Orthokeratology and High Myopia

Eman Bani Mohammad

iman.bani@ymail.com
School of Advanced Education, Research and Accreditation (SAERA), Germanías 3, 1C,
12001, Castellón de la Plana (Spain)

Abstract

The aim of this study is to review the current literature on ortho-K lenses use in myopia with a particular focus on the efficacy and safety of orthokeratology in myopia, and its effects in the case of high myopia, as well as the impact of COVID-19 pandemic on myopia and orthokeratology.
COVID-19 pandemic influenced the incident of myopia as well as progression of myopia. Ortho-K lenses have been shown to be safe and effective in reducing the axial elongation and decreasing myopia progression in low to moderate myopia and with some limitations in high myopia patients. During the COVID-19 pandemic, ortho-K treatment was not affected, and the pandemic had no effect on the axial elongation in myopia children undergoing treatment with ortho-K lenses.
Myopia is becoming a major health problem worldwide that is increasing to an alarming rate. The progression of myopia can lead to serious irreversible complications. There is sufficient evidence proving that orthokeratology lenses are effective and safe in myopia. More studies need to be done in high myopia. Long term success of the use of ortho-k lenses increases with the proper lens fitting.

Keywords: Orthokeratology;overnight orthokeratology;high myopia,COVID-19 myopia.

1. Introduction

In recent years, orthokeratology has become one of the recent interventions that eliminates the need for glasses or daytime contact lenses by using special contact lenses worn overnight to produce a temporary reduction, modification, or elimination of refractive error (Nti and Berntsen,2020). The corneal epithelial cells are being redistributed temporarily causing the myopia to be corrected the next day following lens removal (Németh et al., 2021). Another term to describe this method is overnight orthokeratology or as in the case of myopia it is sometimes referred to as myopic orthokeratology, a technique for reshaping the corneal surface, and reducing the level of myopia.

1.1. Background

The shape of the cornea can be changed and deformed by the application of an external power. Early studies demonstrated that the use of polymethylmethacrylate can induce changes to the surface of the cornea, altering its curvature as well as the refractive error hence the visual acuity. The undesirable effects of what was then known as a poorly fitted lens, has become nowadays a new modality to manipulate the corneal toricity to achieve the desirable effect.

Historically, deliberately attempting using rigid lenses to correct myopic refractive error was done by George Jessen in the 1960s. He used a technique known as ortho-focus, which consisted of using a progressively flatter polymethylmethacrylate lenses that flattens the corneal radius resulting in a variable change of the refractive power according to Singh et al. (2020). Afterwards, many attempts to use this technique were made. However, many reports from early studies during the 1970's and 1980's emerged, but they lacked appropriate scientific analysis. These studies did not have one single approach in accordance with lens design and the wearing schedule, as well as no control subjects were included. Furthermore, according to Carney (2002), some studies reported that a reduction of myopia up to -4.00 can be achieved whereas it was less than that, and the regression of the change induced, caused limitations to the procedure.
In the 1970's, orthokeratology was first evaluated by Kerns, who concluded that despite a reduction in myopia was observed, the outcome of the procedure was unpredictable and uncontrollable. Bullimore and Johnson (2020), noted that this conclusion was also found by Binder et al. (1980) and by Polse et al. (1983), who conducted a randomised clinical trial in the 1980's and concluded again that the reductions of myopia were unpredictable and variable.

1.2 Modern orthokeratology

With the revolution of a new design of rigid gas permeable lenses, the new advances in technology (such as corneal topography), as well as the improvement of the lens material (highly oxygen-permeable materials), and computer-guided lathes, all led to a revolution in orthokeratology, which is nowadays known as modern orthokeratology.
In modern orthokeratology, the lens used is a reverse geometry lens and was designed by Wlodyga and Stoyan in the late 1980s. A reverse geometry lens has a base curve radius designed to be flatter than the corneal curvature, and the secondary curve steeper than the base curve radius. These three zone lenses allowed better lens centration, more predictable results, and faster reduction of myopia. Furthermore, better lens centration was achieved by designing a lens with four to five curves allowing for more predictable and rapid results in the cases of high myopia. The computer-guided lathes technology enabled the ease for manufacturing any reverse geometry lens design.

The lens material of an ortho-K lens has a high oxygen permeability (Dk) which plays a vital part in being able to be worn safely overnight and avoid hypoxia. Improvement in gas permeable lens materials has resulted in better surface wetting quality and stability and higher oxygen transmissibility (DK/t), leading to less incidence of hypoxic and other ocular complications. Currently, there are many orthokeratology lenses that have been approved by regulatory bodies, yet they are only used to correct myopia up to -6.00 D, and 1.75 D of astigmatism, and only two ortho-k lenses have been approved for myopia control in Europe, Bloom Night by Menicon which corrects up to -4.00D and ≤1.50 D with-the-rule astigmatism and ≤0.75 D against-the-rule astigmatism and Paragon CRT by Cooper Vision, which corrects up to- 6.00 D and 1.75 D astigmatism. Thus, any other use of lenses for myopia control is considered off-label as reported by Vincent et al. (2021).

The fitting of orthokeratology lenses has become easier with the use of modern corneal topographers, since accurate baseline measurements can be provided, which aids in determining the initial lens selection and design as well as providing a precise aftercare lens follow-ups, monitoring the changes in the curvature of the cornea as well as the flattening of the corneal surface. Corneal topography also allowed the customisation of ortho-k lenses based on the patient's own corneal topography map. This map allows more precise contact lens fitting and lower fitting visits. The advances in the ortho-K lens design and materials as well as in technology, has made the use of orthokeratology lenses in myopia more beneficial.

1.3 Myopia

Myopia is recognized worldwide as a global public health issue. The definition of myopia quantitatively has not been agreed internationally according to the International Institute of Myopia (IMI). In 2019 the IMI published their white paper and proposed a definition for myopia, high myopia, and pathologic myopia based on analysing myopia thresholds statistically used in studies as shown in table 1.

Table 1. Myopia definition as proposed quantitative thresholds for myopia (Flitcroft et al., 2019)

Term	Definition
Myopia	A condition in which the spherical equivalent refractive error of an eye is ⩽−0.50 D when ocular accommodation is relaxed
Low myopia	A condition in which the spherical equivalent refractive error of an eye is ⩽−0.50 and >−6.00 D when ocular accommodation is relaxed.
High Myopia	A condition in which the spherical equivalent refractive error of an eye is ≤ –6.00 D when ocular accommodation is relaxed.
Pre-myopia	A refractive state of an eye of ⩽+0.75 D and >−0.50 D in children where a combination of baseline refraction, age, and other quantifiable risk factors provide a sufficient likelihood of the future development of myopia to merit preventative interventions.

According to Jong et al., (2021), the aim of this proposal is to avoid confusion regarding the differentiation of myopia grades, especially in high myopia and pathological myopia hence improving the comparability of research findings. Despite the proposal, many studies that have been included in this review and published between 2019 and Jan 2021 still used the definition that was set in 2015 by World Health Organization (WHO).The World Health Organization (2015) defined myopia as "a condition in which the spherical equivalent refractive error of an eye is ⩽0.50 in either eye" and defined high myopia as "A condition in which the spherical equivalent refractive error of an eye is ⩽−5.00 D".

1.4. Myopia Incidence and Prevalence

The myopia prevalence is increasing worldwide, as well as the prevalence of high myopia and pathological myopia. Even if the appropriate refractive correction is provided, myopia continues to increase the risk of sight threatening diseases, such as glaucoma, cataract and retinal tears, which may lead to irreversible complications such as retinal detachment and myopic maculopathy i.e., pathological myopia. Axial elongation is considered as the main risk factor for the development of myopia complications, hence many young myopes may develop a pathology later in their lives if no interventions were made to decrease the prevalence and to reduce the progression to high myopia in Europe and worldwide. According to researchers, myopia is predicted to reach by 2050 up to 4.9 billion worldwide. East Asian countries have the most increase in the prevalence of myopia with a predicted prevalence of 65% of the population in Asia, 56% in Western Europe, 54% in Central Europe, and 50% in Eastern Europe according to Németh et al. (2021).

Myopia develops in early childhood and progresses until late adolescence. Frogozo and Kumar

(2021) stated that when children develop myopia at an early age, the likelihood of myopia progressing is faster and higher. For instance, those with myopia greater than -6.00 D are at 14.4 times higher risk of developing glaucoma is and 3.3 times higher risk for developing posterior subcapsular cataract. The risk is even 7.8 times higher for myopes over -8.00 D for developing retinal detachment.

Many researchers have widely studied Myopia incidence and progression in children, but few studies investigated myopia incidence in adults. Recent research conducted by Lee et al. (2022) suggests that myopia can progress during young adulthood, and myopia-related complications may become more prevalent as young adults approach middle and old age.

According to Pugazhendhi et al. (2020) environmental factors in addition to genetic factors have been found to be closely associated with the prevalence and progression of myopia in addition to age. Gifford et al. (2018) reported that the risk of myopia is higher in children with lower hyperopia than age-normal and in children who show less hyperopic refractions up to four years before onset of myopia compared with age matched group who remained emmetropic. Li et al. (2022) also recommended that pre-school children with hyperopia should be monitored, since their hyperopia reserve may progress to myopia and high myopia. Furthermore, myopia incidence is higher in children if both parents were myope according to Kaur et al. (2020). According to Berke, (2021), the risk of developing myopia with both myopic parents triples when compared to children with non myopic parents. The effect of ethnicity on the prevalence of myopia is higher in Asian descent children regardless of where they live worldwide Cho et al., (2019) reported. Yet the underlying ethnicity risk factors are still uncertain due to the interaction between genetics and environmental other risk factors such as genetic and environmental factors.

Environmental factors such as the increased use of digital devices and lack of natural light are leading to an increase in myopia among children. Gifford et al. (2018) reported that close work or reading at a very close distance (less than 20cm) and for more than 45 minutes is associated with risk of developing myopia and progression.

3.5. Myopia during the COVID-19 Pandemic

On March 11, 2020 the World Health organisation declared COVID-19 as a global pandemic after the spread of the novel coronavirus worldwide according to Cucinotta and Vanelli, (2020). To restrict the spread of the virus, the population were forced to quarantine. While the pandemic was occurring, most of the children stayed at home, outdoor activities were reduced, near work demands increased, as well as increasing time spent on digital devices such as smartphones, tablets, computers, and televisions. The increasing myopia since the pandemic has been described as ‘quarantine myopia’. The global incidence of myopia could be greatly impacted by extended home confinement according to Pellegrini et al., (2020).

2. Methodology

The aim of this study is to present an overview of the current research regarding the use of ortho-K lenses in myopia with an emphasis on the latest literature regarding the efficacy and safety of orthokeratology in controlling myopia, and its effect in the case of high myopia to reveal the strengths and limitations of the current use of ortho-K lenses in high myopia cases. Furthermore, since the COVID-19 pandemic affected the world in so many different aspects, this study aims to emphasize its effect on the vision of children and myopia.

Many resources and databases were searched to find as many relevant articles as possible pertaining to orthokeratology and High Myopia between 2019 until February 2022. Electronic searches were made on PubMed. The following keywords combination for searches were used:

- “Orthokeratology” or “Myopia orthokeratology” or “Overnight orthokeratology”.
- Myopia management

- COVID-19 pandemic and vision.

Yet with this broad search many articles came up with little correlation to the aim of this review, thus the search was narrowed to papers related orthokeratology and high myopia, orthokeratology and myopia control, and COVID-19 and myopia. When reviewing the results, emphasis on orthokeratology and high myopia was made as well as the effect of the pandemic on myopia to be included in this review.

The eligibility of the articles and studies were first assessed based on titles and abstracts. Full manuscripts were achieved for the chosen articles and studies and the decision for final inclusion was made after thorough examination of the papers. The papers reference lists were evaluated to identify any other studies that could have been included in this review. The articles and studies that were included in this review were in English and published during the duration of 2019 and February 2022. Non-English articles were excluded.

PubMed produced 138, after applying the above inclusion criteria and exclusion criteria, 32 articles were included in this review, in addition to other relevant studies that were published before 2019. The internet was also searched, to include any other relevant material.

3. Results:

After reviewing the articles and studies that were published between 2019 and February 2022, there was a trend recently in investigating the effect of the COVID-19 pandemic and home confinement on the onset and progression of myopia. Many studies concluded that the COVID-19 pandemic influenced the incidence of myopia as well as the progression of Myopia. Wang et al. (2021), reported a significant myopic shift in children aged 6-8 years. Zhang et al. (2020), concluded also that the incidence and progression increased during the pandemic. The acceleration of myopia progression which could be related to the increase of digital device use, was investigated by Ma et al. (2021) and Wong et al. (2021). Both studies found a correlation, but more studies need to confirm this.

Numerous researchers have studied myopia progression and the relationship between accommodation and progression to establish the effectiveness of orthokeratology in controlling myopia. Previously studies by Felip-Marquez et al. (2015) and Kang et al. (2018) revealed no association but recent studies by Prousali (2021), Gillford et al. (2020) and Ding (2021) concluded that accommodative lag is reduced with the use of ortho-K lenses thus slowing myopia progression. Zhang (2022) also studied the effectiveness of orthokeratology in slowing myopia progression, but his focus was on children with anisometropic myopia, and concluded orthokeratology to be effective and safe in controlling the axial length elongation of the monocular myopia eyes, thus reducing anisometropia.

Ortho-K lenses have been shown to be effective in High myopia patients with some limitations. Since few studies have been found to show the efficacy of ortho-k lenses to reduce high myopia ($\geqslant$ 5.00 D) in accordance with the definition of high myopia by WHO. Most of the studies evaluated the effect of ortho-k lenses in low and moderate myopia and concluded the effectiveness of ortho-k. Recently, Singh et al. (2020) found orthokeratology to be effective and safe up to -5.50D. Another study by Yu et al. (2021) included participants with $\leqslant$ -6.00D and found ortho-k lenses effective in reducing the progression of myopia. Park et al. (2021) confirmed the result of previous studies, in which myopes with up to -7.50D were included in his study. Orthokeratology treatment during the COVID-19 pandemic, was not affected according to Lv et al. (2022), it was found that the pandemic had no effect on the axial elongation in myopia children wearing ortho-k lenses.

The Safety of ortho-K lenses was studied by Lyu et al. (2020) and Hu et al. (2021), both studies enrolled patients with up to -6.00 D and concluded orthokeratology to be safe, yet in high myopia and younger age patients, corneal adverse events were higher. When investigation the cause, Vincent et al. (2021) found poor lens compliance and inadequate hygiene procedures contribute greatly to ortho-K lenses complications

4. Discussion:

Many studies emerged investigating the effect of the lockdown on the myopia incidence in children. Wang et al. (2021) reported in his prospective cross-sectional study that during the COVID-19 pandemic, a significant myopic shift was noted in children aged 6 to 8 years according to school-based non-cycloplegic photo-screenings conducted in China. The prevalence of myopia in 2020 was higher than that during 2015 and 2019. In children aged 6, it increased from 5.7% to 21.5%, in children aged 7 it increased from 16.2% to 26.2% and in those aged 8, from 27.7% to 37.2%. However, there was a limitation to this, because the refraction was not under cycloplegia, hence decreasing the accuracy of the results. However, a study conducted by Zhang et al. (2020) in Hong Kong also concluded that there was an increase in the incidence of myopia and reported myopia progression during this pandemic. Myopia incidence was 19.44% over 8-months' follow-up in COVID-19. A −0.50 D SER progression and 0.29mm axial elongation over the 8 months was also reported as well as the drop in the time spent outdoor 1.27±1.12 to 0.41±0.90 hours/day ($p<0.001$) and an increase in screen time from 2.45±2.32 to 6.89±4.42 hours/day ($p<0.001$) during the COVID-19 pandemic. The acceleration of myopia progression in children aged 7 to 12 years in China was investigated by Ma et al. (2021). It was reported in their study that myopia increased nearly three times greater than that from baseline measurement and found an association between myopia progression and increased use time of digital devices due to COVID-19 Quarantine, this was also found by Wong et al. (2021).

Due to severity of ocular complications that are associated with high myopia, and the increase in the prevalence of myopia worldwide, especially during the last couple of years due to COVID-19 pandemic, the need for early interventions is needed to prevent myopic onset if possible, and to slow the progression of myopia into high myopia thus decreasing the severity at maturity.

In a review by Kaur et al. (2020), it was stated that the progression of myopia could be explained in terms of three proposed theories: the high lag of accommodation that causes foveal hyperopic retinal blur during near work tasks, causing an abnormal axial growth of the eye, the restriction of the equatorial growth of the eye due to the ciliary choroidal tension during short periods of accommodation, which causes the shape of the eye to become more prolate, hence an increase in the axial length of the eye, and the peripheral hyperopic defocus known as the peripheral refraction theory is thought to explain myopia progression.

The progression of myopia and factors affecting it were investigated by many researchers. This is vital as it contributes to establishing the efficacy of orthokeratology in the control of myopia.

Bullimore and Johnson (2020) reported sufficient evidence to support the correlation between myopia development and accommodation. This association was reconfirmed by a recent paper by Prousali et al. (2021). The lag of accommodation causes a blurred image that provokes axial elongation leading to the progression of myopia.

Nti and Bernsten (2020) reported that some studies conducted to investigate the effect of orthokeratology on accommodation such as Felip-Marquez et al. (2015), and Kang et al. (2018) found no significant changes on the accommodative facility when using orthokeratology short term or long term. However, a study that was conducted by Gillford et al. (2020) in which twelve children aged between 8-16 years old, and 8 adults aged between 18-29 years old were enrolled in their study, and examined their near point binocular vision, concluded that in both children and young adults, there was in increase in the accommodative response in the ortho-k group when compared to the soft contact lens group. This result supports the efficacy of ortho-K lenses for myopia control. Another study conducted by Han et al., (2018) also reported that with ortho-K lenses the accommodative lag is reduced, and the accommodative facility increased, hence orthokeratology influences the progression of myopia in children.

Recently, a study by Ding et al. (2021) studied the correlation between the orthokeratology effect on both accommodation and aberrations. This was investigated to find out their role in myopia control. In this prospective case-controlled study, 61 children between the age of 8 and 13 years old, with myopia up to -5.00 D were recruited. A total of 30 children were fitted with ortho-K lenses and wore them overnight, and 31 used single vision spectacles to correct their refractive error. Accommodation and ocular wavefront aberrations were measured. It was concluded that accommodation and aberrations in myopic children treated with single vision spectacles remained steady and showed no correlation with myopia progression. On the other hand, the accommodative function positively improved, and the axial elongation was slowed in children who wore ortho-k lenses.

According to Bullimore and Johnson (2020), there is also a correlation between axial elongation and myopia progression, and a difference in 1mm is equivalent to 0.25 D. Furthermore, the effectiveness of the use of ortho-K lenses is proved by the measurement in the axial length of the eye since most corneal changes and the induced refractive errors are transient. In the case of myopic anisometropia, Zhang et al. (2022) conducted a retrospective five-year study on fifty children to investigate the long- term efficacy of orthokeratology on the progression of myopia in anisometropic children. Patients had myopia in one eye (SER ⩽-1.0 D) and wore ortho-k lens monocularly while the other eye was relatively emmetropic in the study SER (<±0.5 D); during the study the emmetropic eye developed myopia and began binocular ortho-k treatment. It was concluded that orthokeratology was effective and safe in controlling the axial length elongation of the monocular myopia eyes, thus reducing anisometropia. However, after the emmetropic eye developed myopia, no effectiveness of orthokeratology was found to control interocular difference of the axial length during binocular treatment.

Orthokeratology aims to flatten the central cornea, causing corneal thinning, and thickening of the mid peripheral cornea. Corneal thinning occurs within the first week of wearing ortho-k lenses, as reported by Li et al. (2016) and the corneal changes rate is associated with the amount of the targeted refractive change. Kim et al. (2018) reported that the amount of refractive change was proportional to the amount of epithelial thinning and inversely proportional with the treatment zone diameter. Which reconfirms a previous study by Alharbi and Swarbrick (2003) that linked the epithelial thickness change and refraction using Munnerlyn's formula which was used for refractive surgery.

Ablation depth = $RD^2 / 3$,

However, Kim et al. (2018) in his study substituted the ablation depth with central epithelial thickness changes and diameter with treatment zone diameter in orthokeratology. It was concluded that there is a linear relationship between the targeted myopic reduction and the magnitude of the central epithelial thinning, and it is inversely proportional with the diameter zone diameter. This is important in the case of high myopia, since the treatment zone should be too small to produce the targeted refraction. Chen (2020) reported that not only the center treatment zone of an ortho-k lens should be small, but it also should be within the pupil. Therefore, specially designed ortho-k lenses for high myopia need to be used to achieve the targeted refraction.

There has been recently many available orthokeratology contact lenses, yet most of these are being used to reduce myopia up to -6.00. Few studies have been found to show the efficacy of orthokeratology lenses to reduce high myopia (⩾ 5.00 D) in accordance with the definition of high myopia by WHO.

Ortho-K lenses were approved to temporarily correct myopia, and that axial elongation and myopia progression were associated with one another as previously reported. Many studies confirmed this association such as Cho and Cheung (2012) and Kakita et al. (2011).

Cho et al. (2005) conducted a two-year pilot study in Hong Kong, recruiting 70 children aged between 7-12 years with SER between−0.25 D and −4.50 D, less than −2.00 D astigmatism. The axial length and vitreous chamber depth were monitored for both groups (35 children wore ortho-K lenses and the other 35 children wore single vision spectacles. It was concluded that orthokeratology reduced axial elongation by 46 per cent in myopic children when compared with spectacle wearers. In the orthokeratology group the mean increase in the axial length was 0.29 mm whereas in the control group wearing single vision spectacles was 0.54mm according to Cho and Tan (2018). Another study conducted by Walline et al. (2009), in the USA concluded the same.

The previous conducted studies were over a period of two years. To confirm the effect of ortho-k on axial length elongation for a longer duration, Hiraoka et al. (2012), in a 5-year prospective study evaluated how ortho-k lenses slows myopia progression in children when compared with the group who used single vision spectacles. The long-term effect of orthokeratology lenses on the elongation of the axial length and reducing myopia progression was concluded. However, these studies evaluated low to moderate myopia and not high myopia. A study was conducted by Charm and Cho (2013), in which they recruited children aged 8 to 11 years old with high myopic at least spherical equivalent refraction -5.75 D and myopia -5.00 D or more. They were assigned randomly into two groups, the first group wore partial reduction four zone ortho-k lens with a -4.00D targeted refraction and the rest of the refractive error was corrected with spectacle glasses to maintain good vision for the day, and the other group were fully corrected using single vision spectacles. It was reported that Axial length elongation was 63% slower in partial reduction ortho-k-treated children compared with children wearing spectacles. However, there was a limitation to this study because of the relatively small sample size, causing a high dropout rate in the Partial reduction ortho-k. Despite these limitations, the conclusion in this study confirms the results of a previous study conducted by Cho and Cheung (2012), that ortho-k can control myopic progression and it was found that the axial elongation decreased by 43% compared with spectacle glasses worn by the other group in the study.

As for the myopic children with orthokeratology treatment who were also in home confinement, Lv et al. (2022) conducted a study and recruited ninety-two myopic children with orthokeratology treatment. The axial lengths during and before COVID-19 home quarantine were measured and were followed up after ending the quarantine. It was found that home confinement during COVID-19 pandemic does not affect the elongation of axial length in myopic children with ortho-k lenses treatment. Another issue was regarding children wearing their ortho-K lenses during the COVID-19 home quarantine, as reported by Cho and Boost (2020), is that home confinement has increased the sleeping hours for children, resulting in the wear of the ortho-k lenses for extended periods. This may cause corneal oedema as observed in a few children in Hong Kong. Yet more studies need to confirm that.

Orthokeratology was found to be effective and safe in another study that was conducted by Singh et al. (2020). Thirty patients with myopia up to -5.50 D were included in the study, Patients were divided randomly into two groups, the study group wore orthokeratology lenses during the night and the other control group used daily conventional soft contact lenses and were followed up periodically.

Lee et al. (2017) published their retrospective cohort study, investigating the progression in myopia in patients using orthokeratology for twelve years. The patient's refractive error ranged between -0.50 and -8.00 D and an accelerated ortho-k reverse geometry design lens was used. Despite that myopia progression was measured by change of refraction over the lens but not by measuring the axial length, Lee et al. concluded that orthokeratology is effective in reducing the progression of myopia in addition to its safety. Their result confirmed another study conducted by Downie and Lowe (2013), that used the same approach in their study.

Recently, a retrospective study was conducted by Yu et al. (2021), in which they investigated the effect of orthokeratology on axial length elongation in children with one moderate myopic eye (spherical equivalent refractive (SER) error ⩽-3.00 D) and the other with high myopia eye (SER ⩽-6.00 D). Sixty-five patients were recruited, 35 females and 30 males, between the age of 7 and 15. Patients wore orthokeratology lenses overnight for at least 8 hours for a year. It was determined in this study that orthokeratology lenses proved to be effective in reducing the progression of myopia in both eyes. The sex of the patient had no impact on the outcome.

A recent study conducted by Park et al. (2021) reconfirmed that result. Park et al. assessed the effectiveness of overnight orthokeratology in myopia using a new contact lens design that is a six-curve design. Forty-four participants aged between (6 to 48 years) with a mean age of 23.11 ± 7.89 years were enrolled into the study , with a myopia between -3.00D and -7.50 D and astigmatism ⩽2.00D. Fitted with an aspheric reverse geometric lens called White OK lens, made from Acuity 100 (hexa- focon A) lens material (Dk was 100 × 10 − 11 [cm2 mL O2]/[s mL mmHg]) manufactured by the Interojo Optical Company (Pyungtaek, Korea). The measurement of the minimum angle of resolution determined the success in this study. Participants should achieve logMAR $\leqslant$ 0.1. It was concluded that overnight orthokeratology for myopia was successful in low to moderate myopic participants with myopia between –3.00 and –6.00D, the success rate was 94.59%. In 9 high myopic participants with myopia between –6.00 and –7.50D, the success rate was 88.89%. There was a limitation to this study, that it is not a long-term study, despite its effectiveness, more studies need to be done to prove long term efficacy.

The safety of the use of ortho-K lenses was also studied by Lyu et al. (2020). Their study compared three groups of high myopes. A total of 102 patients participated in the study. The first group consisted of patients with a target myopia reduction of 6.00 D. The second group consisted of patients with a target myopia reduction of 4.00 D, and the third group, which was a control group, wore single vision spectacles to correct their refractive error. When the two orthokeratology regimens were compared, it was found that both regimens had the same effect regarding the control of the axial length increase and refractive error in high myopia, yet participants with a high myopia reduction target of -6.00 D had a higher risk of corneal staining than other myopia participants.

Corneal staining is considered the most common complication in orthokeratology. It was reported by Liu and Xie (2016), that the frequency and severity of staining in ortho-k high myopia patients is higher regardless of the age of the patient. One of the factors that causes persistent corneal staining is lens binding, which according to Nti and Bernsten (2020), could be due to several causes: coated lens, decreased thickness and increased viscosity of the teat film, as well as poor lens fitting. These can be resolved however by improving the fitting as well as monitoring the tear exchange, since chronic wear of ortho-K lenses is also found to be associated with reduced basal tear secretion and instability in the tear film and adding more fenestration to the lens, as well as advising patients to use artificial tears all can aid in minimising the risk of staining.

Despite that ortho-k lenses are made of highly oxygen permeable materials, yet an association between the overnight wear and infectious keratitis was found. Some researchers such as Watt and Swarbrick (2005a) reviewed the first reported 50 cases of microbial keratitis and Liu and Xie (2016) found a link between cases of microbial keratitis and poor compliance by the patient. It was suggested that by educating the patient and improving compliance to lens care regimen, since almost one-third of the microbial keratitis cases was associated with Acanthamoeba and was related to the use of tap water as reported by Watt and Swarbrick (2007b), as well as attending regular follow up visits, all contribute to the reduction of infection incidence.

In 2021 Hu et al. investigated the safety wear of Orthokeratology overnight and whether there were other factors such as refraction, age and history of allergic conjunctivitis associated with corneal adverse events. Medical records of patients were reviewed. Patients aged between 8-15 years who have started orthokeratology for myopia correction and continued for another year were included. The spherical equivalent refractive (SER) error was between -1.00 and -6.00. It was concluded that despite orthokeratology was safe for myopic children, yet in high myopia and younger age patients, the risk for corneal adverse events and corneal conjunctivitis were higher.

Compliance to hygiene procedures and lens care regimen is very important in the use of all contact lenses and in orthokeratology to minimise any adverse reactions related to their use. According to Vincent et al. (2021), poor lens care and inadequate hand washing in orthokeratology are the two most noncompliant behaviours observed. Ortho-k lens, lens case and the use of the suction holder to aid in the insertion and removal of lenses were a great source of microbial contamination, it was suggested better to use the fingers for ortho-k insertion and removal to minimise infection risk. Despite the correlation between the use of ortho-k use and infection, it is important to also note that the risk of infection is found in all types of contact lenses use. Thus, the rate of infection in orthokeratology should not discourage its use.

Investigating the use of ortho-k lenses to fully correct high myopia is still not available. However, a recent on-going study is currently being conducted by Cho (2022), in which the aim is to investigate the use of Ortho- K lenses to fully correct high myopic patients (those with at least -5.00 D), compared to another group undergoing partial reduction, using a specially designed ortho-k lenses for high myopia. This lens was designed by Euclid and is commercially available to correct high myopia for up to -10.00 D. Yet evidence of its effectiveness for slowing the progression of myopia needs to be cleared. This study is expected to be completed in January 2024 and it will give a better insight on the use of orthokeratology in high myopia cases. Patients would prefer when specially designed ortho-k lenses for high myopia become available to allow the full correction of their myopia.

5. Conclusion

Myopia is becoming a major health problem worldwide that is increasing to an alarming rate. The progression of myopia can lead to a series or irreversible complications. The COVID-19 Pandemic had also a serious impact on people during the lockdown, especially children, whose outdoor time was decreased, and their near work increased due to, the online learning process and the use of the digital devices. Studies proved an association between home confinement during the pandemic and the increased incidence of myopia. Thus, early intervention through orthokeratology can be an alternative. There is sufficient evidence proving that orthokeratology lenses are effective and safe for low to moderate myopia as well as for anisometropic myopia. Long term success of the use of ortho-k lenses increases with the proper lens fitting, patient's compliance to lens care regimen to avoid contact lens complications or infections related to the lenses. In high myopia, more studies need to be done to investigate the efficacy and the safety of ortho-k, despite the recent few published studies that prove efficacy.

6. References

Alharbi, A. and Swarbrick, H.A. (2003). The effects of overnight orthokeratology lens wear on corneal thickness. Investigative ophthalmology & visual science, 44(6), pp.2518-2523.

Berke, A. (2021). Prevalence of myopia in children and adults in Europe and North America. Retrieved December 15,2021 from http: www.ocl-online.de

Binder, P.S., May, C.H. and Grant, S.C. (1980). An evaluation of orthokeratology. Ophthalmology, 87(8), pp.729-744.

Bullimore, M. A., & Johnson, L. A. (2020). Overnight orthokeratology. Contact lens and anterior eye, 43(4), 322-332.

Carney, L. (2002). Orthokeratology. In N. Efron (Ed.) Contact Lens Practice. (pp. 332-338). United Kingdom: Butterworth-Heinemann.

Charm, J., Cho, P. (2013). High myopia–partial reduction ortho-k: a 2-year randomized study. Optometry and Vision Science, 90(6), 530-539.

Chen, L.Z. (2021). Ortho-K Management of the Higher Myopic Patient. Contact Lens spectrum. Retrieved September 20, 2021, from https://www.clspectrum.com/newsletters/orthokeratology-in-practice/january-2021.

Cho P. (2019). Orthokeratology for High Myopia (OHM) Study. Retrieved February 11, 2022, from http://Orthokeratology for High Myopia (OHM) Study - Full Text View - ClinicalTrials.gov.

Cho, P. Boost, M. (2020). COVID 19—An eye on the virus. Contact Lens & Anterior Eye, 43(4), p.313.

Cho, P., Cheung, S.W. (2012). Retardation of myopia in Orthokeratology (ROMIO) study: a 2-year randomized clinical trial. Investigative ophthalmology & visual science, 53(11), pp.7077-7085.

Cho, P., Tan, Q. (2019). Myopia and orthokeratology for myopia control. Clinical and Experimental Optometry, 102(4), pp.364-377.

Cho, P., Cheung, S.W., Edwards, M. (2005). The longitudinal orthokeratology research in children (LORIC) in Hong Kong: a pilot study on refractive changes and myopic control. Current eye research, 30(1), pp.71-80.

Cucinotta, D., Vanelli, M. (2020). WHO declares COVID-19 a pandemic. Acta Bio Medica: Atenei Parmensis, 91(1), p.157.

Ding, C., Chen, Y., Li, X., Huang, Y., Chen, H., & Bao, J. (2022). The associations of accommodation and aberrations in myopia control with orthokeratology. Ophthalmic & physiological optics: the journal of the British College of Ophthalmic Opticians (Optometrists), 42(2), 327–334.

Downie, L. E., & Lowe, R. (2013). Corneal reshaping influences myopic prescription stability (CRIMPS): an analysis of the effect of orthokeratology on childhood myopic refractive stability. Eye & contact lens, 39(4), 303–310.

Felipe-Marquez, G., Nombela-Palomo, M., Cacho, I., & Nieto-Bona, A. (2015). Accommodative changes produced in response to overnight orthokeratology. Graefe's Archive for Clinical and Experimental Ophthalmology, 253(4), pp.619-626.

Flitcroft, D. I., He, M., Jonas, J. B., Jong, M., Naidoo, K., Ohno-Matsui, K., Rahi, J., Resnikoff, S., Vitale, S., & Yannuzzi, L. (2019). IMI - Defining and Classifying Myopia: A Proposed Set of Standards for Clinical and Epidemiologic Studies. Investigative ophthalmology & visual science, 60(3), M20–M30.

Frogozo, M., Kumar, S. (2021). Recent advances in orthokeratology Why you should incorporate into practice. Contact Lens Spectrum, 36, 30-32, 34-37.

Gifford, K. L., Gifford, P., Hendicott, P. L., & Schmid, K. L. (2020). Zone of Clear Single Binocular Vision in Myopic Orthokeratology. Eye & contact lens, 46(2), 82–90.

Gifford, K.L., Richdale, K., Kang, P., Aller, T.A., Lam, C.S., Liu, Y.M., Michaud, L., Mulder, J., Orr, J.B., Rose, K.A. and Saunders, K.J. (2019). IMI–clinical management guidelines report. Investigative ophthalmology & visual science, 60(3), pp.M184-M203.

Han, X., Xu, D., Ge, W., Wang, Z., Li, X., & Liu, W. (2018). A Comparison of the Effects of Orthokeratology Lens, Medcall Lens, and Ordinary Frame Glasses on the Accommodative Response in Myopic Children. Eye & contact lens, 44(4), 268–271.

Hiraoka, T., Kakita, T., Okamoto, F., Takahashi, H., & Oshika, T. (2012). Long-term effect of overnight orthokeratology on axial length elongation in childhood myopia: a 5-year follow-up study. Investigative ophthalmology & visual science, 53(7), 3913-3919.

Hu, P., Zhao, Y., Chen, D., & Ni, H. (2021). The safety of orthokeratology in myopic children and analysis of related factors. Contact lens & anterior eye : the journal of the British Contact Lens Association, 44(1), 89–93.

Huang, H. H., Chen, Y. Y., Wu, R., & Lin, W. P. (2020). Effectiveness and Safety of Overnight Orthokeratology with Roflufocon E High-Permeability Lens Material-A 36 Week Follow-Up Study. Biomedical Journal of Scientific & Technical Research, 32(1), 24736-24741.

Jong, M., Jonas, J. B., Wolffsohn, J. S., Berntsen, D. A., Cho, P., Clarkson-Townsend, D., Flitcroft, D. I., Gifford, K. L., Haarman, A., Pardue, M. T., Richdale, K., Sankaridurg, P., Tedja, M. S., Wildsoet, C. F., Bailey-Wilson, J. E., Guggenheim, J. A., Hammond, C. J., Kaprio, J., MacGregor, S., Mackey, D. A., … Smith, E. L., 3rd (2021). IMI 2021 Yearly Digest. Investigative ophthalmology & visual science, 62(5), 7.

Kakita, T., Hiraoka, T., & Oshika, T. (2011). Influence of overnight orthokeratology on axial elongation in childhood myopia. Investigative ophthalmology & visual science, 52(5), 2170–2174.

Kang, P., Watt, K., Chau, T., Zhu, J., Evans, B., & Swarbrick, H. (2018). The impact of orthokeratology lens wear on binocular vision and accommodation: A short-term prospective study. Contact lens & anterior eye: the journal of the British Contact Lens Association, 41(6), 501–506.

Kaur, K., Gurnani, B. and Kannusamy, V. (2020). Myopia: current concepts and review of literature. TNOA Journal of Ophthalmic Science and Research, 58(4), 280.

Kim, W. K., Kim, B. J., Ryu, I. H., Kim, J. K., & Kim, S. W. (2018). Corneal epithelial and stromal thickness changes in myopic orthokeratology and their relationship with refractive change. PLOS ONE, 13(9), e0203652.

Lee, S. S., Lingham, G., Sanfilippo, P. G., Hammond, C. J., Saw, S. M., Guggenheim, J. A., Yazar, S., & Mackey, D. A. (2022). Incidence and Progression of Myopia in Early Adulthood. JAMA ophthalmology, 140(2), 162–169.

Lee, Y. C., Wang, J. H., & Chiu, C. J. (2017). Effect of orthokeratology on myopia progression: twelve-year results of a retrospective cohort study. BMC ophthalmology, 17(1), 243.

Li, F., Jiang, Z. X., Hao, P., & Li, X. (2016). A Meta-analysis of Central Corneal Thickness Changes with Overnight orthokeratology. Eye & contact lens, 42(2), 141–146.

Li, S. M., Wei, S., Atchison, D. A., Kang, M. T., Liu, L., Li, H., Li, S., Yang, Z., Wang, Y., Zhang, F., & Wang, N. (2022). Annual Incidences and Progressions of Myopia and High Myopia in Chinese Schoolchildren Based on a 5-Year Cohort Study. Investigative ophthalmology & visual science, 63(1), 8.

Liu, Y. M., & Xie, P. (2016). The Safety of orthokeratology--A Systematic Review. Eye & contact lens, 42(1), 35–42.

Lv, H., Wang, Y., Sun, S., Wei, S., Guo, Y., Wu, T., & Li, X. (2022). The impact of COVID-19 home confinement on axial length in myopic children undergoing orthokeratology. Clinical & experimental optometry, 1–5.

Lyu, T., Wang, L., Zhou, L., Qin, J., Ma, H., & Shi, M. (2020). Regimen Study of High Myopia-Partial Reduction Orthokeratology. Eye & contact lens, 46(3), 141–146.

Ma, M., Xiong, S., Zhao, S., Zheng, Z., Sun, T., & Li, C. (2021). COVID-19 Home Quarantine Accelerated the Progression of Myopia in Children Aged 7 to 12 Years in China. Investigative ophthalmology & visual science, 62(10), 37.

World Health Organization (2015). Retrieved February 12, 2022. From http://MyopiaReportforWeb.pdf (who.int).

Németh, J., Tapasztó, B., Aclimandos, W. A., Kestelyn, P., Jonas, J. B., De Faber, J., Januleviciene, I., Grzybowski, A., Nagy, Z. Z., Pärssinen, O., Guggenheim, J. A., Allen, P. M., Baraas, R. C., Saunders, K. J., Flitcroft, D. I., Gray, L. S., Polling, J. R., Haarman, A. E., Tideman, J., Wolffsohn, J. S., … Resnikoff, S. (2021). Update and guidance on management of myopia. European Society of Ophthalmology in cooperation with International Myopia Institute. European journal of ophthalmology, 31(3), 853–883.

Nti, A. N., & Berntsen, D. A. (2020). Optical changes and visual performance with orthokeratology. Clinical & experimental optometry, 103(1), 44–54.

Park, Y., Kim, H., Kang, J.K. and Cho, K.J. (2021). Effectiveness of Overnight Orthokeratology with a New Contact Lens Design in Moderate to High Myopia with Astigmatism. Medical Lasers; Engineering, Basic Research, and Clinical Application, 10(4),229-237.

Pellegrini, M., Bernabei, F., Scorcia, V., & Giannaccare, G. (2020). May home confinement during the COVID-19 outbreak worsen the global burden of myopia? Graefe's archive for clinical and experimental ophthalmology, 258(9), 2069–2070.

Polse, K. A., Brand, R. J., Schwalbe, J. S., Vastine, D. W., & Keener, R. J. (1983). The Berkeley Orthokeratology Study, Part II: Efficacy and duration. American journal of optometry and physiological optics, 60(3), 187–198.

Prousali, E., Haidich, A. B., Tzamalis, A., Ziakas, N., & Mataftsi, A. (2021). 'The role of accommodative function in myopic development: A review'. Seminars in ophthalmology, 1–7.

Pugazhendhi, S., Ambati, B., & Hunter, A. A. (2020). Pathogenesis and Prevention of Worsening Axial Elongation in Pathological Myopia. Clinical ophthalmology (Auckland, N.Z.), 14, 853–873.

Singh, K., Bhattacharyya, M., Goel, A., Arora, R., Gotmare, N., & Aggarwal, H. (2020). Orthokeratology in Moderate Myopia: A Study of Predictability and Safety. Journal of ophthalmic & vision research, 15(2), 210–217.

Vincent, S.J., Cho, P., Chan, K.Y., Fadel, D., Ghorbani-Mojarrad, N., González-Méijome, J.M., Johnson, L., Kang, P., Michaud, L., Simard, P. and Jones, L. (2021). BCLA CLEAR-Orthokeratology. Contact Lens and Anterior Eye, 44(2),240-269.

Walline, J. J., Jones, L. A., & Sinnott, L. T. (2009). Corneal reshaping and myopia progression. The British journal of ophthalmology, 93(9), 1181–1185.

Wang, J., Li, Y., Musch, D. C., Wei, N., Qi, X., Ding, G., Li, X., Li, J., Song, L., Zhang, Y., Ning, Y., Zeng, X., Hua, N., Li, S., & Qian, X. (2021). Progression of Myopia in School-Aged Children After COVID-19 Home Confinement. JAMA ophthalmology, 139(3), 293–300.

Watt, K., & Swarbrick, H. A. (2005). Microbial keratitis in overnight orthokeratology: review of the first 50 cases. Eye & contact lens, 31(5), 201–208.

Watt, K. G., & Swarbrick, H. A. (2007). Trends in microbial keratitis associated with orthokeratology. Eye & contact lens, 33(6 Pt 2), 373–382.

Wong, C. W., Tsai, A., Jonas, J. B., Ohno-Matsui, K., Chen, J., Ang, M., & Ting, D. (2021). Digital Screen Time During the COVID-19 Pandemic: Risk for a Further Myopia Boom?. American journal of ophthalmology, 223, 333–337.

Yu, L. H., Jin, W. Q., Mao, X. J., & Jiang, J. (2021). Effect of orthokeratology on axial length elongation in moderate myopic and fellow high myopic eyes of children. Clinical & experimental optometry, 104(1), 22–27.

Zhang, X., Cheung, S., Chan, H. N., Zhang, Y., Wang, Y. M., Yip, B. H., Kam, K. W., Yu, M., Cheng, C. Y., Young, A. L., Kwan, M., Ip, P., Chong, K. K., Tham, C. C., Chen, L. J., Pang, C. P., & Yam, J. (2021). Myopia incidence and lifestyle changes among school children during the COVID-19 pandemic: a population-based prospective study. The British journal of ophthalmology, bjophthalmol-2021-319307.

Zhang, K. Y., Lyu, H. B., Yang, J. R., & Qiu, W. Q. (2022). Efficacy of long-term orthokeratology treatment in children with anisometropic myopia. International journal of ophthalmology, 15(1), 113–118.