terms included ”myopia,” ”nearsightedness,” ”myopia causes,” ”myopia risk factors,” ”myopia progression,” ”myopia effects,” ”myopia treatments,” ”non-surgical myopia treatments,” ”surgical myopia treatments,” and ”pediatric myopia.” The review was restricted to studies published within the last 15 years to ensure the incorporation of recent research developments. Only peer-reviewed articles, systematic reviews, meta-analyses, clinical trials, and observational studies were included to verify the reliability, validity, and rigor of the information present in the review. Studies that evaluated patients between 6 and 50 years of age were included. This age range encompasses the critical developmental stages during which myopia commonly manifests and progresses. Adolescence is a period marked by significant physical and visual changes, making it a crucial time for monitoring and understanding myopia development. Furthermore, adulthood represents a stage where myopia stability or progression can have substantial implications for long-term eye health and quality of life. Animal studies were also excluded to ensure the content of this review prioritized relevance to human myopia. The relevance of studies to the research question was assessed through the alignment of study objectives with the key components of the research question, including management options, scientific gaps, and preventative measures of myopia in adolescents and adults, were evaluated. Studies that directly addressed these aspects were used as highly relevant sources. Additionally, the study population's age range and sample size were also considered for determining the generalizability of results.

Causes of Myopia

The causes of myopia are multifactorial, complex, and poorly understood. Myopia is a trait that can be inherited[8–10]. If one or both of a person's parents have myopia, they have an increased chance of developing the condition[7–9]. Myopia is neither a dominant nor a recessive trait, but multifactorial, meaning that it is caused by numerous factors[7–9]. More research is needed to better characterize the heritability and genetic component of myopia[6,10]. In doing so, vision needs could be better predicted for adolescents[6,10]. Environmental factors can also contribute to myopia[11]. Some of these factors include more education, near work, and lack of outdoor exposure[10]. Past studies have shown that people who earn advanced degrees are at twice the risk of nearsightedness as people who do not[10]. Near work refers to any work that requires focusing on an object close-up and is associated with an increased rate of myopia[10]. Since considerable time is now spent on computers and devices, the rate of myopia has increased[10]. Additionally, when people spend long periods indoors, their eyes do not focus on faraway objects, which may increase the risk of myopia[5,9]. The current literature suggests a strong correlation between reduced outdoor time, increased near-work activities, and a higher risk of developing myopia[12–14]. One study in particular, comprising of 1388 students from 1st to 3rd grade in Wenzhou, found that parental myopia and outdoor time were greatly associated with myopia in children, and a high level of outdoor time was a protective factor for children with one myopic parent[13]. However, a significant weakness lies in the complexity of interactions between genetic predispositions and environmental influences, making it challenging to isolate specific factors responsible for myopia development[11–13]. Additionally, the varying methodologies and populations across studies contribute to the difficulty in drawing universally applicable conclusions[11–13].

Financial Challenges

Myopia comes with various challenges, with one of the most apparent being its financial burden. Treatments such as contact lenses, glasses, and surgery can be very costly, and, unlike other conditions that may result in a one-time cost, the chronic nature

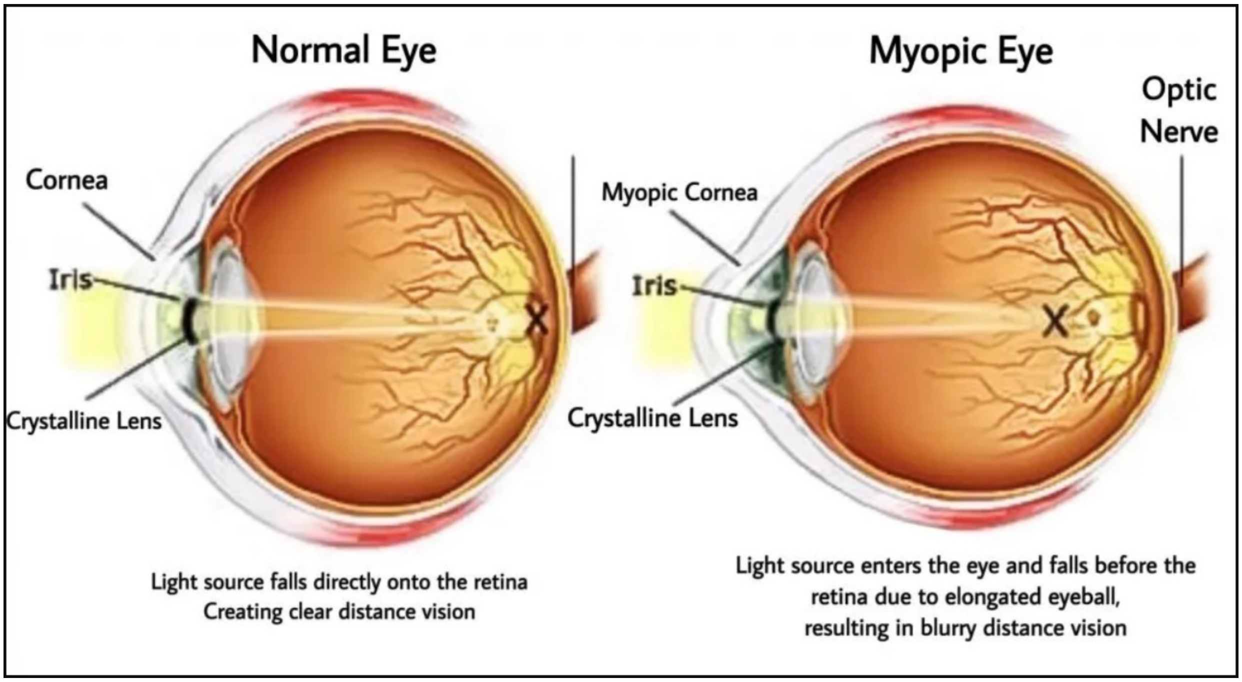

Fig. 1 Comparison of light refraction in a normal eye (left) versus a myopic eye (right), demonstrating the differences in focal points and resultant vision impairment.

of myopia translates to a life-long financial burden[15–19]. The annual cost and treatment of myopia in the US is estimated at 10.1 billion USD[18]. Moreover, a recent study showed that annual expenses of myopia in the U.S. exceeded $670 billion in 2018 and are projected to rise to 1.7 trillion in 2050[20]. Costs of glasses and lenses are set to double, and costs of myopic retinopathy, a consequence of severe myopia, are estimated to quadruple[21].

Social Challenges

Glasses are the most popular treatment option for myopia, but their use can contribute to social stigma[21]. This can be a significant challenge for young adolescents who are experiencing critical periods of socialization in their early life[22]. Stigma of glasses can cause poor social interactions and bullying, especially since most adolescents begin wearing glasses from elementary to middle school[21]. In fact, one study found that adolescents who wear glasses are 35-37% more likely to be victims of bullying.22 Adolescents may experience social withdrawal, have underdeveloped social skills, and have higher levels of depression and anxiety[23–27]. Long-term consequences into young and middle adulthood are also possible, such as suicidality, drug abuse, lower wealth status, and increased susceptibility to chronic disease[23–26,28]. This may explain why another study found that 48.9% of the participants did not wear their eyeglasses due to teasing and bullying by their peers[29]. Students without poorer presenting visual acuity and lesser correction of visual acuity were more likely to not be wearing their eyeglasses[30].

Common Management Challenges

Contact lenses can be an effective treatment option for anyone needing vision correction. However, many adolescents prefer glasses over contact lenses, as contact lenses require more upkeep. Hygiene and care routines are important to maintain contacts[29]. Some people might find this more challenging than others, especially for young patients or in the early stages of diagnosis[29]. Contacts come with a risk of eye infection[31–34]. In fact, some have concluded that the users of daily-wear lenses who wore them overnight had a risk of ulcerative keratitis 9 times higher than the users of daily-wear lenses[35]. While contact lenses may be excellent for vision correction and avoiding issues such as childhood bullying, there are still some minor risks involved[31–34,36].

Complications of Untreated Myopia

Untreated myopia is not without complications. Common symptoms include eyestrain and headaches, which can be bothersome and intrusive[7,35]. A feared consequence of untreated disease is retinal detachment, a condition in which the retina gets pulled away from its normal position[37–39]. Retinal detachment is a medical emergency that is five to six times more common in people with severe myopia and requires immediate treatment[35,37,38].

Treatment Options for Myopia

Currently, there are many treatments for myopia, and many patients elect non-surgical approaches. Non-surgical treatments include prescriptive glasses, prescription contact lenses, orthokeratology, and atropine eye drops.

Atropine Eye Drops

Atropine, an acetylcholine receptor inhibitor widely used outside ophthalmology for indications such as slow heart rate or as an antidote for nerve agent poisoning, can be used to slow the progression of myopia[40].Atropine eye drops work by dilating the pupil and temporarily relaxing the focusing muscles of the eye[41]. This dilation may help slow down the progression of myopia by reducing accommodative effort and potentially affecting other biochemical pathways involved in myopia development[41]. One study conducted in 2023 concluded that atropine 0.01% worked most effectively when combined with ortho-k contact lens wear in children aged 6-11 years old[42]. Factors such as patient age can affect the effectiveness of non-surgical interventions like atropine in treating myopia, with younger patients potentially experiencing greater benefits[43]. This can impact treatment outcomes and patient satisfaction, as younger individuals will show slower myopia progression and higher satisfaction rates with atropine treatment compared to older patients who will experience limited effectiveness and seek alternative options[44].Another recent study randomly assigned eligible children 1 eye drop of atropine, 0.01%, nightly or 1 drop of placebo, and performed automated cycloplegic refraction on each child[45]. This study found that while 0.01% eye drops did not slow myopia progression or axial elongation, 0.05% atropine eye drops were effective[39]. Another head-to-head analysis, through revision of all randomized clinical trials of atropine eye drops for myopia progression present in the current literature concluded that 0.05% atropine was more effective in slowing myopia progression than 0.01% atropine[42]. Thus, there is strong evidence to suggest that atropine eye drops, in higher doses, may slow the progression of myopia. Unintentional under-dosing may occur only due to various reasons such as improper administration or inconsistent use[46,47]. Side effects of atropine eye drops include blurred eyesight, stinging, and eye irritation[48]. Long-term studies are needed to determine the long-term effects of atropine eye drops on myopia progression. The use of these studies will help incorporate the use of atropine eye drops more frequently in myopia treatment prescriptions.

Orthokeratology (Ortho-K)

One of the newest forms of non-surgical myopia treatment is orthokeratology (Ortho-K). Ortho-K is the use of specially designed contact lenses that temporarily reshape the too-long or oval-shaped myopic cornea to improve vision[49]. This reshaping aims to correct refractive errors like myopia during the day without the need for glasses or contact lenses[45]. Two studies involving 337 adolescents found evidence that Ortho-K use significantly slowed myopia progression both after short (1-year) and long-term (12-year) usage[50,51]. There is evidence that Ortho-K lenses are similarly effective to low-dose atropine in slowing myopia progression[42]. One study indicated that the use of ortho-k lenses was most effective specifically for the correction of low to moderate myopia in children[52]. Patients with higher levels of myopia may have a greater risk of progression and associated complications, making it more challenging to manage effectively[43]. This is why interventions such as orthokeratology are more beneficial for patients with moderate myopia compared to those with severe myopia[53]. Additionally, a 3-year study found that while all modalities of treatment, including atropine eye drops and soft multifocal contact lenses, showed some efficacy in myopia management, for 184 out of the 342 adolescents in the study (55%), Ortho-K was the most prescribed modality[47]. Furthermore, a recent study conducted with 248 eyes in 124 adolescents with anisomyopia demonstrated that after a 2-year follow-up, the group treated with Ortho-K showed greater suppression of axial elongation as compared to the group treated with 0.01% and 0.05% atropine, indicating that Ortho-K was able to slow the progression of anisomyopia faster than low-dose atropine[54]. Also, while the majority of studies on orthokeratology showcase the positive aspects of its effectiveness, it is critical to note that long-term success of Ortho-K treatment also requires a combination of proper lens fitting, rigorous compliance to lens care regimen, good adherence to routine follow-ups, and timely treatment of complications. 47 Patients who adhere closely to the prescribed interventions for orthokeratology lenses are more likely to experience positive results[50]. On the other hand, non-compliance or inconsistent use of treatments can lead to less-than-optimal outcomes and may contribute to dissatisfaction with treatment[52]. Currently, the body of literature on Ortho-K is nascent, and more research is needed on long-term efficacy and safety as its adoption continues to become more popular amongst school-aged adolescents.

Glasses and Prescriptive Contact Lenses

Several studies have concluded that prescription contact lenses also slow the progression of myopia[46,55–57]. Single-vision prescriptive glasses did not contribute to controlling myopia progression[40,52]. However, several studies have shown that certain special types of myopia control or myopia management glasses, such as defocus incorporated multiple segments (DIMS) spectacle lenses and spectacle lenses with aspherical lenses, slow the rate of myopia progression[58–62]. Studies have shown that DIMS lenses may be more effective in slowing myopia progression in patients with higher levels of myopia, particularly during childhood and adolescence when myopia typically progresses more rapidly[51,52,54–56]. Since myopia tends to worsen more rapidly during childhood and adolescence, early intervention in younger patients is more effective in slowing down its progression[51,52,54–56]. Additionally, younger patients may adapt more readily to treatment regimens such as DIMS and spectacle lenses with aspherical lenses, leading to better outcomes[51,52,54–56]. These non-surgical treatments temporarily improve vision by slightly reshaping the cornea, but do not provide permanent vision correction[40].

Photorefractive Keratectomy (PRK)

One of the most popular myopia surgical options is photorefractive keratectomy (PRK). During PRK, an eye surgeon uses a laser to reshape the misshaped myopic cornea, with 41%-85% of eyes achieving perfect visual acuity and 90-99% of eyes achieving near-perfect visual acuity[63–65]. PRK is also considered a very successful procedure for long-term visual outcomes, with studies reporting 59-74% of patients maintained near-perfect vision as many as 16 years later[66,67]. However, the minimum corneal thickness considered appropriate for refractive procedures such as PRK to be successful has been considered to be 500 µm or 0.5 mm[68]. This thickness ensures that there's enough tissue for the laser to reshape the cornea and fix vision, while also keeping the eye safe and healthy[69].

Techniques to improve the safety profile of PRK are being developed constantly. For example, Mitomycin-C is a medication that is sometimes used during PRK to reduce the risk of corneal haze[70]. Emerging techniques involve optimizing MMC concentration and application protocols to achieve the desired effect while minimizing the risk of adverse events[70]. Side effects and complications of PRK are quite rare; however, some more common complications are corneal haze, dry eye, and vision regression[71,72]. Corneal ectasia, occurring in 0.04%-0.6% of PRK procedures, causes the cornea to thin and bulge[73,74]. Some treatment options to manage corneal ectasia include corneal cross-linking (CXL), which strengthens the cornea by applying riboflavin eye drops and exposing the cornea to ultraviolet light, and a corneal transplant, where the damaged cornea is replaced with a healthy donor cornea[75]. Another rare complication of these is corneal haze. Corneal haze is a cloudy layer in the eye that most commonly appears after trauma, infection, or surgery[58]. A large, single-center study carried out in 2017 reported an incidence of post-PRK haze of 1.3%[76]. Fortunately, corneal haze typically gets better over time[70]. Using the medication, mitomycin C, during surgery can help prevent corneal haze altogether[70]. Additionally, the frequency of dry eye post-PRK can vary, with one study reporting that dry eye incidence was around 38.7% out of 25,317 total patients[77]. For patients with occasional or mild dry eye symptoms, it's enough to regularly use nonprescription eye drops[78]. If symptoms are persistent and more serious, other options include medicines to reduce eyelid inflammation, eye drops to control cornea inflammation, and tear-stimulating medicines[78]. Another complication of PRK is vision regression, with one study concluding the frequency of myopic regression in the different age groups to be 5.0% at 18 – 20 years, 7.46% at 26 – 30 years, 12.28% at 21 – 25 years, 21.31% at 31 – 35 years, and 26.53% at 36 – 50 years out of 254 eyes in 132 patients[79]. Treating vision regression will most likely require additional treatment for myopia through either surgical or non-surgical interventions[80]. All of these complications occur postoperatively and may require retreatment[62]. Overall, though, patients are highly satisfied with PRK, reporting an 80-98% satisfaction rate[81–83]. Additionally, undergoing PRK has many benefits, including less risk of removing too much cornea and less risk of complications caused by the flap in the cornea made during the surgery[84]. PRK is also less expensive than LASIK, and it can be done on people who have thin corneas or less corneal tissue caused by poor vision or severe nearsightedness[84].

Laser-assisted in situ keratomileusis (LASIK)

A popular surgical technique for treating myopia is laser-assisted in situ keratomileusis or LASIK. The dome-shaped transparent tissue at the front of the cornea is carefully reshaped using a mechanical blade or specialized cutting laser during the LASIK surgery to improve vision[85]. This is beneficial since myopia alters the shape of the eye to be too long or oval-shaped, so by flattening the cornea slightly, LASIK helps to redirect the light entering the eye so that it focuses directly on the retina, improving distance vision[74]. Patients with higher degrees of myopia can experience less predictable outcomes, and those with corneas less than 0.3 mm are not suitable candidates for these procedures[74]. Several large studies show greater than 99% achieving near-perfect visual acuity and 70% - 95% achieving perfect vision after LASIK[86,87]. In addition, LASIK has a 95% patient satisfaction rate[88,89]. LASIK surgery is also considered a very successful and popular elective procedure, with approximately 16.3 million procedures performed worldwide since the inception of LASIK in 1989[90]. Furthermore, new technology for LASIK is continuously emerging. For example, femtosecond lasers offer greater precision and control compared to traditional mechanical tools for creating the corneal flap in LASIK[91]. This can reduce the risk of complications such as flap-related issues and enhance the predictability of the procedure[91].

One complication after LASIK is dry eye. Several studies have shown that immediately after LASIK, 95% of patients reported dry eye symptoms. Dry eye symptoms were reported in as high as 50% of patients 1 month after LASIK[92–95]. In fact, dry eye was more common following LASIK than PRK surgeries[96]. This issue may require the use of nonprescription eye drops, medicines to reduce eyelid inflammation, eye drops to control cornea inflammation, and tear-stimulating medicines[78]. Additionally, the risk of epithelial ingrowth (EI) is significantly increased in various clinical circumstances of LASIK, especially when the flap is lifted for retreatment[97–99]. General treatment for removing epithelial ingrowth involves lifting the flap and scraping the epithelial cells from the stromal bed and undersurface of the flap, typically followed by the placement of a bandage contact lens[100]. Other complications of LASIK surgery include corneal flap abnormalities, which can be treated by repositioning the flap, suturing the flap in the event of persistent fold, and using lubricants, corneal ectasia, which can be treated with either CXL or a corneal transplant, and loss of vision, which may require additional treatment for myopia through either surgical or non-surgical interventions[75,80,101]. Along with dry eye, common temporary side effects of LASIK include infectious keratitis and diffuse lamellar keratitis[23–25,28]. Depending on the cause of the infection, treatment for infectious keratitis may require the use of antibiotic, antifungal, antiviral, or antiparasitic eye drops, or oral antifungal or antiviral medications[102]. Furthermore, given its inflammatory nature, all stages of diffuse lamellar keratitis typically respond well to corticosteroid therapy. In certain cases, irrigation beneath the flap followed by flap repositioning can minimize complications associated with the condition[103]. One advantage of LASIK is that patients are also typically able to see full results after just a few hours of having undergone the procedure, whereas PRK patients tend to start seeing a difference after a few days[104]. One study also demonstrated that LASIK provided better visual outcomes than PRK in patients who have undergone cataract extraction and intraocular lens placement[105]. Patients who undergo LASIK surgery may also be able to save money by not requiring the use and yearly cost of contact lenses and glasses[106]. Also, LASIK can significantly reduce the rates of eye infections compared to those who continuously wear contact lenses[106].

Phakic intraocular lens surgery

Another type of surgical treatment for myopia is intraocular surgery. Intraocular surgery is performed inside the eye rather than on the cornea[107]. The 2 types of intraocular surgery are phakic intraocular lens surgery and refractive lens exchange surgery[95]. Phakic intraocular lens surgery involves placing an artificial lens inside the eye without disturbing the eye's natural lens[108]. The eye is numbed with eye drops or local anesthetic[96]. Microscopic holes are created in the peripheral iris either with a laser or with scissors to encourage normal eye pressure after phakic intraocular lens placement[96]. This helps in reshaping and flattening the cornea since in myopia, the cornea is often too steeply curved or the eye is too long, causing light rays to focus in front of the retina instead of directly on it[96]. Currently, advancements in surgical techniques, such as femtosecond laser-assisted implantation, can enhance the safety and accuracy of phakic IOL placement, leading to better visual outcomes and reduced risk of intraoperative and postoperative complications[109]. Phakic intraocular lens surgery comes with complications as well. After phakic intraocular lens surgery, some patients may experience eye discomforts such as halos and glare, especially in low light[110]. Although uncomfortable, they usually resolve on their own[110]. The phakic implantation process may also potentially cause cataract formation[110]. In this situation, the phakic lens should be removed first, and then cataract surgery should be performed[110]. Overall, the incidence of these complications is typically very low, and phakic intraocular lens surgery is a very safe and effective procedure[110]. An 8-year follow-up study, comprising 67 eyes that underwent toric phakic intraocular lens surgery, found that the mean corrected distance visual acuity (CDVA) and uncorrected distance visual acuity (UDVA) significantly improved from preoperative levels to 1 year postoperatively and remained stable over the 8year follow-up[111]. Additionally, the spherical equivalent (SE) significantly improved after surgery[97]. Furthermore, phakic intraocular lens surgery is considered to have expanded the range of refractive surgery to cover higher degrees of myopia (6.0 D or more), hyperopia, and astigmatism that were previously not possible to treat with other forms of refractive surgery, such as PRK and LASIK[112].

Refractive lens exchange (RLE)

Refractive lens exchange (RLE) is a type of eye surgery where the natural lens in the eye is removed, and a clear artificial lens is put in its place[113]. This option corrects the refractive error and eliminates the formation of cataracts in the future[98]. By selecting an artificial lens with appropriate optical power, the surgeon can effectively adjust the focal point of the eye, thereby correcting myopia[98]. Also, since myopia occurs when the eye's focal point falls in front of the retina, instead of directly on it, by replacing the natural lens with an artificial one of the appropriate power, the focal point can be shifted backward onto the retina, ultimately correcting myopia[98]. This can be a good alternative for people who are not candidates for LASIK or PRK[98]. This includes those whose vision is not stable, those who have corneal scars or disease, and those who have a history of certain eye infections[89,90]. Improving the safety profile of RLE involves advancements in the technologies used during the procedure. Intraoperative aberrometry devices measure the eye's refractive error during surgery, allowing surgeons to make real-time adjustments to the IOL power or position to optimize visual outcomes[114]. This technology helps minimize residual refractive errors and improves postoperative visual acuity, especially in cases where preoperative measurements may be less accurate[114]. RLE is known to be quite a successful procedure. A study comprising of 39 patients with refractive lens exchange found that 99% and 100% of patients achieved perfect and near-perfect monocular corrected distance visual acuity (CDVA), respectively[115]. Binocularly, 100% of patients achieved a perfect binocular corrected distance visual acuity (CDVA)[99]. A study comprising of 4 age groups, 45-49 years (group A), 50-54 years (group B), 55-59 years (group C), and 60-65 years (group D), with 320 individuals in each group who each underwent RLE with a multifocal intraocular lens at least in one eye concluded that 91.6% (group A), 93.8% (group B), 91.6% (group C), and 88.8% (group D) of patients near-perfect binocular uncorrected distance visual acuity (UDVA)[116]. It is important to note that the efficacy of the RLE procedure can also depend on individual patient characteristics[117]. For example, a 2020 study mentions that certain pre-existing ocular pathologies, including corneal disease, age-related macular degeneration, diabetic retinopathy, and ocular inflammatory diseases, can result in poor vision for patients postoperatively[113]. Additionally, along with its high visual acuity results, RLE surgery has many postoperative complications. Studies have demonstrated that complications such as retinal detachment and cystoid macular edema can occur after RLE[118,119]. Several treatment options exist for retinal detachment, including pneumatic retinopathy and scleral buckling[44]. In pneumatic retinopexy, the surgeon injects a bubble of air or gas into the center part of the eye[44]. If positioned properly, the bubble pushes the area of the retina containing the hole or holes against the wall of the eye, stopping the flow of fluid into the space behind the retina[44]. Fluid that is collected under the retina is absorbed by itself, and the retina can then adhere to the wall of your eye[44]. In scleral buckling, the surgeon sutures a piece of silicone material to the white of your eye over the affected area[44]. This procedure indents the wall of the eye and relieves some of the force caused by the tugging on the retina[44]. Cystoid macular edema is when fluid builds up in a part of the eye located in the center of the retina called the macula, distorting the vision[53]. Some management options for cystoid macular edema include anti-VEGF drugs, which help reduce leakage from blood vessels in the eye, steroid treatment, which reduces inflammation, and vitrectomy surgery[53].

Myopia in Adolescents

There are several medical and surgical management options for myopia in adults. Still, none of these are safe for adolescents, even though the average onset of myopia is reported to range from 6 to 14 years old[120–122]. The U.S. Food and Drug Administration (FDA) has only approved LASIK and PRK surgery for individuals over the age of 18 years old[4,123]. Fortunately, there are current ways to prevent the progression of myopia with non-surgical treatments such as contact lenses, glasses, and low-dose atropine eye drops. All of these treatments can be used to slow the growth of myopia in adolescents. Additionally, some of the methods to help prevent the diagnosis of myopia altogether include spending more time outside, using electronic devices for shorter periods, and protecting the eyes from the sun[41,80]. Spending increased time outdoors can help control myopia[124]. A study conducted in Taiwan showed that when sunlight comes in contact with the retina, it releases dopamine into the eye[119]. This may prevent the eye from elongating and becoming more myopic[119]. In addition, decreased use of electronic devices has been shown to protect eye health in adolescents[125]. Furthermore, if most of a child's early and middle childhood is spent staring at a screen, the child is training their eyes to focus on a near-field object[80,126]. Over time, they will lose part of their ability to stop focusing on near-field objects, leaving them with permanently near-focused eyes, or myopia[117,127]. Also, wearing sunglasses will protect adolescents' eyes from harmful ultraviolet rays and help slow the progression of myopia if they spend a lot of time outdoors[128]. It is important to consider these methods of prevention and implement them thoroughly so adolescents can ensure better eyesight.

Discussion

The management (treatment) options for myopia for adults and children are well-researched, though gaps remain. The table above captures various non-surgical and surgical treatments along with the effectiveness of the treatment in both adults and adolescents. As surgical options are not available for adolescents, the non-surgical options do help in slowing down the progression of Myopia in adolescents. Additionally, while non-surgical therapies such as orthokeratology (Ortho-K), contact lenses, glasses, and atropine eye drops are effective, they can be costly. For some, especially those with low socioeconomic status, myopia can become a life-long financial burden. The same applies to surgical treatments such as refractive lens exchange (RLE), photorefractive keratectomy (PRK), and laser-assisted in situ keratomileusis (LASIK).

Furthermore, there are currently no safe surgical treatments for adolescents due to their eyes being underdeveloped. The synthesis of the literature on myopia in adults and adolescents offers new perspectives on surgical treatment for minors with myopia, highlighting emerging trends and advancements in this area. Specifically, the review suggests novel surgical management options for myopia that could be potentially tailored for younger patients, emphasizing the importance of early intervention to address myopia progression effectively. Theoretical frameworks that emerge from this synthesis underscore the need for a multidisciplinary approach to myopia management, integrating ophthalmology, optometry, and pediatric medicine to optimize treatment outcomes while considering the unique physiological and psychological factors of minors. However, it is

Name of the treatment	Type of treatment	Treatment Description	Positives	Negatives
Atropine eye drops	Non-surgical	Dilates the pupil and temporarily relaxes the focusing muscles of the eye to slow down myopia progression	• Between 6-11 years of age, atropine combined with Ortho-K was effective in slowing Myopia progression • 0.05% was more effective than 0.01% of atropine	• Slightly expensive • Requires everyday discipline to apply the eye drops • Should not be used by patients with glaucoma or those who have a tendency to develop glaucoma
Ortho-Keratology	Non-surgical	Specially designed contact lenses that temporarily reshape the too-long or oval-shaped myopic cornea to improve vision and correct refractive errors like myopia during the day without the need for glasses or contact lenses.	• Evidence shows that Ortho-K use significantly slowed myopia progression both after short (1-year) and long-term (12-year) usage. • In adolescents with anisomyopia a 2-year treatment with Ortho-K showed greater suppression of axial elongation as compared to the group treated with 0.01% and 0.05% atropine	• Expensive • Long-term success of Ortho-K treatment also requires a combination of proper lens fitting, rigorous compliance to lens care regimen, good adherence to routine follow-ups, and timely treatment of complications.
Glasses and prescriptive contact lenses	Non-surgical	Daily usage of defocus incorporated multiple segments (DIMS) spectacle lenses and spectacle lenses with aspherical lenses that slows down the rate of myopia progression.	• Effective in slowing myopia progression in patients with higher levels of myopia, particularly during childhood and adolescence when myopia typically progresses more rapidly.	• Expensive • Less effective than atropine and Ortho-K
Photorefractive Keratectomy (PRK)	Surgical	Uses a laser to reshape the misshaped myopic cornea.	• 41%-85% of eyes achieving perfect visual acuity and 90-99% of eyes achieving near-perfect visual acuity. • Successful procedure for long-term visual outcomes, with studies reporting 59-74% of patients maintained near-perfect vision as many as 16 years later.	• One complication of PRK is vision regression, with one study concluding the frequency of myopic regression in the different age groups to be 5.0% at 18 – 20 years, 7.46% at 26 – 30 years, 12.28% at 21 – 25 years, 21.31% at 31 – 35 years, and 26.53% at 36 – 50 years out of 254 eyes in 132 patients. • Cannot be performed on adolescents • PRK patients tend to start seeing a difference after a few days of surgery rather than a few hours like with LASIK surgery • Patients with advanced glaucoma, cataracts, corneal injuries or diseases, or eye infections should not undergo PRK
Laser-assisted in situ keratomileusis (LASIK)	Surgical	The dome-shaped transparent tissue at the front of the cornea is carefully reshaped using a mechanical blade or specialized cutting laser to improve vision.	• Greater than 99% achieving near-perfect visual acuity and 70% - 95% achieving perfect vision after LASIK. • 95% patient satisfaction rate • LASIK provided better visual outcomes than PRK in patients who have undergone cataract extraction and intraocular lens placement • Patients are typically able to see full results after just a few hours of having undergone the procedure	• One complication after LASIK is dry eye. 95% of patients reported dry eye symptoms. • Cannot be performed on adolescents • Can be expensive • Patients who have unstable vision or have significant medical conditions like glaucoma are ineligible for LASIK
Phakic intraocular lens surgery	Surgical	Involves placing an artificial lens inside the eye without disturbing the eye's natural lens. This helps in reshaping and flattening the cornea, causing light rays to focus in front of the retina instead of directly on it.	• The mean corrected distance visual acuity (CDVA) and uncorrected distance visual acuity (UDVA) significantly improved from preoperative levels to 1 year postoperatively and remained stable over the 8-year follow-up. • The spherical equivalent (SE) significantly improved after surgery.	• More expensive than LASIK surgery • Cannot be performed on adolescents • May lead to the formation of cataracts in patients postoperatively • Patients who have medical conditions such as glaucoma are not good candidates for phakic intraocular lens surgery
Refractive lens exchange (RLE)	Surgical	The natural lens in the eye is removed, and a clear artificial lens is put in its place. This option corrects the refractive error and eliminates the formation of cataracts in the future.	• Good alternative for people who are not candidates for LASIK or PRK. • 99% and 100% of patients achieved perfect and near-perfect monocular corrected distance visual acuity (CDVA), respectively • RLE with a multifocal intraocular lens at least in one eye across different age groups (320 individuals per age group) that achieved near-perfect binocular uncorrected distance visual acuity (UDVA): 45-49 years (group A): 91.6% success, 50-54 years (group B): 93.8% success, 55-59 years (group C): 91.6% success, and 60-65 years (group D): 88.8% success	• Efficacy of the RLE procedure can depend on individual patient characteristics • Certain pre-existing ocular pathologies, including corneal disease, can result in poor vision for patients postoperatively. Those who have these conditions may not be ideal candidates for RLE. • Complications such as retinal detachment and cystoid macular edema can occur after RLE

Table 1 Comparison of Myopia Treatments

critical to acknowledge the limitations of the study and address potential biases in the interpretation of findings. One limitation is the potential for publication bias, as the review primarily included studies with positive results, potentially falsifying the overall findings. Additionally, the inclusion criteria and search strategy may have inadvertently excluded relevant studies, leading to a limited scope of evidence. Moreover, the review may have been subject to reviewer bias during data extraction and synthesis, which could have influenced the interpretation of results. To address these limitations, future research should aim to conduct more comprehensive literature searches, consider alternative perspectives, and employ rigorous methodologies to minimize bias. Additionally, transparent reporting of study limitations in the discussion section is crucial for providing readers with a balanced assessment of the review's findings and implications. This literature review had several strengths, such as highlighting surgical and non-surgical treatments for myopia. It also stated the effectiveness of each treatment when comparing different treatments for myopia. Additionally, this review emphasized the crucial fact that minors are unable to receive surgical treatment due to their eyes being underdeveloped. Furthermore, this paper incorporated the use of high-quality studies and systematic reviews. This research was limited by a lack of literature that discusses how heritability affects the risk of myopia. To address this, further investigation could involve large-scale genetic studies to identify specific genetic variants associated with myopia risk. Collaborative efforts across multiple research institutions could facilitate the collection of genetic data from diverse populations, allowing for a comprehensive analysis of genetic predispositions to myopia development. More research should be done to determine the relationship between certain environmental factors and the risk of myopia. Exploring the relationship between environmental factors and myopia risk warrants interdisciplinary research combining epidemiology, environmental science, and ophthalmology. Utilizing advanced statistical modeling techniques could help ease apart the relative contributions of different environmental exposures, considering potential interactions and confounding variables. Also, the mechanism involved in how near work leads to myopia is not entirely clear. Investigating the mechanisms underlying the association between education, near work, and myopia development requires detailed physiological studies at the cellular and molecular levels. Experimental research employing animal models or in vitro cell cultures could explain how prolonged near-work or intense educational demands influence refractive error development. Advanced imaging techniques, such as MRI, could provide insights into structural changes in the eye associated with educational activities, appraising potential therapeutic interventions. There is no scientifically proven way to cure or reduce myopia naturally. Exploring natural approaches to managing myopia requires interdisciplinary collaboration between traditional medicine, nutrition science, and ophthalmology. Randomized controlled trials could evaluate the efficacy of dietary supplementation with specific nutrients such as vitamin D or omega-3 fatty acids, or lifestyle modifications like outdoor activities and reduced screen time in preventing myopia onset or slowing its progression. Long-term observational studies tracking the myopia status of individuals adopting natural interventions could provide valuable real-world evidence of their effectiveness and safety. Moreover, researchers are not sure what directly causes myopia. Unraveling the etiology of myopia necessitates integrated research efforts combining epidemiology, genetics, and molecular biology. Large-scale population-based studies could investigate potential risk factors for myopia onset, such as early-life exposures, socioeconomic status, and urbanization. The fundamental processes underlying the development of myopia may be clarified by molecular research examining the function of genetic and biochemical pathways connected to ocular growth regulation. Furthermore, multicenter collaborations could enhance statistical power and facilitate the identification of novel risk factors for myopia through pooling data from diverse populations. More conducive studies are needed to fill these gaps in myopia research. While non-surgical treatments like glasses, contact lenses, and orthokeratology exist for minors, they may not always be convenient or suitable for every individual. The absence of safe surgical options means that minors with severe myopia have limited choices for long-term correction of their visual impairment[69,129]. This can significantly impact their quality of life, academic performance, and overall well-being, including increasing the risks of trait anxiety and depression[121,122].

More research is needed to thoroughly understand the causes of myopia and possible additional management options for adolescents. This work should include studies on how to alleviate the effect of refractive surgery on growing eyes and more studies on how to effectively reduce the acute repercussions of refractive surgery. Research into the causes of myopia should encompass a multifaceted approach, delving into genetic predispositions, environmental factors such as excessive screen time and outdoor activity levels, as well as lifestyle habits like diet and sleep patterns. Understanding the interplay between these factors and how they contribute to the onset and progression of myopia is crucial for developing targeted prevention and intervention strategies.

Promising management options are on the horizon. Interventions such as advancements in orthokeratology, pharmacological interventions to slow myopia progression, and surgical techniques that address the underlying mechanisms of myopia could be developed to prioritize safety, especially for minors. Additionally, exploring the potential of stem cell therapy and gene editing technologies holds promise for addressing the root causes of myopia and providing long-term solutions. Stem cells are unique cells with the ability to differentiate into various cell types in the body, allowing them to repair and replace damaged tissues[130]. There are two main types of stem cells: embryonic stem cells, derived from embryos, and adult or somatic stem cells, found in various tissues throughout the body[123]. Stem cell therapy is a promising and evolving field of regenerative medicine that holds significant potential for treating a wide range of medical conditions and diseases, including myopia[123]. Evidence supporting the efficacy of stem cell therapy or gene editing in the context of myopia treatment is still emerging but shows promising potential. Stem cell therapy holds the promise of repairing damaged tissues in the eye, potentially reversing or halting the progression of myopia[123]. One study has even shown encouraging results in animal models, demonstrating the ability to regenerate corneal tissue or modulate the growth of the eye[131]. Similarly, gene editing techniques offer the possibility of targeting specific genes associated with myopia development, potentially correcting underlying genetic factors contributing to the condition[132,133]. However, before clinical implementation, several challenges must be addressed. Safety remains a primary concern, as any therapeutic intervention must ensure minimal risk of adverse effects such as tumor formation or unintended genetic mutations. Additionally, the complexity of the eye's structure and the multifactorial nature of myopia necessitate thorough understanding and precise targeting to achieve effective outcomes. Regulatory approval, ethical considerations, and the scalability and cost-effectiveness of these approaches also pose significant hurdles that need to be overcome for widespread clinical adoption. Nonetheless, ongoing research efforts continue to explore these innovative therapies, offering hope for more effective and personalized treatments for myopia in the future. With advancements in surgical techniques, such as customizable corneal procedures and implantable devices, ongoing research can aim to develop safe and effective surgical options for younger patients. The future of the financial burden on myopia depends on early intervention and prevention efforts, along with the development of cost-effective treatment modalities. Investing in public health initiatives that promote awareness, screening, and access to vision care services can mitigate the economic impact of myopia-related healthcare expenses over time. In the future, a comprehensive longitudinal study involving diverse populations of minors could be designed to track the progression of myopia from childhood through adolescence and into adulthood. Future studies could incorporate genetic profiling, environmental monitoring, ocular imaging techniques, and detailed lifestyle assessments to elucidate the complex interactions underlying myopia development. Additionally, randomized controlled trials evaluating the efficacy of emerging treatment modalities, including pharmacological interventions and novel surgical approaches, could be conducted to establish evidence-based guidelines for managing myopia in minors. One example of these novel approaches is a systematic review of 12 randomized control trials published between 2019 and 2021 that investigated the effectiveness of interventions to control myopia progression[40]. This review found that highly aspherical lenslets (HAL), MiSight contact lenses, low-dose atropine 0.05%, Biofinity +2.50 D, defocus incorporated multiple segments (DIMS), and ortho-k lenses were effective in slowing myopia progression[40]. These findings provide valuable insights into potential treatments for myopia. Furthermore, another clinical trial, centered on ongoing global efforts to study myopia that aim to discover effective methods for controlling it, concluded that the epidemiology and pathophysiology of myopia continue to evolve, and new therapies are expected to emerge soon[134]. Ultimately, such research endeavors would pave the way for personalized and preventative strategies that optimize visual outcomes and improve the quality of life for individuals affected by myopia.

Conclusions

In this review, the current understanding of the causes, challenges, management options, and preventative measures of myopia in adults and adolescents was summarized, and gaps were identified for future research. The current literature regarding the effects and treatments for myopia is well-researched, though areas remain for future research, especially in understanding the causes of myopia and possible future management options for adolescents. This review on myopia in adults and adolescents sheds light on the factors contributing to this common vision issue. While genetics play a role in myopia development, further exploration is needed to understand the genetic factors involved. Environmental aspects like time and increased near-work activities also influence myopia progression underscoring the need to address these factors through targeted interventions. The review points out gaps in knowledge including how education and near work relate to myopia and the absence of proven natural remedies for managing it. The theoretical implications of the study suggest an approach to myopia care by integrating insights, environmental science, and ophthalmology for personalized treatment plans. It emphasizes intervention and lifestyle changes as crucial in slowing down myopia progression highlighting the roles of healthcare providers, educators, and policymakers in raising awareness, about eye health and implementing measures. However, it's important to recognize some limitations of the literature review, such as bias in publications that are directed towards positive results and the focus on research from geographic areas or healthcare environments which could restrict the applicability of results. It is clear that myopia has far-ranging impacts on patients, and more research can change how the quality of life of millions of Americans can be improved.

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