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Impact of the coronavirus disease 2019 pandemic on the progression, prevalence, and incidence of myopia: A systematic review

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Abstract:

We systematically reviewed the literature on the effects of the coronavirus disease 2019 (COVID-19) pandemic on the progression, prevalence, and incidence of myopia. A comprehensive literature search was performed on PubMed, Cochrane Central Register of Controlled Trials, and Scopus databases. Studies included in the review assessed myopia progression, prevalence, and/or incidence as the primary outcome. Of 523 articles yielded in the initial search, 23 studies (6 cross-sectional and 17 cohort) were eligible for inclusion. Sixteen of these were conducted in China and one each in Hong Kong, Turkey, Spain, Israel, India, Korea, and Tibet. Quality appraisals were conducted with the Joanna Briggs Institute Critical Appraisal Checklists. Of the included studies, a large majority reported a greater myopic shift and increase in myopia prevalence during the COVID-19 pandemic compared to the pre-COVID-19 years. All three studies on myopia incidence showed increased incidence during the COVID-19 pandemic. Myopia progression accelerated during the COVID-19 pandemic, even in individuals using low-concentration atropine eye drops in two studies but not in those using orthokeratology treatment in one study. Overall, the studies found that the COVID-19 pandemic and its associated home confinement measures generally increased myopia progression, prevalence, and incidence, even in individuals using low-concentration atropine eye drops.

Keywords:

Coronavirus disease 2019 pandemic, myopia control, myopia incidence, myopia prevalence, orthokeratology

Introduction

Myopia is the most common refractive error in children and young adults[1] and is a potentially sight-threatening condition. The worldwide prevalence of myopia has been increasing[2] and is projected to reach 50% by 2050 if effective intervention measures are not implemented.[3] The prevalence of myopia among young adults in East Asia is especially high (80%–90%), and it is a leading cause of blindness in this region.[4]

Myopia is a major public health concern because of the associated visual complications, including cataract, retinal detachment, macular hole, myopic choroidal neovascularization, and glaucoma, all of which can lead to vision loss.[3] In addition, myopia is associated with significant negative societal and economic impacts. In addition to direct costs, indirect costs of myopia include loss of productivity related to caregiver time and absenteeism from educational activities as well as reduced quality of life.[5]

While there is a general consensus that refractive status is partly genetically

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determined, environmental factors such as increased urbanization have been shown to have a major contribution to refractive error development.[6] Recently, several nonpharmacological interventions have been found to be effective in delaying the onset of myopia, such as spending more time outdoors and decreasing the duration of time spent on near work.[7]

The coronavirus disease 2019 (COVID-19), caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), was first reported in Wuhan, China, in December 2019 and has since become one of the most consequential global health crises since the influenza pandemic of 1918.[8] The COVID-19 pandemic has had broad-ranging impacts on societal demographics, financial expenditure in the form of increased health-care costs and indirect costs such as lost productivity,[9] and global health. At the time of writing this review, more than 7 million deaths worldwide have been attributed to the pandemic.[10]

To curb COVID-19 infection rates, strict public health measures were implemented globally to various degrees, especially before the availability of vaccines.[11] These measures included isolation and quarantine rules, physical school closures, home-based online learning, and physical distancing.[12] As a result, billions of children worldwide experienced drastic changes to their daily routines. Specifically, the potential impact of the pandemic and its associated measures on the onset and progression of myopia is a major concern. We examined the impact of the COVID-19 pandemic on the progression, prevalence, and incidence of myopia through a systematic assessment of the literature for qualitative and quantitative data. In addition, we reviewed the impact of the COVID-19 pandemic on myopia progression in individuals who were using myopia-control interventions before and during the pandemic.

Methods

This systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines[13] and its protocol was registered in PROSPERO, the International Prospective Register of Systematic Reviews (CRD42022328939).

Search strategy

We performed a literature search of PubMed, Cochrane Central Register of Controlled Trials (CENTRAL), and Scopus databases for relevant studies, limiting the search to publications from December 2019, when COVID-19 was first identified, to May 29, 2023. The complete search strategies were: (1) (COVID* OR coronavirus OR sars-cov-2) AND (myopi* OR nearsight* OR near-sight* OR shortsight* OR short-sight*) for PubMed and Cochrane Central Register of Controlled Trials and (2) (COVID-19 OR coronavirus OR [sars-cov-2]) AND (myopia OR nearsightedness OR [near-sightedness] OR shortsightedness OR [short-sightedness]) for Scopus. All search results were uploaded onto the Rayyan platform (http://rayyan.ai) and duplicates were removed.[14] Manual screening of the references of the included articles was also conducted for a more comprehensive search.

Study selection and data collection

Two independent reviewers (KSC and BHKT) screened all titles and abstracts for relevance and subsequently performed a full-text assessment for eligibility. Any disagreements on study inclusion were resolved through consensus with a third independent reviewer (KGAE).

A customized data extraction form was used to collect the following information from each included study: (1) author(s), (2) geographic location, (3) study design, (4) sample size, (5) baseline characteristics (e.g. age and myopia-control interventions), and (6) outcome (e.g. change in spherical equivalent refraction [SER], ocular axial length [AL], prevalence, and incidence).

Eligibility criteria

Studies were selected based on the following criteria: (1) observational studies (cohort or cross-sectional studies); (2) participants: children and/or adults ≤40 years old; (3) exposure: COVID-19 pandemic measures; and (4) outcomes: myopia progression (change in SER and/or AL), prevalence, and/or incidence.

Exclusion criteria were as follows: (1) studies reporting only subjective assessment of myopia and its progression; (2) studies that did not present original research data (e.g., editorials, reviews, and commentaries); and (3) case reports, case series, and conference abstracts.

Risk of bias assessment

All included studies were appraised using the Joanna Briggs Institute (JBI) Critical Appraisal Checklist for Analytical Cross-sectional Studies and the JBI Critical Appraisal Checklist for Cohort Studies to assess the risk of bias.[15] Questions assessing different study domains to determine the risk of bias were answered with "yes," "no," or "not applicable." Before critical appraisal commenced, decisions about the scoring system and cutoff points were agreed on by all reviewers as recommended by the JBI reviewers' manual.[16] The risk of bias was determined using the following percentage cutoffs: low risk if 70% of the answers were "yes," moderate risk for 50%–69%, and high risk for below 50%.

Results

Search results

The literature search result and subsequent selection processes are represented in a PRISMA diagram [Figure 1]. The initial search yielded 523 articles, of which 36 duplicates were removed. A total of 487 titles and abstracts were screened. After the study title and abstract screening, 462 articles were excluded and 25 were retrieved for full-text review. Twenty articles met the inclusion criteria and were analyzed. Separately, three additional articles were identified and included through manual screening of references of included articles.

Study characteristics

A total of 23 studies were included in this systematic review.[17-39] Sixteen of these were conducted in China[19-22,24-29,31-36] and one each in Hong Kong,[39] Turkey,[18] Spain,[17] Israel,[23] India,[30] Korea,[38] and Tibet.[37] Six of these studies were cross-sectional studies[17,21,22,31,32,34] while 17 were cohort studies.[18-20,23-30,33,35-39] The main characteristics of the included studies are summarized in Table 1. All studies considered $P < 0.05$ to be statistically significant.

Risk of bias assessment

All six cross-sectional studies included in our review were assessed to have a low risk of bias [Table 2]. Two studies did not clearly specify the inclusion and exclusion criteria for their samples[22,34] while three studies did not identify confounding factors or use appropriate strategies to deal with these confounders.[17,31,32]

For the 17 cohort studies included in our review, more than half (n = 10) were assessed to have a low risk of bias while one study[20] was assessed to have a high risk [Table 3]. The latter study did not identify and account for confounding factors appropriately, and follow-up on the cohort was also incomplete without substantiation of the reasons for the incomplete follow-up.[20]

Impact of coronavirus disease 2019 pandemic on the progression of myopia in individuals with no specified myopia-control intervention

Eighteen studies examined the impact of the COVID-19 pandemic on myopia progression in terms of changes in SER [Tables 4 and 5].[17-21,24,26-30,32-37,39] All studies except three[19,28,33] found a greater myopic shift during the COVID-19 pandemic compared to the pre-COVID years. One study was not statistically significant,[28] and the statistical significance was not reported in two studies.[19,33] Wang *et al*. found a greater myopic shift among those aged 10–15 years but the opposite trend in students aged 6–9 years, although the statistical significance was not reported.[33]

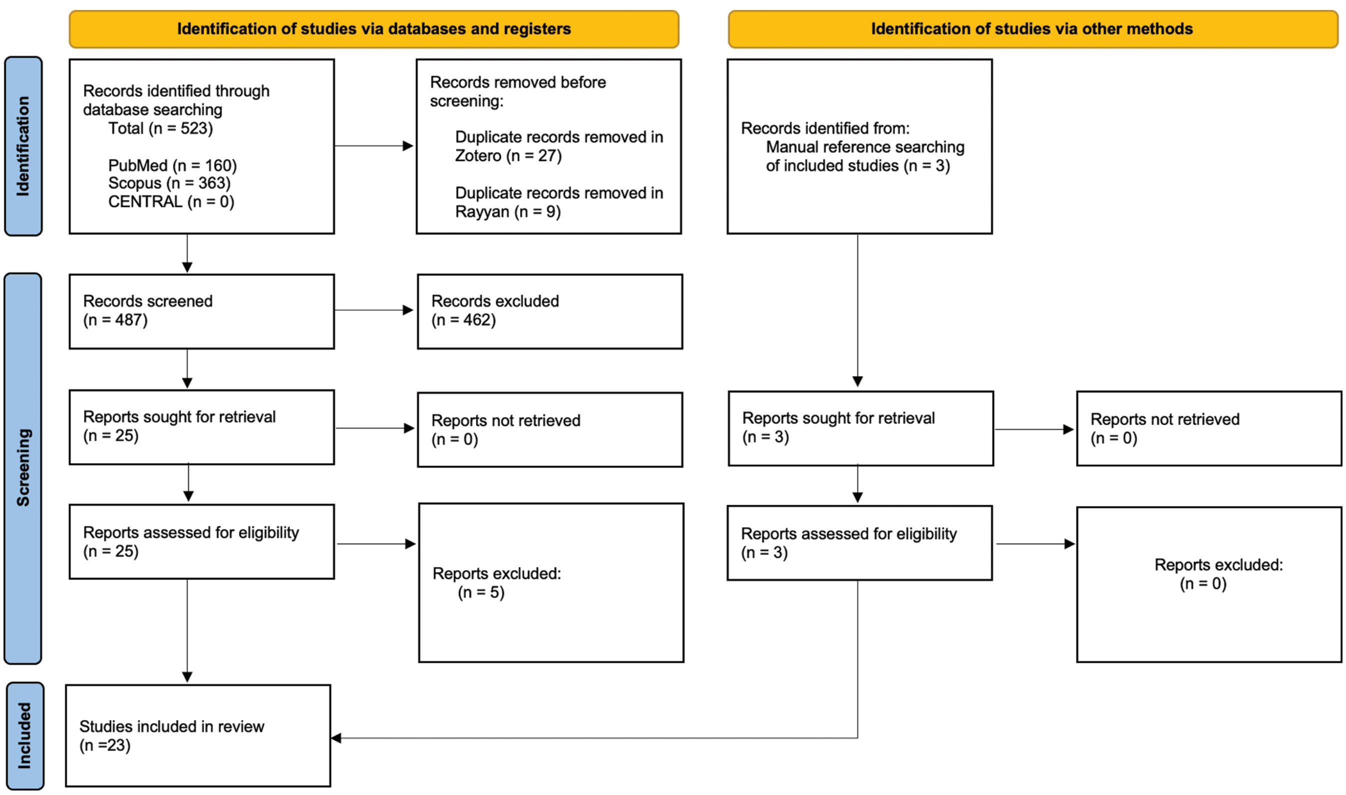

Figure 1: Preferred Reporting Items for Systematic Reviews and Meta-Analyses diagram outlining the process of study selection

Table 1: Characteristics of included studies

Study author(s)	Country	Study design	Age, range (years) (mean±SD)	Sample size (n), % male	Existing myopia control intervention	Outcome measure(s)
Alvarez-Peregrina *et al.*[17]	Spain	Serial cross-sectional study	5–7	2019: *n*=4227, 51.2% 2020: *n*=1600, 49.5%	No	Noncycloplegic refraction
Aslan and Sahinoglu-Keskek[18]	Turkey	Retrospective cohort study	8–17 (12.06±2.29)	*n*=115, 34.8%	No	Cycloplegic autorefraction
Cai *et al.*[19]	China	Cohort study	Age pre-COVID lockdown: 9.34±2.00 Age at beginning of COVID-lockdown: 9.60±2.30	*n*=115, 57.4%	No	Noncycloplegic autorefraction AL
Chang *et al.*[20]	China	Cohort study	Round 1†: 9.4±2.0 Round 2†: 9.9±2.0 Round 3†: 10.5±2.0 Round 4†: 10.9±2.0	*n*=29,719, 53.0%	No	Noncycloplegic autorefraction
Chen *et al.*[21]	China	Serial cross-sectional study	6–18	2019: 118,479 2020: 121,881	No	Noncycloplegic autorefraction
Dong *et al.*[22]	China	Serial cross-sectional study	7–18	*n*=14,296, 50.0%	No	Noncycloplegic refraction
Erdinest *et al.*[23]	Israel	Retrospective cohort study	10.5±2.1	*n*=14, 64.3%	Atropine 0.01% eye drops	Cycloplegic refraction AL
Hu *et al.*[24]	China	Prospective cohort study	7.76±0.32	*n*=2679, 53.1%	No	Cycloplegic autorefraction and subjective refraction as needed AL
Lv *et al.*[25]	China	Cohort study	8–18 (11.43±1.99)	*n*=92, 35.9%	Orthokeratology	AL
Ma *et al.*[26]	China	Cohort study	8–10 (8.9±0.69)	Study group: *n*=208, 52.4% Control group: *n*=83	No	Cycloplegic autorefraction AL
Ma *et al.*[27]	China	Cohort study	8.65±0.29	Exposed group: *n*=77, 51.9% Control group: *n*=77, 51.9%	No	Cycloplegic autorefraction AL
Ma *et al.*[28]	China	Cohort study	6–12	*n*=913, 50.1%	No	Noncycloplegic autorefraction
Ma *et al.*[29]	China	Cohort study	7–12 (9.9±1.7)	*n*=201, 48%	No	Cycloplegic autorefraction
Mohan *et al.*[30]	India	Cohort study	6–18	*n*=133, 60.9	No	Cycloplegic autorefraction
Mu *et al.*[31]	China	Serial cross-sectional study	Grade 1 to Grade 12 students	Control group: *n*=1,472,957, 54.8% Exposed group: *n*=1,573,824, 54.6%	No	Noncycloplegic autorefraction
Wang *et al.*[32]	China	Serial cross-sectional study	6–13	*n*=123,535, 52.1%	No	Noncycloplegic photorefraction
Wang *et al.*[33]	China	Cohort study	6–15	*n*=468,094, 54.7%	No	Noncycloplegic autorefraction
Wang *et al.*[34]	China	Serial cross-sectional study	6–18	2019: *n*=1728, 49.8% 2020: *n*=1733, 49.6%	No	Noncycloplegic refraction
Xu *et al.*[35]	China	Cohort study	7–18	Baseline: *n*=1,001,749, 55.0% Follow up visit (December 2019): *n*=813,755	No	Noncycloplegic autorefraction

Contd...

Table 1: Contd...

Study author(s)	Country	Study design	Age, range (years) (mean±SD)	Sample size (n), % male	Existing myopia control intervention	Outcome measure(s)
				Follow up visit (June 2020): *n*=768,492 Follow up visit (August 2020): *n*=12,013		
Yang *et al.*[36]	China	Cohort study	6–18	*n*=2792, 53.6%	No	Noncycloplegic autorefraction
Yao *et al.*[37]	Tibet	Cohort study	7.9±0.5	*n*=1819, 52.8%	No	Cycloplegic autorefraction AL
Yum *et al.*[38]	Korea	Cohort study	5–15 (10.1±2.5) 0.05% atropine group: 9.9±1.7 0.025% atropine group: 9.8±2.6 0.01% atropine group: 11.7±3.1	*n*=103 0.05% atropine group: *n*=36, 58.3% 0.025% atropine group: *n*=52, 46.2% 0.01% atropine group: *n*=15, 40.0%	Atropine 0.01%, 0.025% or 0.05%	Cycloplegic autorefraction AL
Zhang *et al.*[39]	Hong Kong	Cohort study	6–8 Nonexposure (control) group: 7.29±0.75 Exposure group: 7.25±0.92	Nonexposure (control) group: 1084 Exposure group: 709	No	Cycloplegic autorefraction AL

†Four rounds of examinations (referred to as rounds 1–4) were conducted at approximately 6-monthly interval. AL=Axial length, Nonexposure (control) group=Participants not exposed to COVID-19 pandemic, Exposure group=Participants exposed to COVID-19 pandemic, COVID-19=Coronavirus disease 2019, SD=Standard deviation

Table 2: Risk of bias assessment for cross-sectional studies

Study author(s)	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Percentage yes, risk*
Alvarez-Peregrina *et al.*[17]	✔	✔	✔	✔	×	×	✔	✔	75, low
Chen *et al.*[21]	✔	✔	✔	✔	✔	✔	✔	✔	100, low
Dong *et al.*[22]	×	✔	✔	✔	✔	✔	✔	✔	88.75, low
Mu *et al.*[31]	✔	✔	✔	✔	×	×	✔	✔	75, low
Wang *et al.*[32]	✔	✔	✔	✔	×	×	✔	✔	100, low
Wang *et al.*[34]	×	✔	✔	✔	✔	✔	✔	✔	88.75, low

*Q1–8 indicate questions 1 to 8 based on the Joanna Briggs Institute risk assessment tool for cross-sectional studies. ✔=yes, ×=no

Five studies looked at the impact of the COVID-19 pandemic on the progression of myopia by measuring the change in ocular AL or its monthly growth rate [Table 5].[19,24,26,27,39] Three of these studies found a significantly faster rate of AL elongation during the COVID-19 pandemic compared to pre-pandemic,[19,24,39] while two studies found no significant difference in AL change during the pandemic.[26,27]

Impact of coronavirus disease 2019 pandemic on the progression of myopia in individuals using myopia-control interventions

Three studies investigated the effect of the COVID-19 pandemic on the progression of myopia in participants who were using myopia-control interventions [Table 6]. In two studies,[23,38] the participants were using low-concentration atropine eye drops, and in one study,[25] individuals were using orthokeratology treatment.

Compared to before the COVID-19 pandemic, myopia progression accelerated during the pandemic in participants using low-concentration atropine eye drops.[23,38] For those using orthokeratology treatment, the COVID-19 pandemic did not increase the AL elongation rate, suggesting that the efficacy of orthokeratology in retarding myopia progression during the pandemic was sustained.[25]

Impact of coronavirus disease 2019 pandemic on the prevalence and incidence of myopia

Sixteen studies[17,20-22,24,26-29,32-37,39] investigated the impact of the COVID-19 pandemic on the prevalence of myopia while three examined its effect on its incidence [Table 7].[24,26,39] Of the 16 studies on the prevalence of myopia, 13 showed that myopia prevalence increased during the COVID-19 pandemic, 2 showed mixed results depending on the age group,[32,33] and 1 found a decrease in myopia prevalence.[17]

All three studies investigating myopia incidence showed higher myopia incidence during the COVID-19 pandemic.[24,26,39]

Table 3: Risk of bias assessment for cohort studies

Study author(s)	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Percentage yes, risk of bias*
Aslan *et al.*[18]	-	-	✔	✔	✔	×	✔	✔	✔	-	✔	87.5, low
Cai *et al.*[19]	-	-	✔	✔	✔	×	✔	✔	✔	-	✔	87.5, low
Chang *et al.*[20]	-	-	✔	×	×	×	✔	✔	×	×	✔	44.4, high
Erdinest *et al.*[23]	-	-	✔	×	×	×	✔	✔	✔	-	✔	62.5, moderate
Hu *et al.*[24]	✔	✔	✔	×	×	×	✔	✔	✔	?	✔	63.6, moderate
Lv *et al.*[25]	-	-	✔	×	×	×	✔	✔	✔	-	✔	62.5, moderate
Ma *et al.*[26]	✔	✔	✔	×	×	×	✔	✔	✔	-	✔	70, low
Ma *et al.*[27]	✔	✔	✔	×	×	×	✔	✔	✔	-	✔	70, low
Ma *et al.*[28]	-	-	✔	✔	✔	×	✔	✔	✔	-	✔	87.5, low
Ma *et al.*[29]	-	-	✔	✔	✔	×	✔	✔	✔	-	✔	87.5, low
Mohan *et al.*[30]	-	-	✔	✔	✔	×	✔	✔	✔	-	✔	87.5, low
Wang *et al.*[33]	-	-	✔	×	×	×	✔	✔	✔	-	✔	62.5, moderate
Xu *et al.*[35]	-	-	✔	✔	✔	×	✔	✔	×	×	✔	66.7, moderate
Yang *et al.*[36]	-	-	✔	×	×	×	✔	✔	✔	-	✔	62.5, moderate
Yao *et al.*[37]	-	-	✔	✔	✔	×	✔	✔	✔	-	✔	87.5, low
Yum *et al.*[38]	-	-	✔	✔	✔	×	✔	✔	✔	-	✔	87.5, low
Zhang *et al.*[39]	✔	✔	✔	✔	✔	×	✔	✔	×	×	✔	72.8, low

*Q1–11 indicate questions 1 to 11 based on the Joanna Briggs Institute risk assessment tool for cohort studies ✔=yes, ×=no, -=not applicable, ?=unclear

Table 4: Impact of coronavirus disease 2019 pandemic on myopia progression in terms of spherical equivalent refraction in serial cross-sectional studies in which participants were not utilizing any myopia-control interventions

Study author(s)	Sample (*n*)		SER (D)		
	Pre-COVID-19	COVID-19	Pre-COVID-19	COVID-19	Δ
Alvarez-Peregrina *et al.*[17]	4227	1600	5 years old: +0.66±2.03 D	5 years old: +0.48±1.81 D	5 years old: −0.18 D (*P*=0.005)
			6 years old: +0.77±2.07 D	6 years old: +0.57±1.73 D	6 years old: −0.20 D (*P*=0.078)
			7 years old: +0.61±1.96 D	7 years old: +0.35±1.82 D	7 years old: −0.26 D (*P*=0.008)
			All: +0.66±2.03 D	All: +0.48±1.81 D	All: −0.18 D (*P*≤0.001)
Chen *et al.*[21]	118,479	121,881	−1.16±1.92 D	−1.34±2.03 D	−0.18 D (*P*<0.05)
Wang *et al.*[32]	123,535	123,535	6 years old: +0.15 D	6 years old: −0.17 D	6 years old: −0.32 D
			7 years old: −0.03 D	7 years old: −0.31 D	7 years old: −0.28 D
			8 years old: −0.30 D	8 years old: −0.59 D	8 years old: −0.29 D
			9 years old: −0.66 D	9 years old: −0.80 D	9 years old: −0.14 D
			10 years old: −1.03 D	10 years old: −1.17 D	10 years old: −0.14 D
			11 years old: −1.45 D	11 years old: −1.51 D	11 years old: −0.06 D
			12 years old: −1.82 D	12 years old: −1.87 D	12 years old: −0.05 D
			13 years old: −2.49 D	13 years old: −2.54 D	13 years old: −0.05 D
					All findings were significant at *P*<0.001
Wang *et al.*[34]	1728	1733	−1.64±5.49 D	−1.94±2.13 D	−0.30 D (*P*<0.001)

SER: Spherical equivalent refraction, D: Diopter, COVID-19=Coronavirus disease 2019

Discussion

We conducted an updated and large systematic review on the impact of the COVID-19 pandemic on the progression, prevalence, and incidence of myopia. Previous reviews on this topic, such as that by Cyril Kurupp *et al*.[40] and Li *et al*.,[41] were conducted at the height of the pandemic and analyzed a total of 10 and 7 papers, respectively. These earlier reviews had provided researchers and clinicians with an understanding of the impact of home confinement early in the pandemic. Another systematic review and meta-analysis by Najafzadeh *et al*. on myopia progression during the COVID-19 era included 33 studies.[42] Our review specifically studied myopia progression during the COVID-19 pandemic while the aforementioned review included studies on lifestyle and behavioral changes during the pandemic that could affect myopia progression, which was not the primary focus of our review. However, as more studies emerged, an up-to-date review on the impact of the pandemic on myopia is worthy and timely. Importantly, our systematic review also evaluated the impact of the COVID-19 pandemic on myopia progression in individuals using myopia-control interventions.

Our review suggests that the COVID-19 pandemic and its related home-confinement and home study measures were associated with a greater myopic shift compared to prepandemic values in terms of SER. However, the effect of the pandemic on AL showed mixed results.

Table 5: Impact of coronavirus disease 2019 pandemic on myopia progression in terms of spherical equivalent refraction and/or axial length in cohort studies in which participants were not utilizing any myopia-control interventions

Study author(s)	Sample (*n*)		SER (D) or SER change (D)/duration		
	Pre-COVID-19	COVID-19	Pre-COVID-19	COVID-19	Δ
Aslan and Sahinoglu-Keskek[18]	115	115	SER change in 12 months 2019: −0.54±0.43 D	SER change in 12 months 2020: −0.71±0.46 D	Δ SER change in 12 months 2019–2020: −0.17 D (*P*=0.003)
Cai *et al.*[19]	115	115	SER change in 3 months: −0.20 D	SER change in 3 months: −0.45 D	Δ SER change in 3 months: −0.25 D
Chang *et al.*[20]	29719	29719	SER change/month: −0.030 D/month (95% CI, −0.031– −0.029 D/month)	SER change/month: −0.074 D/month (95% CI, −0.075–−0.074 D/month)	Δ SER change/month: −0.044 D/month (*P*<0.001)
Hu *et al.*[24]	1060	1054	SER change in 12 months: −0.31±0.46 D	SER change in 12 months: −0.67±0.56 D	Δ SER change in in 12 months: −0.36 D (*P*<0.001)
Ma *et al.*[26]	83	208	SER change in 7 months: −0.33±0.47 D	SER change in 7 months: −0.93±0.65 D	Δ SER change in 7 months: −0.60 D (*P*<0.001)
Ma *et al.*[27]	77	77	SER change in 7 months: −0.33±0.46 D	SER change in 7 months: −0.83±0.56 D	Δ SER change in 7 months: −0.50 D (*P*<0.001)
Ma *et al.*[28]	913	913	Mean SER: −0.43±0.92 D	Mean SER: −0.95±1.07 D	Δmean SER: −0.76±0.85 D (*P*>0.05)
Ma *et al.*[29]	201	201	Mean SER Baseline: −1.86±0.76 D First follow-up: −2.25±0.75 D	Mean SER Second follow-up: −3.23±0.65 D	Δ first follow-up: −0.39±0.58 D Δ second follow-up:−0.98±0.52 D (*P*<0.001)
Mohan *et al.*[30]	133	133	Mean SER: −4.54±2.70 D SER change in 12 months: −0.25 D	Mean SER: −5.12±2.70 D SER change in 12 months: −0.90 D	Δmean SER: −0.58 D Δ SER change in 12 months: −0.65 D (*P*<0.00001)
Wang *et al.*[33]	468,094	468,094	Mean SER 6 years: −0.19 D 7 years: −0.23 D 8 years: −0.45 D 9 years: −0.70 D 10 years: −1.01 D 11 years: −1.33 D 12 years: −1.53 D 13–15 years: −1.56 D	Mean SER 6 years: −0.09 D 7 years: −0.18 D 8 years: −0.42 D 9 years: − 0.68 D 10 years: −1.04 D 11 years: −1.41 D 12 years: −1.75 D 13–15 years: −1.84 D	Δmean SER 6 years: 0.1 D 7 years: 0.05 D 8 years: 0.03 D 9 years: 0.02 D 10 years: −0.03 D 11 years: −0.08 D 12 years: −0.22 D 13–15 years: −0.28 D
Xu *et al.*[35]	1,001,749	813,755 (December 2019) 768,492 (June 2020) 12,013 (August 2020)	SER change in 6 months: −0.23 D	SER change in 6 months: −0.343 D	Δ SER change in 6 months: −0.113 D (*P*<0.001)
Yang *et al.*[36]	2792	2792	SER change in 12 months: −0.23±0.99 D	SER change in 12 months: −0.38±0.98 D	Δ SER change in 12 months: −0.15 D (*P*<0.001)
Yao *et al.*[37]	1819	1819	Mean SER: +1.07±0.92 D	Mean SER First follow-up (Nov 2020): +0.59±1.08 D Second follow-up (July 2021): +0.19±1.28 D	Δ change in mean SER Pre-COVID-19 and first follow-up: −0.49±0.57 D; *P*<0.05
Zhang *et al.*[39]	1084	709	Mean SER Baseline: +0.34±1.49 D 3-year follow-up: −0.93±2.14 D	Mean SER Baseline: +0.32±1.16 D 8-month follow-up: −0.19±1.33 D	Δmean SER Pre-COVID-19 (3 years): −1.27±1.34 D; *P*<0.001 COVID-19 (8 months): −0.50±0.51 D; *P*<0.001

Study author(s)	AL (mm) or AL elongation, mm/duration		
	Pre-COVID-19	COVID-19	Δ
Aslan and Sahinoglu-Keskek[18]	-	-	-

Contd...

Table 5: Contd...

Study author(s)	AL (mm) or AL elongation, mm/duration		
	Pre-COVID-19	COVID-19	Δ
Cai *et al.*[19]	AL elongation rate: 0.033 mm/month	AL elongation rate: 0.046 mm/month	Δ AL elongation rate: 0.013 mm/month (*P*=0.003)
Chang *et al.*[20]	-	-	-
Hu *et al.*[24]	AL elongation in 12 months: 0.22±0.21 mm	AL elongation in 12 months: 0.31±0.24 mm	Δ AL elongation in 12 months: 0.08 mm (*P*<0.001)
Ma *et al.*[26]	AL elongation in 7 months: 0.23±0.18 mm	AL elongation in 7 months: 0.24±0.19 mm	Δ AL elongation in 7 months: 0.01 (*P*=0.37)
Ma *et al.*[27]	AL elongation in 7 months: Exact value not reported	AL elongation in 7 months: Exact value not reported	Δ AL elongation in 7 months: Not statistically significant
Ma *et al.*[28]	-	-	-
Ma *et al.*[29]	-	-	-
Mohan *et al.*[30]	-	-	-
Wang *et al.*[33]	-	-	-
Xu *et al.*[35]	-	-	-
Yang *et al.*[36]	-	-	-
Yao *et al.*[37]	-	-	-
Zhang *et al.*[39]	Mean AL Baseline: 23.02±0.91 mm 3-year follow-up: 23.89±1.11 mm	Mean AL Baseline: 22.98±0.83 mm 8 months follow-up: 23.27±0.87 mm	Δmean AL Pre-COVID-19 (3 years): 0.88±0.49 mm; *P*<0.001 COVID-19 (8 months): 0.29±0.35 mm; *P*<0.001

AL=Axial length, CI=Confidence interval, SER=Spherical equivalent refraction, D=Diopter, COVID-19=Coronavirus disease 2019

In two studies, its effect on AL elongation was not statistically significant.[26,27] This could be due to (1) the small magnitude of change in AL because of the short follow-up duration and/or (2) transient myopia caused by accommodative spasms from increased near-work activities for extended periods of time during the pandemic.[26,27] In addition, myopia prevalence and incidence were higher during and after, compared to before, the COVID-19 pandemic.

All studies included in the review were cross-sectional or cohort studies. The critical appraisal assessment of included studies using the JBI risk assessment tools for cross-sectional and cohort studies revealed overall good quality, with all except one study[20] demonstrating low or moderate risk of bias [Tables 2 and 3]. The overall weaknesses of the studies included study participants not being free of the outcome of interest (myopia) at the start of the study, and lack of identification of confounding factors and methods to deal with these factors.

The COVID-19 pandemic resulted in swift implementation of home confinements of varying degrees across different countries, including limiting daily interactions between people and country-wide school closures in 143 countries.[43] The pandemic accelerated the transition towards digital learning among children because of home confinements, fundamentally changing the way education was delivered.[43] Conventional paper and pen reading or writing was substituted with digital screen time as digital platforms were used as the primary educational mode during COVID-19 home confinements.[44] For example, Zhang *et al*. found that screen time increased close to 3-fold in Hong Kong, from 2.45 h/day before the COVID-19 pandemic to 6.89 h/day during the pandemic.[39] Ma *et al*. also found that the amount of time spent on near work increased during COVID-19 lockdowns from 2.96 ± 1.05 h to 4.33 ± 1.04 h/day ($P < 0.001$) in China.[27]

The COVID-19 pandemic also caused a reduction in outdoor activity due to home confinement rules restricting time spent outdoors. In China, Xu *et al*.[35] found a decrease of more than 1 h of outdoor activity time during COVID-19 quarantine, while in Hong Kong, Zhang *et al*.[39] found that the mean total time spent on outdoor activities decreased from 1.27 h/day at baseline recruitment to 0.41 h/day at the 8-month follow-up in the COVID-19 cohort.

The associations between myopia and digital screen time or outdoor activity have been well-elucidated. Time spent online has been positively correlated with increased myopia incidence and progression[7,19,34,35] while outdoor time has been found to have a protective effect on myopia onset.[45,46] In addition, visual fatigue caused by accommodative dysfunction could also have an accelerating effect on myopia progression.[36] Small screens used for educational purposes could have crowded fonts and reduced row spacing with limited brightness, generating an increased need for eye accommodation.[36] The COVID-19 pandemic led to significant changes in both lifestyle and behavior, with increased time spent on electronic devices and

Table 6: Impact of coronavirus disease 2019 pandemic on myopia progression in terms of spherical equivalent refraction and/or axial length in cohort studies in which participants were utilizing myopia-control interventions

Study author(s)	Myopia-control intervention	Sample (*n*)	Change in SER (D)/duration			AL elongation, mm/duration			
			Pre-COVID-19	COVID-19	Δ	Pre-COVID-19	COVID-19	Post-COVID-19	Δ
Erdinest *et al.*[23]	Atropine 0.01% eye drops	14	−0.33±0.27 D/year	−0.74±0.46 D/year	−0.41 D/year (*P*<0.001)	0.29±0.20 mm/year	0.47±0.30 mm/year	-	+0.18 mm (*P*<0.001)
Lv *et al.*[25]	Orthokeratology	92	-	-	-	0.023±0.019 mm/month	0.018±0.021 mm/month	0.014±0.016 mm/month	Pre-COVID-19 versus COVID-19: *P*=0.213 COVID-19 versus post-COVID-19: *P*=1.000 pre-COVID-19 versus post-COVID-19: *P*=0.035
Yum *et al.*[38]	Atropine 0.01% eye drops	15	−0.052±0.040 D/month	−0.056±0.031 D/month	−0.004 D/month (*P*=0.950)	0.019±0.015 mm/month	0.023±0.020 mm/month	-	0.004 mm/month (*P*=0.201)
	Atropine 0.025% eye drops	52	−0.051±0.045 D/month	−0.068±0.046 D/month	−0.017 D/month (*P*=0.020)	0.025±0.016 mm/month	0.030±0.019 mm/month	-	0.005 mm/month (*P*=0.026)
	Atropine 0.05% eye drops	36	−0.039±0.036 D/month	−0.071±0.053 D/month	−0.032 D/month (*P*<0.001)	0.025±0.015 mm/month	0.031±0.022 mm/month	-	0.006 mm/month (*P*=0.036)
	All atropine eye drops	103	−0.047±0.042 D/month	−0.067±0.046 D/month	−0.020 D/month (*P*<0.001)	0.024±0.015 mm/month	0.030±0.020 mm/month	-	0.060 mm/month (*P*=0.001)

AL=Axial length, SER=Spherical equivalent refraction, D=Diopter, COVID-19=Coronavirus disease 2019

decreased time spent outdoors likely contributing to accelerated myopia progression. Given that an increase in myopia prevalence of such magnitude was not seen pre-COVID-19 pandemic in at least two studies,[32,35] we can possibly attribute this trend to the pandemic and/or its home confinement and online schooling in 2020.

The impact of the COVID-19 pandemic on the prevalence of myopia could be influenced by age. Wang *et al*. found that myopia prevalence increased in 6- and 7-year-olds but decreased in children above the age of 10 during the pandemic, despite the fact that older children (grades 3–6) spent more time (2.5 h) per day on online classes compared to younger children (grades 1–2, 1 h).[32] Wang *et al*. postulated that this finding could be due to younger children being more susceptible to environmental changes compared to older children.[32] On the other hand, Wang *et al*. found that the prevalence of myopia among first graders decreased during the pandemic, while the prevalence of myopia among third- to sixth-grade students gradually increased, with the highest myopia rate in 2021 amid the pandemic.[33] As age is a known factor affecting SER progression and AL elongation, comparing different generations of the same age before and after COVID-19 can help to negate its confounding effect, as was done in several studies.[17,32,33]

Interestingly, the impact of the COVID-19 pandemic on myopia progression in individuals using myopia-control interventions was mixed. Those on low-concentration atropine eye drops experienced accelerated myopia progression during the pandemic[23,38] while those using orthokeratology treatment did not.[25] Furthermore, in the study on orthokeratology treatment, subgroup analysis comparing younger and older children found that the AL growth rate was significantly slower during COVID-19 confinement than before for older children but not younger children.[25] It was postulated that better adherence to orthokeratology treatment and lens care in the older children might have prevented the increase in near work and time spent at home during COVID-19-associated lockdowns from significantly affecting orthokeratology effectiveness.[25] It is possible that there is a greater understanding of orthokeratology treatment among older children, leading to greater motivation to habitually use the treatment as necessary. Furthermore, it is well known in the literature that age is an independent risk factor for the progression of myopia, with a consensus that younger myopic children show a faster AL growth rate than older myopic children.[47-49] Thus, younger children might experience greater myopic progression due to the compounded effects of age and COVID-19 lockdowns, which may necessitate more aggressive treatment.

Table 7: Impact of coronavirus disease 2019 pandemic on myopia prevalence and incidence

Study author(s)	Myopia prevalence						Myopia incidence	
	Before COVID-19	During/after COVID-19	Δ	Nonexposure (control) group	Exposure group	Δ	Nonexposure (control) group	Exposure group
Alvarez-Peregrina *et al.*[17]	21%	20%	−1%	-	-	-	-	-
Chang *et al.*[20]	Myopia Round 1†: 48.0% Round 2†: 53.2% High myopia: Round 1†: 1.3% Round 2†: 1.9%	Myopia Round 3†: 73.7% Round 4†: 67.9% High myopia Round 3†: 2.8% Round 4†: 2.7%	-	-	-	-	-	-
Chen *et al.*[21]	43.1%	48.9%	+5.8% (P<0.01)	-	-	-	-	-
Dong *et al.*[22]	48.2%	60.0%	+11.8% (P<0.001)	-	-	-	-	-
Hu *et al.*[24]	-	-	-	13.3%	20.8%	7.5% (P<0.001)	7.5%	15.3%
Ma *et al.*[26]	58.7%	85.6%	+26.9%				27.1%	65.1%
Ma *et al.*[27]	-	-	-	Baseline: 32.5% Follow-up: 48.1%	Baseline: 32.5% Follow-up: 84.5%	Nonexposure group: 15.6% Exposure group: 52%	-	-
Ma *et al.*[28]	16.6%	39.4%	+22.8% (P<0.001)	-	-	-	-	-
Mu *et al.*[31]	46.9%	50.5%	+3.6%	-	-	-	-	-
Wang *et al.*[32]	6 years: 5.7%* 7 years: 16.2%* 8 years: 27.7%* 9 years: 43.5%* 10 years: 55.1%* 11 years: 63.3%* 12 years: 75.5%* 13 years: 84.9%*	6 years: 21.5% 7 years: 26.2% 8 years: 37.2% 9 years: 45.3% 10 years: 52.8% 11 years: 59.5% 12 years: 67.1% 13 years: 81.5%	6 years: +15.8% (P<0.001) 7 years: +10% (P<0.001) 8 years: +9.5% (P<0.001) 9 years: +1.8% (P=0.09) 10 years: −2.3% (P=0.03) 11 years: −3.8% (P=0.004) 12 years: −8.4% (P<0.001) 13 years: −3.4% (P<0.001)	-	-	-	-	-
Wang *et al.*[33]	Grade 1 21.1% (2018) 18.3% (2019) Grade 2 22.6% (2018) 20.0% (2019) Grade 3 28.8% (2018) 27.9% (2019) Grade 4 38.3% (2018) 37.9% (2019)	Grade 1 16.8% (2020) 13.8% (2021) Grade 2 24.4% (2020) 22.5% (2021) Grade 3 32.4% (2020) 33.9% (2021) Grade 4 43.8% (2020) 44.2% (2021)	-	-	-	-	-	-

Contd...

Table 7: Contd...

Study author(s)	Myopia prevalence						Myopia incidence	
	Before COVID-19	During/after COVID-19	Δ	Nonexposure (control) group	Exposure group	Δ	Nonexposure (control) group	Exposure group
	Grade 5 46.1% (2018) 47.8% (2019) Grade 6 58.2% (2018) 56.9% (2019)	Grade 5 53.6% (2020) 53.7% (2021) Grade 6 64.0% (2020) 66.0% (2021)						
Wang *et al.*[34]	44.62%	55.02%	+10.4%	-	-	-	-	-
Xu *et al.*[35]	Myopia June 2019: 52.89% December 2019: 53.9% High myopia June 2019: 4.11% December 2019: 4.24%	Myopia June 2020: 59.35% High myopia June 2020: 4.99%	Myopia June–December 2019: +1.01% December 2019–June 2020: +5.45% High myopia June–December 2019: +0.13% December 2019–June 2020: +0.75%	-	-	-	-	-
Yang *et al.*[36]	Mild myopia: 34.71% Moderate myopia: 7.34% High myopia: 5.12%	Mild myopia: 38.25% Moderate myopia: 11.32% High myopia: 6.02%	Mild myopia: +3.54% Moderate myopia: +3.98% High myopia: +0.9%	-	-	-	-	-
Yao *et al.*[37]	3.94%	10.94%	+7.0%	-	-	-	-	-
Zhang *et al.*[39]	-	-	-	Baseline: 19.02% Follow-up: 52.99%	Baseline: 18.97% Follow-up: 35.25%	Nonexposed (3 years): +33.97% Exposed (8 months): +16.28%	36.57% (3 years)	19.44% (8 months)

*Highest prevalence value in each age group during 2015–2019 screening, †Four rounds of examinations (referred to as rounds 1–4) were conducted at approximately 6-monthly interval. Nonexposure (control) group=Participants not exposed to COVID-19 pandemic, Exposure group=Participants exposed to COVID-19 pandemic, COVID-19=Coronavirus disease 2019

The COVID-19 pandemic has created a paradigm shift in work and education, with many companies and schools gradually transiting from traditional modes of work and learning to digital platforms given its success during COVID-19 pandemic-related home confinements. Even without the pandemic, myopia prevalence is expected to increase[3] and the lifestyle changes brought about by the COVID-19 pandemic will only serve to further accelerate the already alarming increase in worldwide myopia prevalence. In light of this, more rigorous and comprehensive myopia-control strategies are required during lockdowns in future pandemics.[38] Apart from ensuring adherence to myopia-control interventions, environmental risk factors for myopia must be mitigated. This includes having children reduce their amount of near work and associated accomodation, limit screen time, take adequate breaks periodically during near work, and spend more time outdoors whenever possible.

One of the strengths of our review is the inclusion of a large number of observational studies with significant sample sizes, which allows for up-to-date findings with the inclusion of recently published studies. Furthermore, we only included studies in which an objective measurement of myopia was used for diagnosis while excluding all studies with self-reported myopia symptoms, thus increasing the reliability and accuracy of our findings. However, this review is not without its limitations. First, we acknowledge that this paper is a systematic review without a meta-analysis. However, we believe that the qualitative synthesis of this review still offers a comprehensive understanding of myopia progression during the COVID-19 pandemic. Second, as a significant majority of the studies in this review were conducted in East Asia, the results may not be generalizable to other ethnicities and regions. Furthermore, there are only three studies that analyzed the effect of the COVID-19 pandemic on myopia progression in individuals using myopia-control interventions. The sample size in these studies is small as well. This is an area that requires further study to better understand the impact of a pandemic on the efficacy of myopia-control interventions.

In conclusion, the COVID-19 pandemic and its associated home-confinement measures increased myopia progression, prevalence, and incidence in children, including those using low-concentration atropine eye drops. As there is only one study investigating the effect of COVID-19 on the efficacy of orthokeratology, more studies can focus on this area in future pandemics.

Data availability statement

Data sharing not applicable to this article as no datasets were generated or analyzed during the current study.

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Conflicts of interest

The authors declare that there are no conflicts of interest in this paper.

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