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Eye health: challenges and solutions

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Eye health: challenges and solutions

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Editorial: Eye health: challenges and solutions

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Editorial on the Research Topic
Eye health: challenges and solutions

As the landscape of vision-threatening diseases continues to evolve with changing lifestyles and population aging, we must adapt our responses and strategies accordingly in a timely manner (1). Currently, age-related and metabolic eye diseases are on the rise, and adolescent refractive errors continue to be a significant concern (Yin et al.). Additionally, the global burden of cataracts and cataract-related blindness, particularly in low-income communities, remains a pressing issue. Therefore, in this Research Topic, we focus on research articles, systematic reviews, and analyses of the epidemiology, prediction, intervention, and policy of disabling eye diseases. By enhancing our understanding of these factors, we hope to inform better development of strategies for preventing vision loss, reducing the prevalence, incidence rate, and progression of eye diseases and ultimately improving both visual quality and quality of life for individuals worldwide.

Cataract is the leading cause of visual impairment and blindness in the older adults. Wang et al. used data from the Global Burden of Disease study to analyze the global distribution and trends in the burden of cataracts in 204 countries and territories from 1990 to 2019. The article proposes that reducing particulate matter pollution, quitting smoking, controlling blood glucose, and lowering BMI can reduce the risk of cataracts. It was found that the age-standardized disability-adjusted life years (DALYs) and mortality caused by each risk factor were highest in the low-middle sociodemographic index (SDI) region, and the overall disease burden of cataracts is lower in males than in females.

Additionally, Lange et al. found that although cataract surgery rates have risen dramatically in the last decade, access to care remains unequal. Low-income patients and women are less likely to receive surgical treatment for cataracts. The lack of funding remains a significant barrier. Ahluwalia et al. also found that the cost of an eye exam can be an obstacle to routine eye care, with the most common reason for not seeking eye care among those with moderate-to-severe visual impairment being cost or lack of insurance. Providing free comprehensive eye examinations and prescription eyeglasses to vulnerable populations, such as homeless individuals and those living in poverty, in the free eye clinic located inside a homeless shelter may be one way to solve the funding shortage.

With the prevalence of myopia increasing sharply over the past decades, preventing visual impairment caused by pathological myopic fundus is a major public health issue. Liu et al. found from a study based on the Genome-Wide Association Study (GWAS) database that genetically predicted taller height, longer time on the computer, and less moderate physical activity are risk factors of myopia. After full adjustment for confounders, height still remained independently and significantly associated with myopia. While a study by Zhou et al. found no significant change in myopia prevalence among senior students in eastern China before and during the COVID-19 epidemic, the prevalence of myopia among vocational high school students is lower compared with general high schools. The effect of educational stress on the prevalence of myopia among students should be paid attention. These findings provide a theoretical basis for future measures to prevent and control myopia in adolescents.

In addition to cataract and refractive error, this issue also discusses ocular trauma. Chen et al. described the epidemiological characteristics of open eye injuries in a multiethnic region of Southwest China. It showed that the type of injury varied by age and occupation, and the cause of injury was related to age, ethnicity, and profession. Ocular trauma disproportionately affected working-aged males, particularly those engaged in manual labor or farming. Sharp objects were identified as the most common cause of these injuries. To effectively reduce the incidence and severity of ocular trauma, it is essential to increase public awareness of ocular trauma prevention and develop personalized prevention and control plans for different population groups.

Majithia et al. discovered a significant correlation between the prevalence of cardiovascular diseases and thinner average peripapillary retinal fiber layer (RNFL) in the multi-ethnic Asian population in Singapore. This association was consistent for the superior and inferior RNFL quadrants. However, cardiovascular diseases were not significantly associated with average macular ganglion cell-inner plexiform layer thickness. This provides a new predictor for cardiovascular diseases. Gao et al. proposed that the reduction of vascular density (VD) in the deep vascular complex seems to be involved in or be accompanied by non-exudative macular neovasculogenesis (MNV) activation. VD could be used as a biomarker for non-exudative MNV, potentially aiding in the early detection and prevention of delayed treatment or overtreatment of subclinical MNV.

Yin et al. conducted a retrospective analysis of trends in the global burden of vision loss among old adults from 1990 to 2019. The prevalence increased and the years lived with disability (YLDs)decreased among individuals aged 65 years and older. The research explored various factors, including the specific types of vision loss, different age groups, geographical regions, countries, and sociodemographic index. Females had higher global prevalence and YLDs compared with males. Cataracts and myopia emerged as the primary drivers of vision loss. Their findings shed light on the complexities of vision loss in the geriatric population and underscore potential areas for targeted interventions across different demographics.

The escalating demand for vision care services, driven by demographic shifts and lifestyle changes, has exacerbated the challenges facing eye health. To effectively address these challenges, we must integrate vision care into broader healthcare strategies, emphasize the importance of preventive measures and available corrective solutions, enhance public awareness of eye health knowledge, strengthen screening and management of eye diseases and their risk factors, and improve the inclusiveness and quality of eye care services.

Author contributions

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Prevalence of myopia among senior students in Fenghua, Eastern China, before and during the COVID-19 pandemic

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Background: Myopia is a common cause of vision impairment worldwide. In China, the prevalence, the affected population, and the onset age of myopia are prominent issues. Prevention and intervention of myopia are great public health concerns.

Methods: This school-based retrospective study retrieved visual acuity and refractive data of senior students (grade 12th) from six high schools in Fenghua City, Zhejiang Province, eastern China, from 2016 and 2022. Noncycloplegic autorefraction was performed for refractive status. Students were divided into three subgroups by their school types. The overall myopia prevalence, as well as the prevalence of low myopia, moderate myopia, and high myopia, were calculated separately for each year. Statistical analyzes were performed using SPSS 25.0 and Graphpad Prism software.

Results: The mean myopia prevalence in Fenghua was 84.5% (95% CI: 84.0–85.0%), and a slightly downward trend was found in myopia prevalence after 2019, but the change was not statistically significant ($p=0.078$). The overall prevalence of myopia was 79.6, 85.2, and 86.1% in vocational high schools, general high schools, and key high schools, respectively, with statistically significant differences ($p<0.001$). The prevalence of myopia among senior students in the vocational high school was significantly lower than that in the other two high schools. There's no significant change in the overall prevalence of myopia (84.7% vs. 84.3%, $p=0.265$) before and during the COVID-19 pandemic, and it remained statistically insignificant after stratifying by gender (male $p=0.207$, female $p=0.918$) or school types (vocational high school $p=0.112$; general high school $p=0.299$; key high school $p=0.393$).

Conclusion: The prevalence of myopia among senior students in Fenghua is relatively high, and the COVID-19 pandemic has no significant impact on it. The prevalence of myopia among vocational high school students is lower than that of general high school and key high school. Attention should be paid to the effects of educational pressure on the prevalence of myopia among students.

KEYWORDS

myopia, prevalence, senior students, COVID-19, academic stress

1. Introduction

Myopia is a common cause of vision impairment worldwide. It is now widely acknowledged that high myopia increases the risk of ophthalmic pathological changes, such as retinal detachment, myopic macular degeneration, glaucoma, and cataracts (1–3), which may eventually result in irreversible vision impairment (4). Myopia, especially high myopia, has a negative impact on public health and quality of life, and it leads to significant healthcare costs and productivity losses (5, 6).

Asia has long been considered to have a high prevalence of myopia (6–8), particularly in China, issues such as the high prevalence of myopia and its fast growth are prominent (5, 7, 9). In our previous study, we have found that from 2001 to 2015, the prevalence of myopia among high school students in Fenghua increased from 79.5 to 87.7%, with a notable increase in the prevalence of high myopia (10). Moreover, changes in myopia prevalence during the COVID-19 pandemic are also issues of interest, with a number of studies reporting an increase trend in myopia prevalence during this period (11–13). For instance, a study conducted in Chongqing, China found that the prevalence of myopia rose from 45.3 to 55.4% following the COVID-19 outbreak (14), and another study also revealed an increase of myopia prevalence by 5.8% compared to 2019 (11).

In the current study, we evaluated changes of myopia prevalence among senior students from six high schools in Fenghua, from 2016 to 2022. We also compared the time trend of myopia prevalence before and during the COVID-19 pandemic aiming to provide some valuable information for myopia prevention and control in China.

2. Methods

2.1. Study population

This school-based retrospective study retrieved visual acuity and refractive data of senior students (grade 12) from six high schools (including 1 vocational high school, 4 general high schools, and 1 key high school) in Fenghua City, Zhejiang Province, eastern China, from 2016 and 2022. Senior students were required to receive a physical checkup before the college entrance examination each year. All the ophthalmic examinations were routinely conducted by experienced ophthalmologists and optometrists from Fenghua People's Hospital, and the results were recorded in the database. Ethical approval was obtained from the ethics committee of Fenghua People's Hospital. The study adhered to the tenets of the Declaration of Helsinki.

2.2. Ophthalmic examination

All students underwent a Standard Logarithmic Visual Acuity E chart test at 5-meter for uncorrected visual acuity (UCVA). If UCVA was less than 5.0, best corrected visual acuity (BCVA) was measured with subjective refraction. Noncycloplegic autorefraction was performed by autorefractor (AR-600; Nidek Ltd., Tokyo, Japan), and the spherical equivalent refraction (SER) was calculated as the spherical refraction plus half of the cylindrical refraction. A slit lamp examination was performed to exclude opacity of the optic media. A self-reported information about previous ophthalmic medical history was also recorded for analysis, including ophthalmic disease, wearing contact lenses or orthokeratology, and/or refractive surgery.

2.3. Definition of refractive status

Due to a good correlation between the right and left eyes ($r = 0.912$, $p < 0.001$; Table 1), the SER of the right eye from each student was chosen for analysis, which was defined as following: non-myopia (SER > −0.5 D), low myopia (−3.0 D < SER ≤ −0.5 D), moderate myopia (−6.0 D < SER ≤ −3.0 D), and high myopia (SER ≤ −6.0 D).

2.4. Statistical analysis

Skewed distribution data was described as medians (interquartile range, IQR), and percentiles were used to describe categorical variables. The overall myopia prevalence, as well as the prevalence of low myopia, moderate myopia, and high myopia, were calculated separately for each year. Changes and differences in myopia prevalence between genders and high schools were analyzed using chi-square tests for dichotomous data or rank sum tests for ranked ordinal data. Correlations of SER between left and right eyes were assessed using the Spearman rank correlation test. Statistical analyzes were performed using SPSS 25.0 (SPSS Inc., Chicago, Illinois, United States) and Graphpad Prism software version 8.0 (Graphpad software Inc., SanDiego, CA, United States) unless otherwise noted, and a p value less than 0.05 was considered statistically significant.

3. Results

3.1. General characteristics

Basic characteristics of the study population were summarized in Table 2. Totally, 17,304 senior students from six high schools in Fenghua City were included in the study from 2016 to 2022. Among them, 118 students were excluded due to history of refractive surgery ($n = 49$), orthokeratology ($n = 43$), hyperopia ($n = 4$), other ophthalmic diseases ($n = 18$), and data missing ($n = 4$). Finally, 17,186 students

TABLE 1 Correlation of SER between right and left eyes.

Year	Right median (IQR)	Left median (IQR)	*P* value[a]	*r*
2016	−3.5(3)	−3.0(4)	<0.001	0.920
2017	−3.5(3)	−3.0(3)	<0.001	0.919
2018	−3.5(4)	−3.0(3)	<0.001	0.923
2019	−3.5(3)	−3.5(4)	<0.001	0.919
2020	−3.5(3)	−3.5(4)	<0.001	0.908
2021	−3.5(3)	−3.0(4)	<0.001	0.902
2022	−3.0(3)	−3.0(4)	<0.001	0.888
Total	−3.5(3)	−3.0(4)	<0.001	0.912

SER, spherical equivalent refraction; IQR, interquartile range. [a]Spearman correlation.

were included for analysis, consisting of 8,107 males (47.1%) and 9,079 females (52.8%), and the ratio of gender was shown in Table 2. Overall, there was no significant difference in gender ratio among the three high schools ($p > 0.05$, except for 2016 $p < 0.001$).

3.2. Uncorrected visual and refractive status

Figure 1 and Table 3 showed the mean UCVA and SER of senior students in Fenghua from 2016 to 2022 that both of them were fluctuating (UCVA $p < 0.001$, SER $p < 0.001$), but not obviously along the time trend.

3.3. Prevalence of myopia in different genders

The mean myopia prevalence in this region was 84.5% (95% CI: 84.0–85.0%). A slightly downward trend was found in myopia prevalence after 2019 in Figure 2, but the change was not statistically significant ($p = 0.078$). Table 3 shows the overall prevalence of myopia was consistently higher among females than males (OR = 1.485, 95% CI: 1.367–1.614, $p < 0.001$). In terms of the prevalence of different degrees of myopia, the distribution of prevalence among males changed in low myopia, moderate myopia, and high myopia ($p < 0.001$; Figure 2), with the prevalence of moderate myopia being the highest, and the prevalence of high myopia seemed to be decreasing. As for females, the prevalence of moderate myopia was also the highest, but there was no significant change among the prevalence of low myopia, moderate myopia, and high myopia ($p = 0.081$).

3.4. Prevalence of myopia in different types of high schools

The prevalence of myopia varied among different types of high schools, with an overall myopia prevalence of 79.6, 85.2, and 86.1% in vocational high schools, general high schools, and key high schools, respectively ($p < 0.001$). *Post hoc* tests showed that the prevalence of myopia in vocational high school was significantly lower than that in the other two types of high schools, while there was no significant difference between general and key high schools.

Table 4 and Figure 3 showed the prevalence of total myopia, low myopia and moderate myopia among senior students in all three types of high schools basically stayed stable (total myopia: vocational high

TABLE 2 Basic characteristics of the study population.

Year	*N*	Male/Female	Vocational high school (Male/Female)	General high school (Male/Female)	Key high school (Male/Female)	*P* value[a]
2016	2,718	1294/1424	361 (135/226)	1874 (936/938)	483 (223/260)	<0.001
2017	2,468	1178/1290	287 (131/156)	1707 (834/873)	474 (213/261)	0.240
2018	2,442	1174/1268	234 (122/112)	1760 (831/929)	448 (221/227)	0.309
2019	2,360	1091/1269	407 (185/222)	1,482 (694/788)	471 (212/259)	0.743
2020	2,332	1090/1242	365 (169/196)	1,504 (724/780)	463 (197/266)	0.107
2021	2,354	1089/1265	447 (207/240)	1,451 (658/793)	456 (224/232)	0.370
2022	2,512	1191/1321	527 (256/271)	1,558 (713/845)	427 (222/205)	0.062
Total	17,186	8107/9079	2,628	11,336	3,222	0.279

[a]Comparison of male/female ratio between different types of schools, Chi-square test.

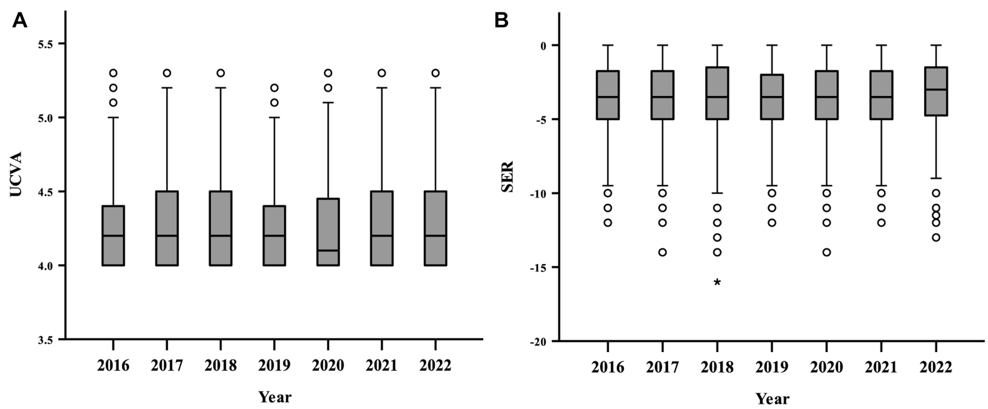

FIGURE 1
The refractive status of senior students in Fenghua from 2016 to 2022. **(A)** Uncorrected visual acuity (UCVA); **(B)** Spherical equivalent refraction (SER). * and ° represent outlier data: °greater than Q3+1.5IQR or less than Q1-1.5IQR, *less than Q1-3IQR. Q, quartile; IQR, interquartile range.

TABLE 3 The mean uncorrected visual acuity and refractive status of senior students in Fenghua, from 2016 to 2022.

	UCVA Median (IQR)	SER Median (IQR)	Myopia prevalence (%)				
			Total prevalence	Male (95%CI)	Female (95%CI)	OR (95% CI)	*P* value[a]
2016	4.2 (0.4)	−3.5 (3)	85.6 (84.2–86.9)	83.2 (81.0–85.2)	87.9 (86.0–89.5)	1.465 (1.181–1.817)	<0.001
2017	4.2 (0.5)	−3.5 (3)	84.2 (82.7–85.7)	81.2 (78.8–83.4)	87.1 (85.1–88.8)	1.562 (1.255–1.943)	<0.001
2018	4.2 (0.5)	−3.5 (4)	83.3 (81.8–84.8)	80.9 (78.6–83.1)	85.5 (83.4–87.4)	1.389 (1.122–1.720)	0.002
2019	4.2 (0.4)	−3.5 (3)	85.6 (84.1–86.9)	83.7 (81.4–85.8)	87.2 (85.2–88.9)	1.323 (1.051–1.665)	0.017
2020	4.1 (0.5)	−3.5 (3)	85.2 (83.7–86.7)	82.6 (80.2–84.8)	87.6 (85.6–89.4)	1.491 (1.185–1.877)	0.001
2021	4.2 (0.5)	−3.5 (3)	84.3 (82.7–85.7)	80.3 (77.8–82.6)	87.7 (85.8–89.5)	1.762 (1.407–2.206)	<0.001
2022	4.2 (0.5)	−3.0 (3)	83.3 (81.8–84.7)	80.6 (78.2–82.8)	85.7 (83.7–87.5)	1.441 (1.168–1.779)	0.001
P value	<0.001[b]	<0.001[b]	0.078[a]	0.208[a]	0.372[a]		

UCVA, uncorrected visual acuity; SER, spherical equivalent refraction; OR, odds ratio; CI, confidence interval. [a]Chi-square test, female vs male; [b]Mann–Whitney *U* test.

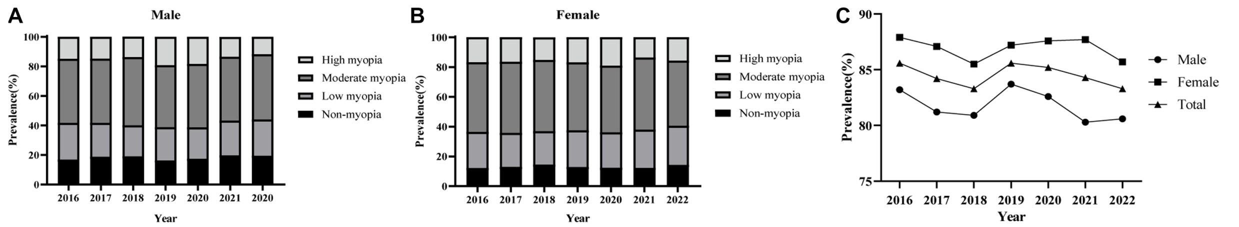

FIGURE 2
Prevalence of myopia by gender. **(A)** The distribution of different degrees of myopia prevalence in males; **(B)** The distribution of different degrees of myopia prevalence in females; **(C)** Trends in myopia prevalence.

school $p = 0.087$, general high school $p = 0.087$, key high school $p = 0.492$; low myopia: vocational high school $p = 0.527$, key high school $p = 0.455$; moderate myopia: vocational high school $p = 0.419$, general high school $p = 0.794$, key high school $p = 0.255$, except for low myopia in general high school $p = 0.036$). Meanwhile, the prevalence of high myopia in general and key high schools seemed to be fluctuating (general high school $p = 0.001$, key high school $p = 0.007$), with a slightly downward trend in vocational high schools ($p = 0.013$).

3.5. Changes in the prevalence of myopia before and during the COVID-19 pandemic

The COVID-19 pandemic broke out at the end of 2019, so we defined the time interval as "before the COVID-19 pandemic (from 2016 to 2019)" and "during the COVID-19 pandemic (from 2020 to 2022)." Table 5 showed that there's no significant change in the prevalence of overall myopia (84.7% *vs* 84.3%, $p = 0.425$), low myopia (23.3% *vs* 24.3%, $p = 0.127$), moderate myopia (45.5% *vs* 44.7%, $p = 0.279$), and high myopia (15.9% *vs* 15.3%, $p = 0.274$) before and during the COVID-19 pandemic. Stratified analysis based on gender (male $p = 0.207$; female $p = 0.918$) and different school type (vocational high school $p = 0.112$; general high school $p = 0.299$; key high school $p = 0.393$) also confirmed that there was no remarkable change in the prevalence of myopia before and during COVID-19.

4. Discussion

Existing studies generally indicate that Asia, especially East Asia, has a high prevalence of myopia (5, 6, 8, 15). A large retrospective review found that 73% of school children in East Asia have myopia, compared with approximately 40% of Europeans and less than 10% of children in African and South American (15). The prevalence of myopia among high school students aged 15 to 19 in Singapore was 73.9% (1), the age-standardized prevalence of myopia among children aged 12 to 18 in South Korea was approximately 80% (15), and our study also showed a high myopia prevalence of 84.5% among senior students in Fenghua City. In contrast, in Germany, only 23% of boys and 35% of girls aged between 14 and 17 years old were diagnosed with myopia (16). On the one hand, ethnic group plays a role in myopia severity. It was reported that myopia progressed faster in Asian American children than in Hispanic, black, and Native American children (17). On the other hand, educational pressure also matters (18–21). It is believed that the prevalent after-school tutoring and intense education began at a young age in school children promote the high prevalence of myopia in Asia (22, 23).

Our study was conducted in Fenghua city, which is located in the eastern coastal region of China, with a regional GDP of over 1,600 billion and a *per capita* GDP of about 137,000 yuan (24). It is generally known that eastern China has a much higher level of economic development and educational attainment than the majority of the rest of the country. We compared the prevalence of myopia in Fenghua City with other similar age groups of adolescents in China

TABLE 4 The prevalence of myopia in different types of high school in Fenghua, from 2016 to 2022.

Year	Vocational high school (%)				General high school (%)				Key high school (%)			
	Total myopia	Low myopia	Moderate myopia	High myopia	Total myopia	Low myopia	Moderate myopia	High myopia	Total myopia	Low myopia	Moderate myopia	High myopia
2016	78.4	24.7	39.3	14.4	86.4	25.7	45.7	15.0	87.8**	20.3	47.4	20.1
2017	78.8	23.7	42.9	12.2	84.5	24.1	45.2	15.2	86.7*	18.1	49.4	19.2
2018	81.2	28.2	37.6	15.4	83.0	21.5	47.0	14.5	85.8	19.2	52.5	14.1
2019	84.5	28.0	40.8	15.7	85.6	22.7	44.9	18.0	86.0	22.9	43.7	19.4
2020	79.5	26.6	36.7	16.2	85.9	22.8	44.3	18.8	87.9*	18.6	48.6	20.7
2021	80.3	26.6	42.5	11.2	85.3	25.2	46.2	13.9	84.9*	21.1	49.3	14.5
2022	76.1	29.8	37.2	9.1	85.7	25.0	45.3	15.4	83.6**	22.2	47.3	14.1
Total	79.6	27.0	39.5	13.1	85.2	23.9	45.5	15.8	86.1**	20.3	48.3	17.5
P value	0.087	0.527	0.419	0.013	0.087	0.036	0.794	0.001	0.492	0.455	0.255	0.007

Chi-square test, *$p < 0.05$, **$p < 0.001$.

(Table 6). The prevalence of myopia among students in eastern cities is generally higher, with two cities in Jiangsu Province reporting prevalence rates of 86.8% for high school students (11, 30). The prevalence of myopia among adolescents in some northern cities was even above 90%, with the prevalence of high myopia reaching more than 20% (32, 33, 36, 37). In contrast, myopia prevalence is relatively low in some western and minority regions such as Xinjiang, with 80.5% of adolescents aged 14 to 18 (38). Overall, myopia prevalence among senior students in Fenghua is above the national average, which may be related to the more developed economy and higher educational pressure in the eastern region.

Also, we compared the results with our previous study which analyzed the myopia prevalence among senior students in Fenghua from 2001 to 2015. The prevalence of myopia in Fenghua was 87.7% in 2015, with a prevalence of myopia of up to 90.8% in females, and a prevalence of high myopia of 16.6%. It seems that there's been a slightly downward trend in myopia prevalence recently. In last several years, the Chinese government attached great importance to the vision health of adolescents, promulgating a series of guidelines on myopia prevention and control. In 2018, the Ministry of Education and the National Health Commission jointly issued an implementation plan for myopia prevention and control among children and adolescents, raising myopia prevention and control to a national strategy (39), the core of which is increasing outdoor activities and reducing educational pressure (40). It is stated that by 2023, efforts should be made to achieve an annual reduction of more than 0.5% in the overall myopia prevalence rate among children and adolescents nationwide from the 2018 baseline. In the current study, the prevalence of myopia among senior students in Fenghua City shows a decreasing trend since 2019, and the annual decrease in myopia prevalence from 2019 to 2022 is 0.4, 0.9, and 1.0% respectively, which have basically achieved the expected target. Meanwhile, we found that the prevalence of high myopia among senior students has also shown a slightly decreasing trend in recent years, which seems to be a good phenomenon. In terms of gender, we found that the prevalence of myopia among female students was higher than that of male students, which was consistent with previous studies (7, 16, 17).

As mentioned above, educational pressure has been recognized as one of the risks factors for myopia (18–21), so we did further analysis by stratifying students by high school. Students in key high schools typically have heavier study tasks, with more educational pressure and less outdoor activity (34). By contrast, students in general high schools have less homework and less educational pressure. The vocational high schools, however, focus on cultivating students' occupational skills. It includes a large number of practice courses in the curriculum, and students do not have to spend long hours burying in books. As expected, our study found that the prevalence of myopia among senior students in vocational high schools was significantly lower than that in general and key high schools, which may be benefit from the abundant practical courses and relatively mild educational pressure in vocational high schools. High level of educational pressure comes along with long hours of homework, less outdoor times, and continuing near work, all of which play roles in myopia onset and progression (15, 41, 42). Interestingly, we found no significant difference between general and key high schools. One possible reason is that students in both types of schools need to take the college entrance examination, and one of their major tasks is to get higher scores in it, which may lead to a similar load of educational stress.

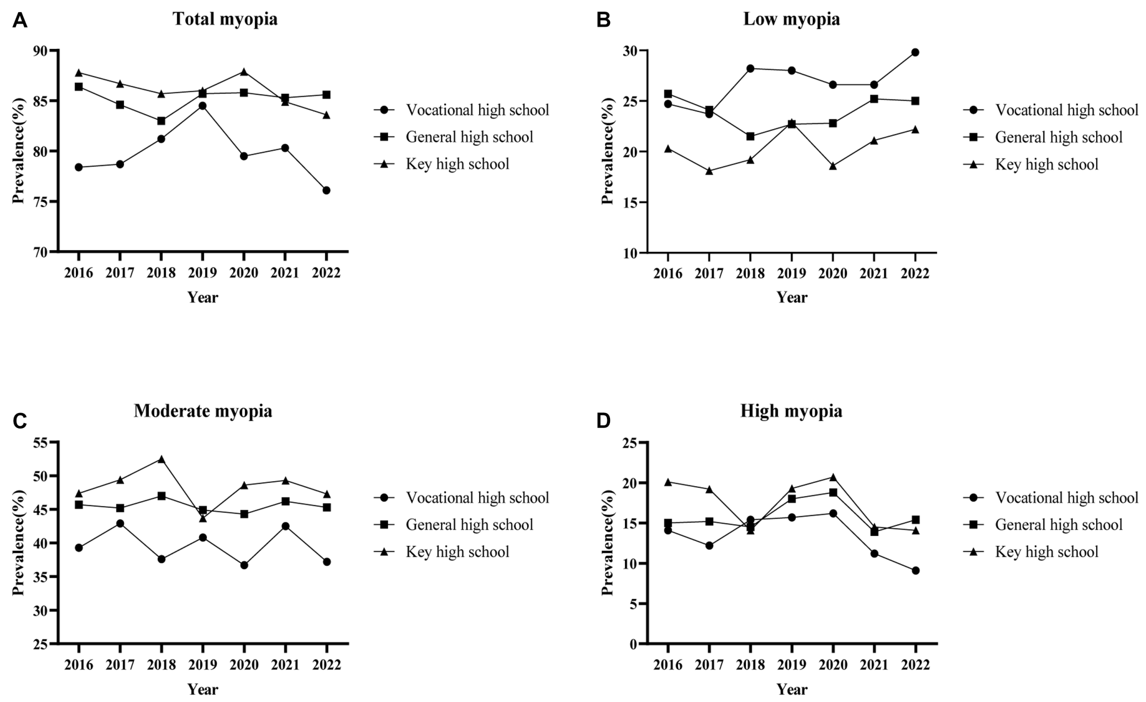

FIGURE 3
Trends in prevalence of different degrees of myopia by high school. **(A)** Total myopia; **(B)** Low myopia; **(C)** Moderate myopia; **(D)** High myopia.

TABLE 5 Prevalence of myopia before and during the COVID-19 pandemic.

Parameters	Myopia prevalence(%)		
	Before COVID-19 (2016–2019)	During COVID-19 (2020–2022)	*P* value[a]
Total myopia	84.7	84.3	0.425
Non myopia	15.3	15.8	
Low myopia	23.3	24.3	0.127
Moderate myopia	45.5	44.7	0.279
High myopia	15.9	15.3	0.274
Gender			
Male	82.2	81.1	0.207
Female	86.9	87.0	0.918
Type of high school			
Vocational high school	80.9	78.4	0.112
General high school	84.9	85.6	0.299
Key high school	86.6	85.5	0.393

COVID-19, Corona Virus Disease 2019; [a]Chi-square test.

Also, this kind of exam-oriented teaching mode makes students spend most of their study time in textbooks, no matter it's in key high schools or general high schools.

We also found there's no significant effect of the COVID -19 pandemic on the prevalence of myopia among senior students in Fenghua City. After the novel coronavirus outbreak in late 2019, the Chinese government implemented a strict home quarantine policy. Schools were shut down nationwide at the end of January 2020 (43), and online courses substituted offline classes. Many surveys have shown a significant reduction in outdoor exercise time, increased electronic devices use, and longer near-work hours for students during home quarantine (44). For example, a study conducted in Shanghai reported that children spent 5.24 h per day on digital devices during home quarantine on average, compared to only around 0.67 h before (44). Similarly, another research reported a reduction of 0.8 h per day in outdoor time and an increase of 4.1 h per day in screen time (13). However, researchers have reached less consistent conclusions regarding the effect of the COVID -19 pandemic on the prevalence of myopia in children and adolescents. Here are some hypotheses that might explain the differences between studies.

First of all, it seems that age may be a significant contributor to this difference. It's worth noting that studies reporting statistically significant differences in increased prevalence of myopia and more negative spherical equivalent after the epidemic outbreak were most likely conducted on younger children (12–14, 45). In contrast, other studies covering a wider group of age showed that the increase in myopia prevalence during the COVID -19 pandemic was less in older children than in elementary school students (14), and some studies even found little change in myopia prevalence in upper-grade adolescents (12, 46), which is consistent with our findings. Previous studies have repeatedly confirmed the relation between age and myopia progression, with the onset and rapid progression of myopia most often occurring during the elementary school years (17, 37), and the development of myopia slows down after puberty (3, 17, 37, 47, 48). As the axial length has generally stabilized (49), the refractive state of senior students included in our study may no longer be sensitive to environmental changes.

Another possible reason is that the environment changes brought by home quarantine may not yet reach the threshold where they can

TABLE 6 Studies of myopia and high myopia prevalence among adolescents in China during the past decade.

Author	Publication year	Province	*N*	Age group/Grade	Prevalence of myopia	Prevalence of high myopia
Lv et al. (25)	2012	Shandong	2,053	18.3 ± 1.8	84.1[a]	/
You et al. (26)	2014	Beijing	1,278	18	72.8[e]	9.1*
Wu et al. (27)	2015	Beijing	3,773	16–18	80.7[e]	9.9*
Song et al. (28)	2017	/	53,010	16–18	83.3[a]	/
Wei et al. (29)	2018	Henan	1,469	18	83.4[a]	12.1*
Chen et al. (10)	2018	Zhejiang	2,932	18.3 ± 0.6	87.7[a]	17.5*
Huang et al. (30)	2019	Jiangsu	968	19.6 ± 0.9	86.8[c]	/
Jiang et al. (31)	2020	Zhejiang	16,309	Senior high school	79.2[a]	/
Wang et al. (9)	2020	Zhejiang	403	Grade 12	89.8[d]	26.1**
Bai et al. (32)	2022	Tianjin	526	18.34	92.4[a]	20.9*
Zhang et al. (33)	2022	Shandong	50,939	Grade 12	94.9[b]	25.1*
Chen et al. (11)	2022	Jiangsu	8,267	Senior high school	88.4[a]	/
Yang et al. (7)	2022	Shanxi	2,338	16–18	86.8[a]	/
Zhao et al. (34)	2022	Shanxi	4,874	15–19	90.6[a]	12.4*
Wang et al. (35)	2022	Chongqing	294	Grade 11	88.7[a]	/
		Tibet	167		74.4[a]	

Definition of myopia: [a]UCVA < 5.0 or/and SE < −0.5D; [b]SE < −0.75D; [c]Self-reported; [d]UCVA < 20/25 and SE < −0.5D; [e]SE ≤ −1.0D.
Definition of high myopia: *SE ≤ −6.0D; **UCVA < 20/25 and SE ≤ −6.0D.

have an impact on myopia progression (44). Influenced by China's college entrance examination system, high school students have a strong educational workload, and they rarely engaged in outdoor activities even before the COVID -19 pandemic. At the same time, with the popularity of multimedia teaching, more and more schools are using electronic screen-casting devices or even tablet PC for auxiliary teaching, and students have long been exposed to various electronic devices in daily lives. Therefore, the impact of the online teaching model may not be as significant as we thought.

Additionally, though current studies generally agree that outdoor activity is a protective factor for myopia onset (6, 11, 15, 16, 41), researchers have also shown that its effect on myopia progression does not seem to be significant in those who already have myopia (17, 44, 50). Such differences in the effect of outdoor activities on people with and without myopia may be another reason for the lack of statistical significance in myopia prevalence after the COVID-19 pandemic in our study. In addition, after the outbreak, the Chinese government attached great importance to the vision health of adolescents and issued a series of guidelines and requirements on myopia prevention, refractive screening, and optometry health protection during the online study, which also played a positive role in controlling the development of myopia.

Our study has several limitations. The refractive data collected for this study were from noncycloplegic autorefraction, because there are difficulties of using cycloplegic in large population health screening, and it is challenging to implement in practice. However, it has been confirmed that there is a high agreement between cycloplegic refraction and noncycloplegic optometry results (51), the latter of which is adequate and has been recommended for screening in populations such as schools (52, 53). Another limitation is the lack of detailed information about reading study time, outdoor activity time, time for extracurricular practical activities and time spent on online courses and digital devices among students in different type of schools before and during the COVID-19 pandemic. Thirdly, we lack the assessment of risk factors associated with myopia, such as axial length, parental myopia, genetic factor, socioeconomic characteristics, and writing posture, mainly because this is a large retrospective study and it is difficult to complete additional questionnaire collection. However, this study provides valuable information for myopia prevention and control among Chinese adolescents.

5. Conclusion

In conclusion, the prevalence of myopia among senior students in Fenghua was still high but remained stable from 2016 to 2022. Students in vocational high school showed a lower myopia prevalence than students in general high school and key high school. COVID-19 pandemic did not affect the prevalence of myopia among students of this age group. Further attention and more efforts should be paid to myopia prevention and control in the future.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding authors.

Ethics statement

The studies involving human participants were reviewed and approved by the ethics committee of Fenghua People's Hospital. Written informed consent from the participants' legal guardian/next of kin was not required to participate in this study in accordance with the national legislation and the institutional requirements.

Author contributions

XZ, TL, and KW designed research. BC and AW conducted research. MC and AW analyzed data. XZ and BC performed statistical analysis. TL and KW wrote the draft of the manuscript. MC revised the manuscript. All authors read, reviewed and approved the final manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Significant improvements in cataract treatment and persistent inequalities in access to cataract surgery among older Poles from 2009 to 2019: results of the PolSenior and PolSenior2 surveys

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Background and aims: Cataract is the leading cause of visual impairment and blindness among older adults worldwide, that can be corrected through surgical interventions. However, diagnosis and treatment bias can be observed, and it is a major issue for improving health policies. Therefore, we assessed a declared prevalence of cataract and the frequency of surgical treatment of this condition in the Polish population in the years 2009–2019. To provide evidence of health inequalities, we compared operated and non-operated seniors using selected socioeconomic factors and identified variables affecting the availability of cataract surgery services over a 10-year follow-up period.

Methods: An analysis based on a survey among 4,905 participants of the nationwide PolSenior study conducted in 2008–2009, and 5,031 participants of PolSenior2 conducted one decade later to assess the health of Poles over 65 years of age.

Results: Cataract diagnosis was declared by 25.5 and 28.2% of the study population in PolSenior and PolSenior2 surveys, respectively. Out of those diagnosed with cataract in PolSenior, 46.5% underwent surgical treatment for at least one eye. This rate increased up to 67.9% in the survey conducted 10 years later. Independent factors increasing the chance for cataract surgery in both cohorts included male sex and age > 75 years. Additional factors were self-reported good health status in PolSenior and lack of financial problems in purchasing medicines in PolSenior2. Over the investigated decade, the chances for cataract surgical treatment increased in single-living and widowed patients. The shortage of funds for medications remained the only significant barrier for surgery.

Conclusion: Although the prevalence of cataract in the older adult population in Poland has not changed from 2009 to 2019, the rate of cataract surgeries has considerably increased over the analyzed decade. Patients with lower socioeconomic status and women have lower access to surgical cataract management.

KEYWORDS

cataract surgery, health inequities, gender, socioeconomic factors, aged, population characteristics, PolSenior, PolSenior2

1. Introduction

Cataract remains the leading cause of blindness worldwide in people ≥50 years of age, accounting for about 45% of global blindness cases and affecting 15.2 million people in 2020. It is also the second leading cause of moderate to severe vision impairment (78.8 million) following uncorrected refractive error (86.1 million) (1). In addition to decreased visual acuity, a patient with cataracts may experience other symptoms such as reduced contrast sensitivity, impaired color vision, double vision, glare, and 'halos' around lights. This condition most often affects older adults as a result of biological aging (age-related cataracts). Cataract is associated with decreased quality of life and reduced life expectancy (1–3).

Although cataract-induced blindness is particularly common in developing countries, together with age-related macular degeneration (AMD), it is still a major public health problem in developed countries (1) including Poland. Poland has a population of 37.6 million and is located in Central and Eastern Europe. However, there is only few published data on the prevalence of cataract in this region (4).

Phacoemulsification combined with intraocular lens implantation is the most common technique for cataract removal both globally and in Poland (5, 6). Treatment rates have been growing successively over the last few years (5, 6), however the issue of inequalities in the distribution of cataract surgery services remains open. There is abundant evidence that social factors, including education, employment status, income level and gender have significant impact on health status (7–10) and accessibility of the health care system regarding diagnostic and treatment in equal measure. The socio-demographic status of the Polish population is becoming diverse, which can cause unfair inequalities in health (11).

Determining the prevalence of cataracts in a representative sample of Poles and identifying groups whose health care is inadequate in this regard would create grounds for active and effective prevention of serious consequences of cataracts including blindness. Identification of subgroups with untreated disease would enable early educational, preventive and therapeutic intervention.

The aim of the study was to assess changes in the prevalence of cataract and surgical treatment rates considering selected socio-economic factors in a representative sample of Poles aged 65 years and older over a decade, based on the PolSenior (12) and PolSenior2 (13) studies.

2. Materials and methods

2.1. Study sample and procedures

PolSenior, a cross-sectional study conducted between 2008 and 2009 in a representative sample of Polish adults aged 65 years and over, comprised 4,979 participants, and has been acknowledged as the most important project monitoring the health of Polish seniors, including eyesight screening (12). After a decade, in 2018–2019, the survey was repeated as part of the PolSenior2 study in a representative sample of 5,987 adults aged 60 years and over (13). In both studies, participants were recruited from all administrative regions in Poland using a three-stage stratified, proportional draw, in 5 years old cohorts. Cohorts were similar in number and consisted of similar numbers of women and men. The representativeness of the sample was obtained by weighting for structure of the older Polish population (12–14). In PolSenior2 project a new cohort was drawn (13), therefore two study populations formed disjoint sets.

Details of sample selection, methods and study design in a randomly selected representative sample of old Poles in PolSenior projects were described in previous publications (12, 13).

The analyses presented in this publication include comparable groups from both studies, 4,979 subjects aged 65 and older from PolSenior and 5,056 subjects of comparable age from PolSenior2. The group of 930 subject aged 60–64 representing PolSenior2 was not included in the analyses.

A small percentage of respondents was removed as they did not provide answers concerning cataract in the survey. A total of 4,905 (2,534 men and 2,371 women, 98.5%) participants responded to the question on cataract diagnosis in PolSenior compared to 5,031 (99.5%) respondents (2,482 men and 2,549 women) in PolSenior2. Of the 1,419 respondents declaring cataract diagnosis in PolSenior, 91.5% (595 men and 703 women) answered the question about cataract treatment. In PolSenior2, cataract was found in 1,715 participants, of whom 95.1% (698 men, 933 women) reported treatment.

This paper compares the findings on the prevalence of cataract, age at diagnosis and surgical treatment in two populations of Polish seniors. The data were analysed by age group (65–74, 75–84, ≥85 years), sex, educational level and place of residence. The impact of socioeconomic factors on cataract surgery rates was also assessed and the intercohorts relationships between PolSenior and PolSenior2 were analysed. Additionally, the analysis included marital status, living status, and self-rated health (SRH).

2.2. Survey procedures

The protocol of the PolSenior2 study was based on the protocol of the PolSenior study and the same questions were included in the analysis. The study protocol consisted of three paper-version questionnaires. Medical and socioeconomic surveys were face-to-face interviews performed by trained nurses during three visits at participants homes. Some data were collected by a self-completion questionnaire, filled in individually by respondents. In the Table 1 we attached a detailed list of questions used for the purpose of the present study.

2.3. Statistical analyses

Continuous variables are presented as means with standard deviations or medians with interquartile ranges. Differences between the groups were verified with the Student's t-test or the Mann–Whitney

TABLE 1 The list of questions and response options included in questionnaires, used for the purpose of the study.

Question	Response options	Comments
Has your doctor ever diagnosed you with cataracts?	Yes No	
How old were you when your doctor first diagnosed you with cataracts?	(age)	
Was the disease…. (treatment)	Operated Unoperated I do not remember/ know	If only one eye was operated, the answer "operated" was marked.
What is your education? (education level)	Primary or incomplete primary Basic vocational or gymnasium Middle secondary and post secondary Higher	
How would you describe your current personal situation? (marital status)	Bachelor/ maiden Married Widower/widow Divorced/living in separation	
Do any other people live in the apartment/house with you? Whom do you live with?" (living status)	Yes/no Husband/wife (including former), partner(s), Children / grandchildren/ great-grandchildren, parents, parents-in-law Other family members, people outside the family	If No Living alone If Yes: with spouse only with other people
How many years in total did you work professionally?	(number of years)	
Which of the following sentences best describes the financial situation in your household? (financial situation of the household)	I/we can afford everything I/we can afford for most thing when saving I/we have difficulties with paying for food or clothes	
Have you run out of money to buy medications in the past 12 months?	Yes (sometimes or often) No	
Please indicate how you assess your current state of health (on a scale of 0 to 10), assuming that 0 is the worst state of health imaginable, while 10 is the best state of health imaginable.	(number between 0 to 10 on *Visual Analogue Scale*)	0–3 – classified as having a poor self-reported health status 4–6 – fair self-reported health status 7–10 good. Self-reported health status.

U-test. Categorical data is presented as counts and percentages. The chi-square test or Fisher's exact test was used to compare the groups. The logistic regression method was applied to assess the relationship between cataract treatment and the set of independent variables. Additional models analysed interaction to assess changes over time, i.e., between the PolSenior and PolSenior2 cohorts. Multivariate models were developed using the backward stepwise procedure, including only cases with a complete set of data. Regression coefficients were used to calculate odds ratios (ORs) with 95% confidence intervals (95% CI). Statistical results were considered significant at $p \leq 0.05$.

The results in Tables 2, 3 are presented after the weighting procedures for the Polish population as percentage or mean values with 95% CI. A statistically significant difference between the groups was assumed for non-overlapping confidence intervals. Statistical packages R (R Core Team, version 3.6.3) and SAS 9.4 TS Level 1 M5 were used for the analysis.

3. Results

3.1. The prevalence of cataract

Cataract diagnosis was declared in the PolSenior project by 25.5% of the Polish population aged ≥65 years. There were no significant differences between women and men (Table 2). The prevalence of cataract increased with age in both sexes. Cataract was reported by urban (>200,000 inhabitants) respondents more often than by rural residents (34.8 vs. 19.2%). In PolSenior2, a history of cataract was reported by 28.2% of the study population, more often by women (33.2 vs. 20.6%) – Table 2. The prevalence increased with age and was higher in city dwellers (>50,000 inhabitants) as compared to rural residents. Although cataract was declared by a comparable percentage of the older population in both editions of PolSenior, the awareness of the disease increased over the decade among women aged ≥75 years and among women with at most primary education (Table 2). There were no significant changes in the prevalence of cataract over the decade among men. In PolSenior, cataract was diagnosed on average 2 years later than in PolSenior2 (74.2 years vs. 72.1 years, $p < 0.005$; Table 4).

It was observed that at the time of diagnosis women were on average 1 year younger than men, which was statistically significant only in the PolSenior study (women – 73.7 years; men – 74.9 years, $p = 0.002$). The age data presented at diagnosis were not weighted (Table 4).

3.2. Surgical treatment

In PolSenior, 46.5% of respondents diagnosed with cataract had at least one eye treated surgically (Table 4). Surgical treatment was

TABLE 2 The frequency of declared cataract diagnosis in the population of Polish seniors depending on age, education, place of residence based on PolSenior and PolSenior2.

	Cataract					
	Diagnosed - PolSenior			Diagnosed - PolSenior2		
	Males	Females	Total	Males	Females	Total
	% (95% CI)	% (95% CI)	% (95% CI)	% (95% CI)	% (95% CI)	% (95% CI)
Age group [years]						
Total 65 and more	21.3 (17.9–24.6)	28.0 (24.2–31.9)	25.5 (22.6–28.4)	20.6 (18.6–22.6)	33.2 (30.5–35.8)	28.2 (26.3–30.1)
65–74	15.9 (10.3–21.5)	21.9 (17.1–26.8)	19.4 (15.5–23.3)	12.6 (10.2–15.1)	21.2 (17.9–24.6)	17.5 (15.4–19.6)
75–84	26.1 (22.2–30.0)	32.9 (28.1–37.6)	30.5 (27.1–33.9)	31.4 (27.3–35.4)	43.4 (38.8–47.9)	39.0 (35.6–42.5)
85+	41.7 (37.2–46.2)	37.3 (30.3–44.4)	38.5 (33.3–43.8)	49.4 (43.4–55.4)	58.5 (53.6–63.5)	56.0 (51.7–60.2)
Education						
Primary or incomplete primary	20.0 (15.9–24.1)	25.2 (20.5–29.9)	23.7 (20.2–27.1)	22.6 (18.0–27.3)	37.6 (33.6–41.6)	32.8 (29.5–36.2)
Basic vocational	15.8 (10.2–21.4)	20.5 (12.9–28.2)	17.6 (13.0–22.3)	17.8 (14.7–21.0)	28.2 (21.6–34.8)	22.5 (19.0–26.0)
Middle, secondary or post-secondary	27.3 (18.2–36.4)	36.1 (29.9–42.3)	33.0 (28.4–37.6)	21.4 (17.7–25.2)	32.4 (27.1–37.8)	28.4 (24.6–32.3)
Higher	23.3 (13.8–32.8)	26.5 (15.0–38.1)	24.7 (17.2–32.2)	22.5 (16.8–28.1)	28.2 (21.7–34.7)	25.9 (21.7–30.1)
Place of residence [number of inhabitants]						
Rural	16.9 (13.1–20.7)	20.3 (14.9–25.8)	19.2 (15.4–23.0)	15.8 (12.3–19.3)	28.5 (24.9–32.1)	23.5 (20.7–26.2)
Urban < 50,000	17.1 (12.5–21.8)	26.7 (22.0–31.5)	23.0 (19.5–26.4)	21.0 (16.7–25.4)	32.7 (27.9–37.5)	28.3 (25.2–31.4)
Urban 50–200,000	23.4 (18.0–28.8)	30.6 (22.8–38.5)	27.7 (22.3–33.2)	24.1 (19.9–28.4)	38.1 (31.4–44.7)	31.9 (27.7–36.1)
Urban > 200,000	28.0 (18.7–37.3)	39.6 (32.9–46.3)	34.8 (29.0–40.6)	26.1 (20.5–31.7)	38.4 (32.7–44.0)	33.8 (29.2–38.4)

CI, confidence interval.

TABLE 3 Cataract surgery rates (in the subgroup of patients with cataract) in the population of Polish seniors by age, education, place of residence, based on PolSenior and PolSenior2.

	Cataract					
	Operated – PolSenior			Operated – PolSenior2		
	Males	Females	Total	Males	Females	Total
	% (95% CI)	% (95% CI)	% (95% CI)	% (95% CI)	% (95% CI)	% (95% CI)
Age group [years]						
Total 65 and more	54.6 (47.5–61.7)	42.8 (37.9–47.6)	46.5 (41.8–51.3)	75.4 (70.7–80.1)	64.9 (61.3–68.6)	67.9 (64.9–71)
65–74	59.9 (45.1–74.6)	34.0 (25.4–42.5)	42.8 (34.9–50.8)	74.5 (65.5–83.6)	58.2 (50.4–66.0)	63.2 (57.5–69)
75–84	46.1 (38.8–53.3)	49.7 (41.2–58.2)	48.6 (42.0–55.2)	74.9 (68.1–81.6)	66.0 (59.5–72.5)	68.6 (63.4–73.8)
85+	64.1 (54.6–73.6)	45.0 (35.9–54.0)	50.4 (43.3–57.5)	78.2 (70.1–86.3)	72.9 (67.6–78.2)	74.2 (69.5–79.0)
Education						
Primary or incomplete primary	51.0 (39.2–62.7)	42.4 (34.5–50.3)	44.5 (38.1–51.0)	79.1 (70.9–87.3)	61.9 (55.9–67.9)	65.5 (59.9–71.1)
Basic vocational	53.7 (41.5–65.8)	44.7 (24.3–65.1)	49.7 (37.3–62.0)	75.9 (67.8–84)	65.8 (55.7–75.8)	70.2 (63.6–76.8)
Middle, secondary or post-secondary	71.3 (57.3–85.3)	43.5 (32.7–54.3)	51.5 (41.1–61.9)	72.3 (62.3–82.3)	65.9 (59.8–72.1)	67.7 (62.6–72.9)
Higher	33.8 (12.4–55.2)	40.5 (23.3–57.8)	36.7 (20.9–52.6)	76.6 (63.6–89.6)	69.7 (59.8–79.7)	72.1 (63.8–80.4)
Place of residence [number of inhabitants]						
Rural	51.3 (42.8–59.9)	42.2 (33.7–50.6)	44.8 (37.8–51.8)	74.9 (66.7–83.0)	63.8 (56.9–70,8)	66.7 (60.9–72.5)
Urban < 50,000	52.1 (39.4–64.7)	40.4 (30.3–50.5)	43.8 (35.3–52.4)	77.5 (71.1–84.0)	64.0 (56.2–71.8)	67.7 (62.3–73.0)
Urban 50–200,000	43.4 (30.6–56.2)	44.0 (32.6–55.4)	43.8 (33.6–54.0)	78.6 (71.5–85.8)	70.7 (62.1–79.4)	73.5 (67.5–79.5)
Urban > 200,000	62.6 (48.5–76.7)	44.0 (34.9–53.2)	50.4 (40.7–60.0)	71.4 (58.2–84.5)	63.1 (56.8–69.4)	65.5 (59.1–71.9)

CI, confidence interval.

TABLE 4 Age at the time of cataract diagnosis in the population of Polish seniors, based on PolSenior and PolSenior2.

	PolSenior1 (K vs. M, $p = 0,002$)			PolSenior2 (K vs. M, p = 0,063)		
	Females	Males	Total	Females	Males	Total
Mean	73,7	74,9	74,2	71,7	72,6	72,1
Median (Q1,Q3)	74 (68,81)	76 (70,82)	75 (69,82)	73 (67,79)	74 (68,80)	73 (67,80)

Unweighted data.

more common in men than in women in the youngest (65–74 years) and oldest age groups (≥85 years), but for the total older population, the difference between the sexes did not reach statistical significance. The percentage of operated respondents did not differ significantly in individual age groups, and it did not depend on the level of education or place of residence (Table 3).

A decade later, cataract surgery was declared by significantly more (67.9%) seniors (Table 3), with male predominance (75.4 vs. 64.9%). The percentage of respondents with a history of cataract surgery was higher in older age groups, but did not depend on the level of education or place of residence.

A significant increase in the percentage of operated patients was observed among women in each of the study age groups, and among men in the 75–84 year subgroup (Table 4). Although cataract surgery rates increased among respondents at all education levels, the largest, two-fold difference was found among those with higher education (36.7 vs. 72.1%). Cataract surgery rates among the inhabitants of rural and urban (up to 200,000 inhabitants) regions were found to increase about 1.5-fold over the decade. For respondents in big cities of >200,000 inhabitants, a significant increase was observed only in the female group (44.0 vs. 63.1%).

3.3. Comparison of operated vs. non-operated PolSenior and PolSenior2 respondents in regard to selected socioeconomic factors

Supplementary Table 1 compares groups of seniors reporting cataract diagnosis who were or were not operated in relation to selected socioeconomic factors. Age and sex were the only variables that significantly differentiated respondents with operated and unoperated cataract in both PolSenior editions. Non-surgical patients were younger. Surgeries were more common in men. Additionally, among the analysed variables in PolSenior, the group of operated/non-operated patients also differed in terms of marital and living status, SRH and financial situation. In PolSenior2, surgical respondents had longer work histories, and were less likely to report lack of funds for medications. Other investigated factors, including the place of residence (rural/urban), level of education, type of work performed in the past, frequency of general practitioner (GP) visits, or the need for regular assistance, were not related to cataract surgery rates in either of the two studies.

3.4. Univariate and multivariate logistic regression analysis

All variables associated with cataract surgery in PolSenior or PolSenior2 were included in the regression analysis. The results for both study cohorts and the changes between the cohorts are presented in Table 5. In both cohorts, age over 75 years and male sex were correlated with higher surgical rates. Men were 1.7 times (95% confidence interval [CI]: (1.359–2.118); $p < 0.001$) more likely to have cataract surgery than women in 2009, and 1.5 times [95%CI, (1.223–1.913); $p < 0.001$] in 2019. In PolSenior, being in a relationship, living with a spouse only, good financial situation and good SRH were additional factors improving access to cataract treatment. On the other hand, in PolSenior2, apart from female sex and age 65–75, the declared lack of funds for medications was the only significant factor related to the failure to undergo cataract surgery. A multivariate analysis (Table 6) confirmed that male sex and age > 75 years were independent factors promoting cataract surgery in both cohorts. Moreover, good SRH and no financial difficulties in purchasing medications were additional factors related to surgical treatment in PolSenior and PolSenior2, respectively.

The analysis of interactions between the cohorts and the risk factors showed that, over the decade, cataract surgery increased in the group of single-living and widowed individuals, while the lack of funds for medications was a significant factor reducing the chances for surgical management (Table 5).

4. Discussion

According to data from the National Health Fund (NHF) in Poland, 187,478 cataract surgeries were performed in 2013, and this number almost doubled (355,470) in 2019 (15). This increase was the result of changes in the organization and financing of cataract surgery. Our study also showed a significant increase in the percentage of cataract surgeries over the decade, i.e., from 46.5 to 67.9%. The increase was observed in each analysed age subgroup, both among women and men, and regardless of education or place of residence. An upward trend in cataract surgeries has also been shown in many other European countries (16), such as England (16, 17), and Germany (17).

The present study explained that despite a significant increase in cataract surgical treatment, there are widening inequalities in the distribution of this type of services. Of great concern is the fact that despite the higher declared prevalence of cataracts among women, they are actually less likely to undergo surgical treatment - this situation highlights inequalities in the distribution of cataract treatment.

Our study showed that the diagnostic rate of cataract in the population of older Poles did not increase over the decade, but significant differences were observed among women ≥75 years of age. This may be related to the improved access to ophthalmic care in this age group as well as growing awareness of cataract. In PolSenior2, women diagnosed with cataract were significantly less likely to receive surgical treatment compared to men. Previously conducted PolSenior also showed a difference in favour of men, but it did not reach

TABLE 5 Univariate regression analysis of relationship between catarct treatment and the set of independent variables in PolSenior and PolSenior2 cohort.

Predictors	Categories	PolSenior cohort OR (95%CI); *p*-value	PolSenior 2 cohort OR (95%CI); *p*-value	Cohort × Predictor interaction OR (95%CI); *p*-value
Sex	Males	1.697 (1.359–2.118);**<0.001**	1.530 (1.223–1.913);**<0.001**	0.902 (0.658–1.236); 0.519
	Females	Ref.	Ref.	Ref.
Age	>75	1.499 (1.165–1.929);**0.002**	1.610 (1.274–2.034);**<0.001**	1.074 (0.761–1.514); 0.683
	65–75	Ref.	Ref.	Ref.
Marital status	Unmarried/Divorced/Separated	0.744 (0.392–1.409); 0.364	0.947 (0.561–1.598); 0.838	1.273 (0.562–2.947); 0.567
	Widowed	0.715 (0.568–0.898);**0.004**	1.076 (0.858–1.349); 0.526	1.506 (1.092–2.078);**0.013**
	Married	Ref.	Ref.	Ref.
Living status	Alone	0.760 (0.570–1.013); 0.061	1.210 (0.901–1.625); 0.204	1.592 (1.056–2.406);**<0.001**
	With other people	0.682 (0.524–0.888);**0.004**	0.957 (0.738–1.241); 0.739	1.403 (0.969–2.032); 0.073
	With spouse only	Ref.	Ref.	Ref.
Working years [years]		1.007 (0.998–1.016); 0.118	1.012 (1.002–1.023);**0.022**	1.005 (0.991–1.019); 0.474
Financial situation of the household	Can afford when saving	0.670 (0.488–0.920);**0.013**	0.880 (0.653–1.185); 0.400	1.313 (0.849–2.025); 0.219
	Difficulties paying for food or clothes	0.613 (0.310–1.210); 0.158	0.615 (0.308–1.228); 0.168	1.004 (0.384–2.684); 0.993
	Can afford everything	Ref.	Ref.	Ref.
Cannot afford medications	Yes	0.921 (0.682–1.244); 0.590	0.589 (0.430–0.807);**<0.001**	0.640 (0.414–0.991);**0.044**
	No + No need	Ref.	Ref.	Ref.
Self-reported health status	Poor (0–3)	0.620 (0.423–0.911);**0.015**	0.811 (0.551–1.195); 0.290	1.307 (0.760–2.266); 0.335
	Fair (4–6)	0.733 (0.569–0.945);**0.016**	0.934 (0.740–1.178); 0.563	1.274 (0.903–1.797); 0.168
	Good (7–10)	Ref.	Ref.	Ref.

Univariate regression results. OR, odds ratio; CI, confidence interval; Ref, reference group.
p-values are indicated in bold.

TABLE 6 Multivariate regression analysis of relationship between catarct treatment and the set of independent variables in PolSenior and PolSenior2 cohort.

Predictors	Categories	PolSenior cohort OR (95%CI); *p*-value	PolSenior 2 cohort OR (95%CI); *p*-value
Sex	Males	1.518 (1.169–1.972);**0.002**	1.490 (1.153–1.929);**0.002**
	Females	Ref.	Ref.
Age	>75	1.593 (1.196–2.129);**0.002**	1.625 (1.247–2.116);**<0.001**
	65–75	Ref.	Ref.
Cannot afford medications	Yes	-	0.605 (0.423–0.871);**0.006**
	No + No need	-	Ref.
Self-reported health status	Poor (0–3)	0.542 (0.346–0.841);**0.007**	-
	Fair (4–6)	0.709 (0.532–0.943);**0.018**	-
	Good (7–10)	Ref.	-

Multivariate regression results. OR, odds ratio; CI, confidence interval; Ref, reference group.
p-values are indicated in bold.

statistical significance. The presented univariate and multivariate regression analyses confirmed in both editions of the study, that men with diagnosis of cataract were approximately 1.5 times more likely to undergo surgery than women. Gender inequality to the disadvantage of women in cataract surgery has also been observed in low-and middle-income countries (8, 18, 19). The accessibility of cataract surgery is diverse in high-income countries. In some countries, such as Sweden (20) and Spain (21), waiting times for cataract surgery are longer for women than for men, while in Canada women use ophthalmic services more often (22).

The reasons for the differences identified in our study may be multiple. Data from the PolSenior2 survey shows that women are more likely to be widowed and more likely to live alone (29.2 vs. 13.0%) (13). In general the burden of treatment, including cataract treatment for a one-person household, is higher. In addition, average pensions received in 2019 by women aged over 65 in Poland were 20% lower than men (23). Similarly, in the United States the most common reason for not having an eye-care visit among women aged 40 years and older with eye disease was cost-related (24). Less educational attainment also hinders the ability of women to obtain sufficient health care information (25, 26). Among Polsenior2 respondents with primary education, men were significantly more likely to undergo cataract surgery than women, and no differences were found among respondents with higher education.

The diagnosis of cataract increased with age in both study cohorts representative of the Polish population aged ≥65 years. The increasing prevalence of cataract with age is supported by other studies in the world (16, 27). In China, the prevalence of cataract was 6.7% among men aged 45–49 years and up to 73.0% among those aged 85–89 years, as well as 8.4 and 77.5%, respectively, among women (28). In PolSenior, no significant differences were found between the incidence of cataract and sex, while in PolSenior2 cataracts were more often reported by women. The inter-sex differences in PolSenior2 were particularly pronounced in the group with the lowest level of education and rural respondents. An international study investigating data from 1990 to 2015 revealed persistent global inter-sex differences in the prevalence of cataracts and found that older age and lower socio-economic status contribute to these differences (18). More common lens opacification in women may be associated with their longer life expectancy and decreased menopausal oestrogen levels (18, 29). In turn, a study which assessed the prevalence of age-related cataracts based on medical examination found no inter-sex differences (16).

PolSenior and PolSenior2 found that awareness of cataract diagnosis was significantly more often declared by inhabitants of large cities than by rural residents. This is probably related to poorer access to medical services in the countryside. Global research based on slit lamp examination for lens translucency did not show significant differences in the prevalence of cataracts between urban and rural regions (18, 20). The mean age at diagnosis in PolSenior was approximately 2 years higher than in PolSenior2 (74.2 vs. 72.1 years). The mean age at cataract diagnosis among Canadians with insurance covering routine annual ophthalmic examinations was 70.8 years, and 72.5 years among those without insurance, due to delayed access to an ophthalmologist (30). In our study, the earlier diagnosis among PolSenior2 respondents was probably associated with improved access to ophthalmic services. However, it cannot be ruled out that lifestyle changes in recent years and greater exposure to risk factors have translated into an increasingly earlier onset of senile cataracts.

Multiple barriers related to socio-economic status, sex, and perceived cost of ophthalmic care can limit patients' access to specialist services (7). On the positive side, the situation of widowed and single people in Poland has improved over the last 10 years, and inequalities in access to cataract surgery among those with poorer self-rated health, poorer financial status, and those living with non-spouses, have been addressed. Many studies describe socio-economic status as a key determinant of the use of ophthalmic care services, which are used less as socio-economic disadvantages increase (7, 31). Unfortunately, the situation of people who declared lack of funds for medication worsened in the PolSenior2 cohort. Although intraocular lens surgery is fully reimbursed by the National Health Fund, patients have to cover the cost of postoperative anti-inflammatory eye drops and topical antibiotics, most of which are not reimbursed. Patients may therefore choose not to undergo the surgery both because of the perioperative costs, which are not limited to the purchase of medications, but also include commuting, the purchase of new glasses, as well as fear of possible complications. It should be emphasised that in contrast to the lack of funds for medications, the overall poor self-reported financial situation was not a factor limiting cataract surgery in PolSenior2. It can therefore be speculated that the lack of funds for medications may affect a group of people with multimorbidity, for whom medical expenses are a significant component of their household budget, and for whom treatment of visual impairment is not a health priority.

The data and conclusions of our study do not include the COVID-19 pandemic period, which had been associated with an approximately 30% decrease in medical services in 2020 compared to 2019 according to NHF data. Due to the pandemic, elective surgical procedures in Poland were suspended from March to May 2020, which again extended the waiting list. Therefore, we face a major challenge to re-establish an easy access to cataract surgery.

A strength of our study is the collection of data on a large, representative, community dwelling population aged 65 and older, with a high proportion of the oldest people. PolSenior projects are the largest studies of health status of older Poles. The almost identical sampling scheme and research methods in both PolSenior studies enabled precise comparisons between the two groups and provided additional evidence for the necessary change of health policies to eliminate health inequalities and improve access to surgical procedures. The limitations of our study are the following: obtaining data only on the basis of medical history, lack of data on waiting time between diagnosis and surgery as well as the source of funding and the type of lens implanted.

5. Conclusion

In 2009–2019, the prevalence of cataracts in the older Polish population remained unchanged, while the rates of cataract surgeries increased significantly over the decade. Despite the increase in declared cataracts among women, they still undergo operations less frequently than men - this situation shows the largest inequality in the distribution of cataract treatment services in Poland. Access to surgery among widowed and single-living people has improved while it has worsened among those declaring financial difficulties in purchasing medications. Cataracts are still a major medical and social challenge, and equalising the chances of its surgical treatment among selected groups of patients (women, people with lower socio-economic status) remains a challenge.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by Bioethics Committee of the Medical University of Gdansk (NKBBN/257/2017). The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

NL and MM conceived the project and analysed results. AW performed the statistical analysis. NL wrote the manuscript. MM, HK-D, NL, KS, AL, DR, JJ-J reviewed and edited the manuscript. MM supervised the project. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2023.1201689/full#supplementary-material

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The impact of having a free community eye clinic located inside a homeless shelter: a retrospective analysis of patient demographics

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Worsening vision is a life-altering process that affects individuals in many aspects of daily life. While worsening vision can be caused by normal physiological processes that occur with age, there can be underlying systemic or ocular diseases that may be the root cause. Routine eye exams can screen for disease as well determine the degree of vision correction required to attain acceptable vision. Access to an eye exam ordinarily requires vision insurance and one must consider the added expense of glasses if they are recommended. While this can be a life-improving visit for many, there are several socioeconomic barriers that discourage homeless and low-income individuals from being able to access this service. The lack of resources to access regular eye exams and the resulting inadequate eye care may lead to underdiagnosis of serious ocular pathology. The Kansas City Free Eye Clinic is located inside a homeless shelter and, therefore, provides a convenient location for homeless and low-income individuals to receive comprehensive eye exams as well as prescription glasses at no cost. In this paper, we discuss the unique setup and demographics of this student-run eye clinic and the ways in which it has served the Kansas City population and how its integration into a homeless shelter could serve as a role model for free community eye clinics.

KEYWORDS

eye care, free eye clinic, homeless shelter, student-run, urban health, vision correction, vision screening

1. Introduction

As the national rate of homelessness and poverty continues to grow, there has been a shift to emphasize the importance of medical resources for routine health maintenance. In the United States, an estimated 582,000 individuals are currently homeless (1). It is well established that homeless populations have an increased risk for infectious disease, dental problems, mental illness, chronic obstructive pulmonary disease, and cardiovascular disease (2). This therefore necessitates resources that offer free to low-cost health services to the vulnerable homeless population. In terms of eye care, this translates to regular eye exams to screen for refractive errors, ocular-specific pathologies, and ocular manifestations of systemic disease.

The American Academy of Ophthalmology recommends that a routine comprehensive eye exam is completed once every year for healthy individuals with no symptoms of vision problems starting at age 40 (3). For those individuals 60 or older, it is recommended to have a complete eye exam every year or more often if someone wears glasses or contact lenses, has a family history of eye disease or loss of vision, has a chronic disease that puts them at greater risk of eye disease, such as diabetes, or takes medications that have potential ocular side effects (3).

The cost of an eye exam can be an obstacle to routine eye care. A recent CDC survey illustrated that the most common reason (39.8%) for not seeking eye care among those with moderate-to-severe visual impairment was cost or lack of insurance (4). In the Midwest, the average cost of a complete eye exam is currently $39 at an optometrist office and $54 at ophthalmologist office (5). While routine eye exams are important, they are oftentimes not affordable to vulnerable populations. However, it is of utmost importance to receive proper care as poor visual acuity and several ocular conditions have a significant impact on an individual's well-being as well as earning potential (6). Among the homeless population, there are special considerations that necessitate greater eye care. Regarding ophthalmic patients in an inpatient setting, trauma-related diagnoses in the homeless population was greater compared with the general population at 38 percent and 23 percent, respectively (7). In an additional study, systemic disease was found to be more prevalent in homeless populations that presented to free clinics: self-reported diabetes (17.1%) was found to be significantly higher than that of the general population (7.5%), and fewer than one-third of diabetic participants had ever been evaluated by an ophthalmologist (8). In the same study, a wide variety of undiagnosed retinal pathologies were discovered by slit-lamp examination including diabetic retinopathy, retinal hypertension, epiretinal membrane, drusen, and nevus (8). Missing routine eye exams can lead to underdiagnosis of sight-threatening conditions that remain silent until later, more difficult to treat stages of such diseases (9).

Additionally, the race distribution of the national homeless population is quite different from the overall population. In the United States, African-Americans make up 13% of the overall population but 37% of the homeless population. Similarly, Latino-Americans make up 19% of the overall population but 24% of the homeless population (10). In terms of age, 75% of homeless individuals nationwide are 24 years of age or older (10). Notably, certain risk factors such as age and race can increase the need for an eye exam. According to the American Academy of Ophthalmology, African and Latino-Americans have a much higher risk of developing diabetic retinopathy, glaucoma and cataracts (11). Age is also a predisposing or contributing factor in diabetic retinopathy, glaucoma, cataracts, macular degeneration and should be taken into consideration for frequency of eye exams (12). Among those who cannot afford eye care, volunteer-based free clinics offer, therefore, a much-needed service.

National surveys have illustrated the importance of volunteer-based free clinics: according to patients, if their current free clinic did not exist, 24% would not seek care, 47% would attempt to seek care at another free clinic, and 23% would present to the emergency room (4). Free clinics appear to have the greatest impact on vulnerable populations. In another recent national survey among free clinics, 92.2% of patients were uninsured, 41.9% were homeless, and 39.3% were immigrants (13). While the free clinics target a variety of health conditions, among all national clinics, only 34.4% offered eye exams while only 11.1% offered eyeglasses (13). Due to the aforementioned reasons, there is a clear need for clinics that offer a combination of reliable, free to low-cost, routine eye care as well as glasses for those that cannot afford care.

Kansas City has not been immune to the national rise in homelessness; in fact, according to the Greater Kansas City Coalition to End Homelessness, there are an estimated 1,800 homeless individuals on the streets of Kansas City on a given night (14). The Kansas City Free Eye Clinic (KCFEC) serves as a resource to provide free eye exams as well as glasses at no cost to patients. Patients are able to be seen on a walk-in basis and are checked in by a team of trained volunteers who perform a basic eye evaluation including a peripheral vision test, ocular motility, pupillary reactions, visual acuity, autorefractor analysis, and intraocular pressure. The patient then receives a comprehensive dilated slit lamp exam by a board certified optometrist to screen for pathology as well as evaluate refractive error. If refractive error is present, patients are eligible to receive custom prescription eyeglasses and choose from a variety for frames, free of cost. The patients are fitted for lenses and are able to pick up their new eyeglasses in 1 to 2 weeks. At the time of receiving glasses, patients are able to evaluate their satisfaction with visual acuity and adjustments can be made as needed. The reliable location of the eye clinic provides ease when picking up glasses and assists in repairing or ordering new glasses if previous pairs are damaged. The clinic has also evolved to accommodate age-related vision change by offering free reading glasses, a service that has offered help to many individuals.

Location that allows for continuity of care is key for reaching vulnerable patient populations at free clinics (15). Continuity of care is associated with increased patient satisfaction, increased take-up of health promotion, greater adherence to medical advice and decreased use of hospital services (16). Currently, the majority of free clinics are located in hospitals and churches at 31.6 and 26.3%, respectively, while free clinics in homeless shelters represent a small minority (12). Only 10.5% of free clinics nationwide were reported to be located inside a homeless shelter (12). The KCFEC is unique because it is part of the minority of clinics located inside a homeless shelter along with the fact that it is part of an even smaller minority of free clinics that provides a combination of eye exams, eyeglasses, and a permanent location for consistency of care. The KCFEC is located in the Hope Faith Homeless Day Center, a shelter that provides services such as food, showers, clothing, laundry service, and case management. This convenient location allows individuals to receive a host of resources that address key social determinants of health in a timely and consistent manner. In addition to convenient location, the KCFEC is a venue for education as it allows students to gain valuable experience in patient care. The KCFEC is a student-run clinic that selects motivated students to provide care through community service, patient interviewing, and important visual testing. If students are selected after applying, they receive training by clinic staff and practicing optometrists to ensure that they are proficient in assessing pupil reactivity, ocular pressure, visual acuity, and autorefraction. In this paper, we describe the demographics of the KCFEC, services offered, and return rates of patients. In doing so, we aim to demonstrate the efficacy of the clinic setup and its ability to provide vulnerable populations with free eye care.

2. Methods

A retrospective chart review of patient data at the KC Free Eye Clinic from January 2017 to December 2021 was performed. Information including the age, gender, race, language, housing, education, employment, insurance status, government benefits, history of eye trauma, ocular diagnosis, referrals, return rates, impact of poor vision, and alternative to care at KCFEC were collected for each patient at every visit.

The services provided at the clinic were also tracked. Patients were de-identified and data was compiled into the Athenanet Electronic Medical Record. IRB approval was obtained from the University of Missouri- Kansas City IRB (protocol # 2093815) to use data for research purposes. Patient information was compiled into a table showing the age, gender, race, education level, housing type, referral source, employment status, insurance status, disability status, government benefits status, impact of poor vision, eye trauma, and help without KCFEC. The findings were presented in the form of a poster presentation at the (14) annual Society of Public Health Education meeting.

3. Results

The clinic demonstrated tremendous growth from 2017 to 2021. The overall number of eye appointments/ patient encounters, prescription glasses, and reading glasses increased (Figure 1). There was a notable increase from 2020 to 2021 in eye exams/patients encounters, prescription glasses given, and reading glasses given (Figure 1).

384 patient visits occurred in 2021 (Table 1). 2021 was chosen as a point in time analysis as it was the most recent year that data was available to the clinic. The data presented in Table 1 is based on the responses given at patient encounters.

Regarding patient demographics, the majority of patients seen at the KCFEC were between the ages of 46 and 60 (43.6%), male (66.6%), and African American (46.7%) (Table 1). The mean age of patients served at the clinic was 46.7 (Table 1).

Regarding socioeconomic status, the majority of patients were unemployed (70.7%), homeless or living in a homeless shelter (67.9%), uninsured (60%), reported using government benefits (65.7%), and completed a high school education (43.6%) (Table 1).

Regarding referrals, the majority of patients (82.7%) were referred to the KCFEC from the Hope Faith Homeless Shelter (Table 1). 49.6% of them stated that they would not receive ophthalmologic care if the KCFEC was not around, and 39.9% reported that they would try to find another free clinic (Table 1).

Regarding medical impact, around 1/5 patients presented with eye trauma (20.9%) (Table 1). Common complaints included difficulty reading (31.6%), anxiety about vision loss (22.2%), and difficulty driving (17.4%) (Table 1). Additionally, a variety of diagnoses were made that impacted future care for patients. Diagnoses included cataracts (27 patients), glaucoma (4 patients), and other various suspected diseases (15 patients) (Table 1).

Regarding continuity of care, the clinic also demonstrated good consistency of care as 102 patients returned to the clinic at least twice from 2017 to 2021. Patients returned up to 5 times between the years of 2017–2021 (Table 1).

4. Discussion

In the present study, we attempted to determine the demographics of the KCFEC and its role in serving the Kansas City population with consistent eye care.

A nationwide study (13) on all free clinics in 2010 sent a questionnaire to every national, regional and state free clinic to help highlight various features of free clinics. Free clinics were affiliated with a variety of locations including hospitals and churches at 31.6 and 26.3%, respectively, as well as universities, social service agencies, and medical schools/centers (13). Notably, homeless shelters represented the smallest minority in regards to affiliations at just 10.5%. Of all

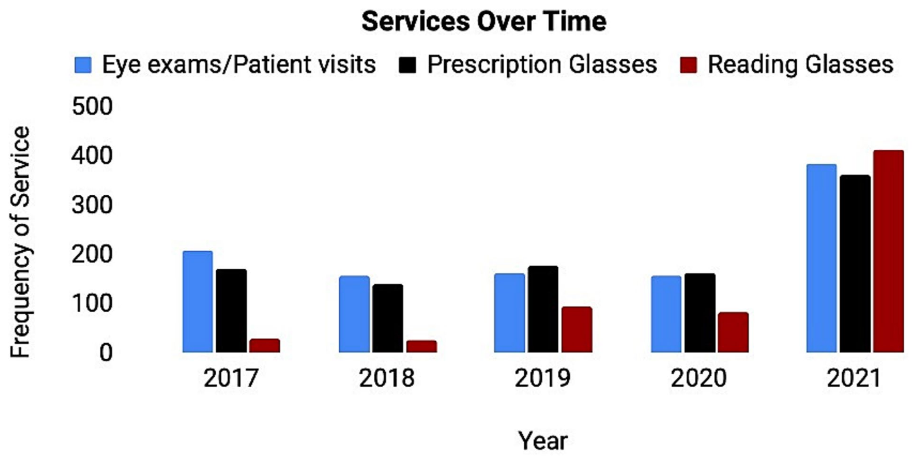

FIGURE 1
Services offered in the KCFEC from 2017 to 2021. Graphic representation of eye exams (blue), prescription glasses (red), and reading glasses (yellow) provided by KCFEC over time. The number of times the service was performed (y-axis) is shown for a given year (x-axis) between 2017 and 2021. Data was collected at each visit and summarized for each fiscal year. A notable increase in all services performed can be observed with the largest change being from 2020 to 2021.

TABLE 1 2021 Kansas City free eye clinic demographics[a].

Total number of patient visits	384
Gender	**Percentage of patients[b]**
Male	66.6 (255/384)
Female	33.4 (129/384)
Age	**Percentage of patients[b]**
0–20	3.6 (14/383)
21–45	38.1 (146/383)
46–60	43.6 (167/383)
61–75	13.1 (50/383)
75+	1.6 (6/383)
Race	**Percentage of patients[b]**
White	40.1 (121/302)
Black	46.7 (141/302)
Hispanic	10.9 (33/302)
Other	2.3 (7/302)
Housing type	**Percentage of patients[b]**
Homeless or shelter	67.9 (182/268)
Someone else's house	13.1 (35/268)
Own house	19 (51/268)
Referral source	**Percentage of patients[b]**
Hope Faith (i.e., at the same location)	82.7 (206/249)
Other center	5.7 (14/249)
Independent	11.6 (29/249)
Education	**Percentage of patients[b]**
Elementary	0.4 (1/266)
High school incomplete	18 (48/266)
High school complete	43.6 (116/266)
College incomplete	23.7 (63/266)
College complete	12 (32/266)
Masters/Grad school	2.3 (6/266)
Patient employment	**Percentage of patients[b]**
Full time	10.9 (29/266)
Part time	7.5 (20/266)
Unemployed	70.7 (188/266)
Unemployed-disability	7.5 (20/266)
Student	0.8 (2/266)
Retired	2.6 (7/266)
Insurance	**Percentage of patients[b]**
Uninsured	60 (159/265)
Medicaid	19.6 (52/265)
Medicare	5.7 (15/265)
Medicaid and medicare	7.2 (19/265)
Veterans	2.6 (7/265)
Private insurance	4.9 (13/265)

(Continued)

TABLE 1 (Continued)

Government benefits	Percentage of patients[b]
Yes	55.7 (146/285)
No	44.3 (116/285)
Impact of poor vision	**Percentage of patients[c]**
Difficulty to drive/use transportation	17.4 (106/608)
Difficulty reading	31.6 (192/608)
Held back at work/school	5.8 (35/608)
Worried about safety/belongings	11.2 (68/608)
Painful/irritated eyes	11.8 (72/608)
Vision is getting worse/worried about losing vision	22.2 (135/608)
Eye trauma	**Percentage of patients[b]**
Yes	20.9 (57/273)
No	79.1 (216/273)
Diagnoses	**Number of patients**
Diabetic retinopathy	3
Cataracts	27
Glaucoma/pre-glaucoma	4
Macular degeneration	1
other suspected disease	15
Help without KCFEC	**Percentage of patients[b]**
Would not get help	49.6 (133/268)
Would try to pay somewhere	7.5 (20/268)
Would visit ED	3 (8/268)
Would visit other free clinic	39.9 (107/268)
Return appointments from 2017–2021	**Number of patients**
2 visits	84
3 visits	14
4 visits	3
5 visits	1

[a]Demographics were self-reported by patients at each visit in the year 2021. Non-responders were excluded from analysis and percentages were calculated based on available responses.
[b]Patients/total responses.
[c]Patients were able to select multiple responses.

respondents, only 34.4% of clinics offered eye exams while only 11.1% offered eyeglasses (13).

Our analysis of the KCFEC allowed us to thoroughly investigate the underutilized affiliation of free clinics with homeless shelters. Currently, there is no literature describing the demographics of a free eye clinic affiliated with a homeless shelter to our knowledge. Our data illustrated that the clinic was able to address many vulnerable populations through its various services. The majority of presenting patients were homeless (67.9%) and uninsured (60%). Patients demonstrated a clear need for free eye care (Table 1). A majority of patients responded saying that without the clinic they would not have gotten care otherwise (49.6%) or would have attempted to get care at another free clinic (39.9%) (Table 1). This further highlights the importance of volunteer-based free clinics which are the only viable option for many homeless and uninsured patients to receive any eye care.

Referral source also seemed to be an important factor in how patients presented. The majority of the patients were referred from Hope Faith, the shelter in which the free eye clinic is located (82.7%) (Table 1). The easily accessible location of the clinic seemed to help disadvantaged patients return to the clinic at a tremendous rate. From 2017 to 2021, 102 patients returned to the clinic at least twice, with some patients returning up to 5 times for routine eye appointments (Table 1). There was also a large increase in the number of eye exams, prescription glasses provided, and reading glasses provided from 2020 to 2021 (Figure 1). This increased number potentially resulted from a variety of factors including but not limited to: resurgence of patients after the COVID-19 pandemic, increased volume of individuals at the homeless shelter, and better turnout due to good continuity and rapport with patients.

Providing free eye care is of the utmost importance (4). With such variability in how free clinics approach providing care, exploring differences in location, services offered, and continuity can potentially expose improved ways of reaching target populations. In this study, the demographics at our given clinic shed light on an underutilized location of free clinics: homeless shelters. With strategic location, the clinic was able to evaluate many underrepresented patients for refractive error and provide them with free glasses (Table 1). Additionally, many previously undetected pathologies were diagnosed, including cataracts, diabetes, macular degeneration, and glaucoma (Table 1).

We suggest this unique setup to others attempting to provide free eye care. Those seen at the shelter receive the most up to date information on the hours of operations, are able to establish strong connections with the staff and volunteers at the clinic and have a direct source of communication if there are any questions about their vision health or replacement glasses. As approaches to care evolve, the need for good eye care will continue to persist. When considering location to best serve all, homeless shelters should be taken into consideration for free clinics to establish rapport and provide good, quality care for vulnerable populations.

5. Limitations

The present study was a single-center study limited to Kansas City, Missouri during 2017 to 2021. Data was not complete for 2022 and thus not utilized. This limited our data to only 2017 to 2021 with 2021 being the most recent data available, and the year we focused our analysis on. During data collection, some patients elected to omit answers pertaining to the given questionnaire. For this purpose, percentages were used to quantify frequency of responses based on all respondents for a desired measure.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by UMKC IRB (protocol number 2093815). The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation was not required from the participants or the participants' legal guardians/next of kin in accordance with the national legislation and institutional requirements.

Author contributions

AA: Formal analysis, Resources, Supervision, Visualization, Writing – review & editing, Conceptualization, Data curation, Investigation, Methodology, Project administration, Validation, Writing – original draft. DM: Formal analysis, Resources, Supervision, Visualization, Writing – review & editing, Conceptualization, Data curation, Investigation, Methodology, Project administration, Validation, Writing – original draft. PK: Formal analysis, Resources, Supervision, Visualization, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The author(s) declared that they were an editorial board member of Frontiers, at the time of submission. This had no impact on the peer review process and the final decision.

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Cardiovascular disease and thinning of retinal nerve fiber layer in a multi-ethnic Asian population: the Singapore epidemiology of eye diseases study

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Introduction: Our study aimed to examine the relationship between cardiovascular diseases (CVD) with peripapillary retinal fiber layer (RNFL) and macular ganglion cell-inner plexiform layer (GCIPL) thickness profiles in a large multi-ethnic Asian population study.

Methods: 6,024 Asian subjects were analyzed in this study. All participants underwent standardized examinations, including spectral domain OCT imaging (Cirrus HD-OCT; Carl Zeiss Meditec). In total, 9,188 eyes were included for peripapillary RNFL analysis (2,417 Malays; 3,240 Indians; 3,531 Chinese), and 9,270 eyes (2,449 Malays, 3,271 Indians, 3,550 Chinese) for GCIPL analysis. History of CVD was defined as a self-reported clinical history of stroke, myocardial infarction, or angina. Multivariable linear regression models with generalized estimating equations were performed, adjusting for age, gender, ethnicity, diabetes, hypertension, hyperlipidaemia, chronic kidney disease, body mass index, current smoking status, and intraocular pressure.

Results: We observed a significant association between CVD history and thinner average RNFL (β = −1.63; 95% CI, −2.70 to −0.56; p = 0.003). This association was consistent for superior (β = −1.79, 95% CI, −3.48 to −0.10; p = 0.038) and inferior RNFL quadrant (β = −2.14, 95% CI, −3.96 to −0.32; p = 0.021). Of the CVD types, myocardial infarction particularly showed significant association with average (β = −1.75, 95% CI, −3.08 to −0.42; p = 0.010), superior (β = −2.22, 95% CI, −4.36 to −0.09; p = 0.041) and inferior (β = −2.42, 95% CI, −4.64 to −0.20; p = 0.033) RNFL thinning. Among ethnic groups, the association between CVD and average RNFL was particularly prominent in Indian eyes (β = −1.92, 95% CI, −3.52 to −0.33; p = 0.018). CVD was not significantly associated with average GCIPL thickness, albeit a consistent negative direction of association was observed (β = −0.22, 95% CI, −1.15 to 0.71; p = 0.641).

Discussion: In this large multi-ethnic Asian population study, we observed significant association between CVD history and RNFL thinning. This finding further validates the impact of impaired systemic circulation on RNFL thickness.

KEYWORDS

retinal nerve fiber layer, ganglion cell-inner plexiform, cardiovascular disease, Asian, optical coherence tomography

Introduction

Glaucoma and cardiovascular diseases are among the top global concerns, given the increasing prevalence of these conditions and the associated burdens they impose (1, 2). Glaucoma is one of the leading causes of irreversible blindness (2), and CVD is one of the leading causes of mortality (1). Glaucoma is characterized by optic disc excavation and retinal nerve fiber layer (RNFL) thinning (3). The vascular theory of glaucoma proposes that impaired systemic circulation could compromise blood supply to the optic nerve, leading to optic nerve damage (4). In this regard, cardiovascular disease (CVD) has been hypothesized to be associated with open angle glaucoma (4–6).

Clinically, onset and progression of glaucoma is monitored by peripapillary RNFL thickness evaluation, and measured by spectral domain optical coherence tomography (SD-OCT) (7–11). In recent years, ganglion cell-inner plexiform layer (GCIPL) thickness measurement has also emerged as a vital clinical evaluation tool for glaucoma.

Notably, previous studies have reported equivocal findings pertaining to the relationship between CVD and RNFL thinning (12–15). The Gutenberg Health Study (3,224 eyes) demonstrated univariate associations between RNFL thickness with coronary artery disease and myocardial infarction (MI), but failed to replicate this association in a multivariable analysis (15). On the other hand, another study observed reduced RNFL thickness in patients with chronic heart failure (14). Furthermore, there is a lack of detailed research on the association between history of CVD and GCIPL thickness. Additionally, previous studies have primarily focused on examining the associations between cardiovascular risk factors such as elevated blood pressure, hypertension, and higher body mass index (BMI) with GCIPL thickness (16–18). Hence, the association between CVD with RNFL and GCIPL remains unclear.

To gain a deeper understanding of this aspect, a comprehensive evaluation on the association between CKD with RNFL and GCIPL thickness is warranted. Hence, utilizing the extensive multi-ethnic population-based Asian dataset from the Singapore Eye Epidemiology of Eye Diseases (SEED) study, we aimed to examine the relationships between CVD with RNFL and GCIPL thickness profiles.

Materials and methods

Study population and recruitment

Study participants were enrolled from the SEED study, comprising of the three major ethnic groups in Singapore (Malays, Indians, and Chinese). Details of the recruitment and methodology of the studies have been published previously (19). In brief, study participants aged 40 to 80 years were randomly sampled from the southwestern part of Singapore, using a standardized protocol across the three ethnic groups. Data for the current study were derived from the 6-year follow-up visits for the Malay (2011–2013, $n = 1{,}901$, response rate: 72.1%), Indian (2013–2015, $n = 2{,}200$, response rate: 75.5%), and Chinese cohorts (2015–2017, $n = 2{,}661$, response rate: 87.7%).

Written informed consent was obtained from all study participants. All study procedures were conducted in accordance to the tenets of the Declaration of Helsinki, and ethics approval was obtained from the SingHealth Centralized Institutional Review Board.

Inclusion and exclusion criteria

Participants 40 years of age or older with complete SD-OCT data of RNFL and GCIPL thickness were included. Additionally, participants with relevant systemic, ocular, and lifestyle-related data such as the presence of hypertension, diabetes, hyperlipidemia, chronic kidney disease (CKD), CVD, smoking status, alcohol consumption and BMI were included. We excluded eyes with neurodegenerative diseases, and poor quality SD-OCT scans including poor signal strength (<6), segmentation errors, and ocular diseases affecting RNFL and GCIPL thickness.

Ocular and systemic measurements

All participants underwent standardized systemic and ophthalmic examinations at the Singapore Eye Research Institute. Visual acuity and subjective refraction were measured by research optometrists. Intraocular pressure (IOP) was measured using a Goldmann applanation tonometer (Haag-Streit, Bern, Switzerland). Additionally, gonioscopy and a 24–2 SITA Fast Humphrey visual field (Humphrey Field Analyzer II; Humphrey Instruments, San Leandro, CA) test were performed for glaucoma suspects and participants with known glaucoma cases (diagnosed based on the International Society for Geographical and Epidemiological Ophthalmology, ISGEO guidelines) prior to dilation. Fundus examination was performed after pupil dilation with tropicamide 1% and phenylephrine 2.5%.

A detailed interviewer-administered questionnaire was used to collect relevant sociodemographic information and participant information including medication use, systemic and ocular history, current smoking status, and alcohol intake. CVD was defined as a self-reported history of stroke, MI, and/or angina. Non-fasting venous blood samples were collected for biochemical testing. Diabetes was defined as a random serum glucose ≥11.1 mmol/L or serum glycated hemoglobin ≥ 6.5%, use of diabetic medication and/or self-reported medical history of diabetes. Hypertension (HTN) was defined as a systolic blood pressure (BP) ≥ 140 mmHg, diastolic BP ≥ 90 mmHg, the use of anti-hypertensive medications and/or a self-reported medical history of hypertension. CKD was defined as an estimated glomerular filtration rate (eGFR) < 60 mL/min/1.73 m^2. Hyperlipidemia was defined as total cholesterol ≥ 6.2 mmol/L, the

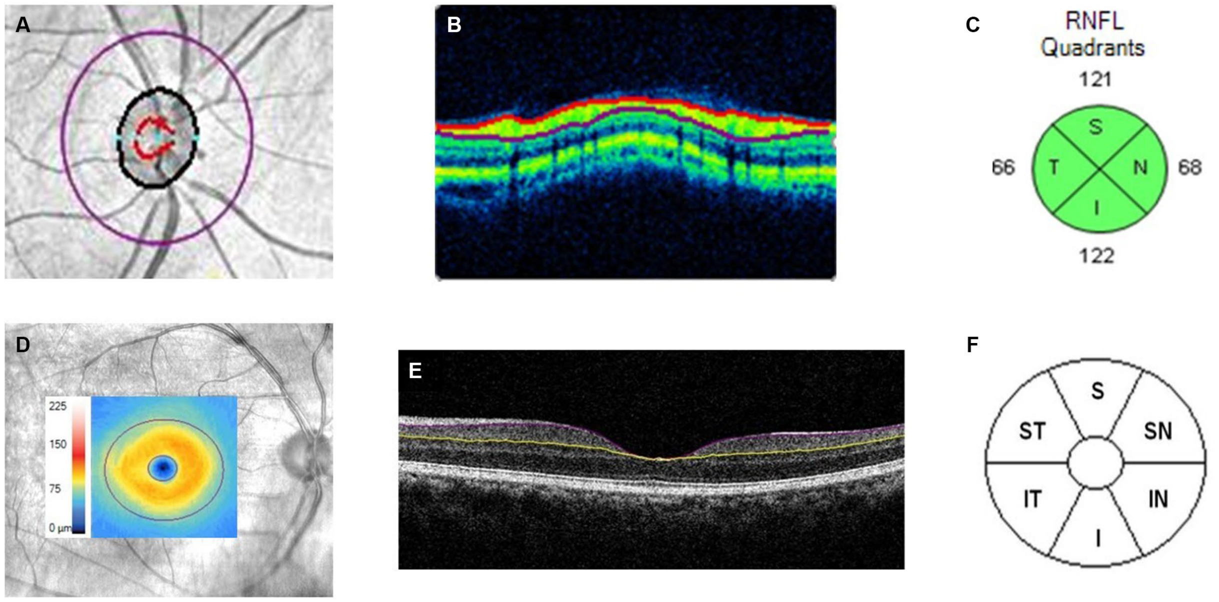

FIGURE 1
Cirrus HD-OCT images of the macular cube (512 × 128) and optic disc cube (200 × 200) scans of the right eye. **(A)** Fundus image of the optic nerve head with an overlay of the RNFL purple calculation circle. **(B)** Boundaries of RNFL segmentation (demarcated by the red and purple lines) extracted from the RNFL purple calculation circle. **(C)** Average thickness along RNFL purple calculation circle for superior (S), nasal (N), inferior (I), and temporal (T) quadrants. **(D)** Fundus image of the macula with an overlay showing a color-coded GCIPL thickness map within the 14.13 mm^2 elliptical annulus area, centered on the fovea; **(E)** Single horizontal B scan of the macula showing segmentation of the GCIPL (boundaries of layer demarcated by the purple and yellow lines); **(F)** Division of the macular region into superior (S), superior-nasal (SN), superior-temporal (ST), inferior (I), inferior-nasal (IN), and inferior-temporal (IT).

use of lipid-lowering drugs and/or self-reported history of hyperlipidemia. Each participant's weight was measured in kilograms using a digital scale, and height measured in centimeters using a wall-mounted measuring tape. BMI was calculated by the individual's weight in kilograms divided by their height in meters squared.

OCT imaging

For RNFL and GCIPL thickness measurements, OCT imaging was done after pupil dilation using Cirrus HD-OCT (Figure 1, Carl Zeiss Meditec, Dublin, CA). Optic disc scan was acquired using the optic disc cube 200 × 200 scan protocol, with a measurement area of 6 × 6 mm^2. The optic nerve head and RNFL algorithms native to the Cirrus HD-OCT were used to measure the average and quadrant-specific peripapillary RNFL thickness automatically. For GCIPL thickness measurement, GCIPL measurements were acquired using the macular cube 512 × 128 scan protocol. An automated ganglion cell analysis algorithm incorporated into the Cirrus HD-OCT software version 6.5 was used to measure the average and sectoral GCIPL thickness. Further details about the measurement algorithms have been previously reported (20). In brief, for RNFL measurements, the algorithm automatically identifies Bruch's membrane as the disc area, and the reference plane was determined 200 µm above the level of Bruch's membrane plane. Additionally, for GCIPL measurements, the algorithm measured GCIPL thickness within a 14.13 mm^2 elliptical annulus area that is centered on the fovea, and the posterior boundary of the RNFL and posterior boundary of the internal limiting membrane were automatically delineated by the ganglion cell analysis algorithm (21).

Statistical analysis

All statistical analyses were performed using STATA statistical software (Version 15: StataCorp LP, College Station, TX). For descriptive statistics, the mean and standard deviation were reported for continuous variables, while frequency and percentages were reported for categorical variables. Associations between CVD with peripapillary RNFL and macular GCIPL parameters were examined using multivariable linear regression models with generalized estimating equation model to account for correlation between paired eyes of each subject. The models were adjusted for age, gender ethnicity, diabetes, hypertension, hyperlipidaemia, CKD, BMI, current smoking status, and IOP based on the rationale of potential confounders for RNFL and GCIPL thickness (13, 21, 22). *p*-value for significance was set at <0.05.

Results

Of the total 6,762 participants, 6,024 participants (11,598 eyes) had OCT scans done. After the exclusion of poor quality scans and retinal diseases which affect RNFL and GCIPL thickness, 9,188 eyes (2,417 Malays, 3,240 Indians, and 3,531 Chinese) were included for final peripapillary RNFL analysis and 9,270 eyes (2,449 Malays, 3,271 Indians, and 3,550 Chinese) for GCIPL analysis (Figure 2).

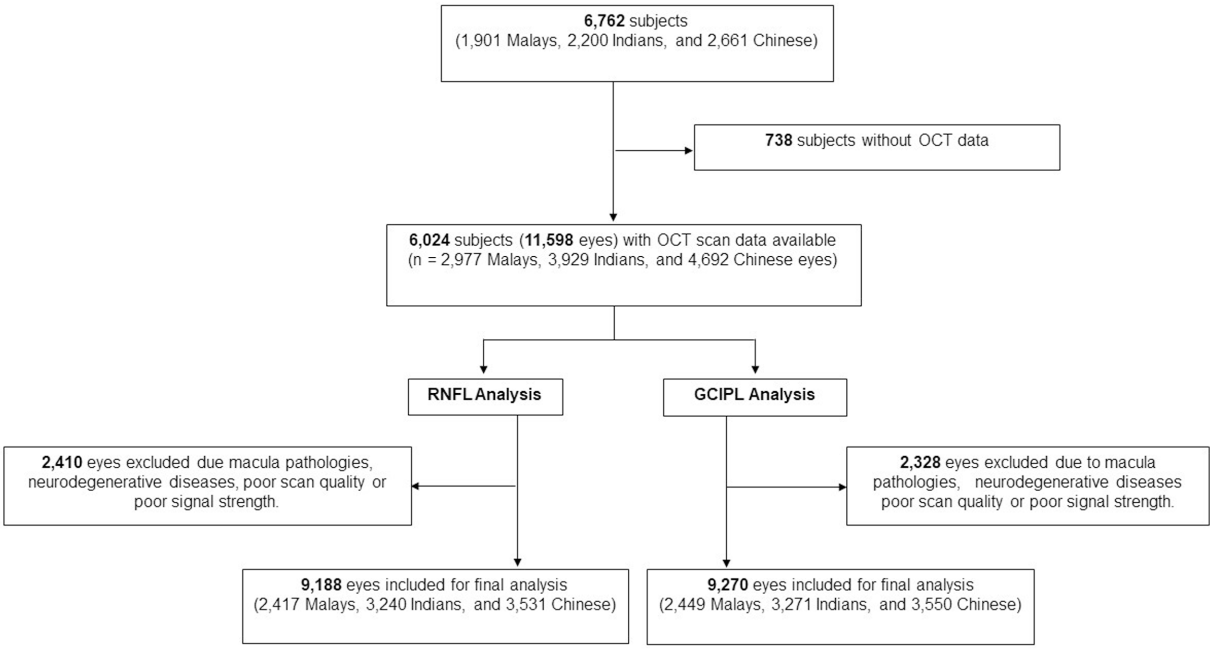

FIGURE 2
Flow chart of included participants.

The mean age of participants was 61.5 ± 8.5 years, and of them 51.8% were females (Table 1). The proportions of participants with systemic comorbidities were as follows: 28.2% of the participants had diabetes mellitus; 65.6% of the participants had hypertension; 8.8% of the participants had chronic kidney disease; and 8.8% of patients had CVD—of which, 2.0% had a stroke (27 Malays, 44 Indians, 34 Chinese), 5.3% had MI (80 Malays, 144 Indians, 54 Chinese), and 2.6% had angina (18 Malays, 90 Indians, 29 Chinese; Table 1).

After adjusting for age, gender, ethnicity, diabetes, hypertension, hyperlipidaemia, CKD, BMI, current smoking status, and IOP, we observed that a positive history of CVD was significantly associated with thinner average peripapillary RNFL (β = −1.63; 95% CI, −2.70 to −0.56; p = 0.003; Table 2). This association was consistent for superior (β = −1.79; 95% CI, −3.48 to −0.10; p = 0.038), inferior (β = −2.14; 95% CI, −3.96 to −0.32; p = 0.021), temporal (β = −1.39; 95% CI, −2.43 to −0.34; p = 0.013) and nasal (β = −1.12; 95% CI, −2.21 to −0.04; p = 0.043) quadrants (Table 2). Of the CVD types, a history of MI was observed to be particularly associated with thinner average RNFL (β = −1.75; 95% CI, −3.08 to −0.42; p = 0.010). This association was also consistently observed for superior (β = −2.22; 95% CI, −4.36 to −0.09; p = 0.041) and inferior RNFL quadrants (β = −2.42; 95% CI, −4.64 to −0.20; p = 0.033; Table 2).

Table 3 shows the association between CVD and GCIPL thickness. After adjusting for age, gender, ethnicity, diabetes, hypertension, hyperlipidaemia, CKD, BMI, current smoking status, and IOP, no significant associations were observed, albeit a consistent negative direction of association was observed (β = −0.59; 95% CI, −1.33 to 0.15; p = 0.118). The non-significant association was also consistently observed for both superior and inferior hemispheres of GCIPL thickness (all $p \geq 0.066$).

The association between CVD with average RNFL and GCIPL thickness by ethnicity are described in Table 4. After adjusting for age, gender, ethnicity, diabetes, hypertension, hyperlipidaemia, CKD, BMI, current smoking status, and IOP, CVD was associated with RNFL thinning in Indian eyes (β = −1.92; 95% CI, −3.52 to −0.33; p = 0.018). Additionally, among CVD subtypes, a history of MI was also associated with RNFL thinning in Indian eyes (β = −2.62; 95% CI, −4.55 to −0.69; p = 0.008). After adjusting for the same covariates, CVD showed a consistent lack of significant associated with GCIPL thinning across all ethnicities (all $p \geq 0.052$).

We further performed subgroup analyses on the association between CVD with RNFL and GCIPL thickness, excluding eyes with a diagnosis of glaucoma (Supplementary Tables 1, 2, respectively). After adjusting for age, gender, ethnicity, diabetes, hypertension, hyperlipidaemia, CKD, BMI, current smoking status, and IOP, we consistently observed that a positive history of CVD was significantly associated with thinner average (β = −1.44; 95% CI, −2.49 to −0.39; p = 0.007) and inferior quadrant peripapillary RNFL (β = −1.79; 95% CI, −3.56 to −0.01; p = 0.049). Additionally, among the different CVD subtypes, a history of MI was also significantly associated with average RNFL thinning (β = −1.67; 95% CI, −2.99 to −0.35; p = 0.013). Furthermore, after adjusting for the same covariates, CVD consistently demonstrated no significant association with GCIPL thinning in normal eyes (Supplementary Table 2).

Discussion

In this large study of 6,762 multi-ethnic Asian participants, we observed a significant association between a history of CVD and RNFL thinning. This association remained significant after excluding eyes with a glaucoma diagnosis. The association of CVD with GCIPL

TABLE 1 Characteristics of included participants.

Baseline characteristics	Mean (SD) or *n* (%)
Age, years	61.5 (±8.5)
Gender, female, *n* (%)	2,702 (51.8)
Current smoking, yes, *n* (%)	723 (13.9)
Alcohol consumption, yes *n* (%)	454 (8.8)
Diabetes mellitus, *n* (%)	1,470 (28.2)
HbA1c, %	6.1 (±1.2)
Random blood glucose, mmol/L	6.8 (±3.2)
Hypertension, *n* (%)	3,408 (65.6)
Systolic blood pressure, mmHg	137.5 (±19.5)
Diastolic blood pressure, mmHg	76.6 (±9.9)
Body mass index (BMI), kg/m^2	25.5 (±4.6)
BMI categories, n (%)	
Underweight (BMI ≤ 18.5)	186 (3.6)
Normal (18.5 ≤ BMI ≤ 25)	2,426 (46.6)
Overweight (25 ≤ BMI ≤ 30)	1,836 (35.3)
Obese (30 ≥ BMI)	755 (14.5)
Total cholesterol, mmol/L	5.4 (±1.2)
High density lipoprotein cholesterol, mmol/L	1.3 (±0.3)
History of cardiovascular disease, *n* (%)	456 (8.8)
History of stroke, *n* (%)	105 (2.0)
History of myocardial infarction, *n* (%)	277 (5.3)
History of angina, *n* (%)	136 (2.6)
Chronic kidney disease, *n* (%)	435 (8.8)
Intraocular pressure, mmHg	14.8 (±2.9)
RNFL thickness, μm	91.3 (±11.4)
GCIPL thickness, μm	79.7 (±7.2)

RNFL, retinal nerve fiber layer; GCIPL, ganglion cell-inner plexiform layer. Data presented are mean (standard deviation) or frequency (proportion) variables.

was not significant albeit a consistent negative direction of association was observed. To the best of our knowledge, our study is the largest multi-ethnic Asian study in evaluating the associations between CVD with RNFL and GCIPL thickness profiles. Our findings further support the notion that systemic circulation is associated with RNFL thinning, indicating that a history of CVD may be taken into account when evaluating the risk of glaucoma.

Previous studies, which evaluated the association between CVD and RNFL thinning have reported non-conclusive findings (12, 13, 15, 23). While the Gutenberg Health Study reported no significant association between RNFL thickness and a history of coronary artery disease, MI, or stroke (15), the Asian Eye Epidemiology Consortium and European Eye Epidemiology Consortium observed that RNFL was 0.94 and 2.06 μm thinner in subjects with a history of CVD and stroke, respectively (13, 23). The latter two studies were consistent with our findings, which demonstrated an average decrease in RNFL thickness of 1.62 μm among participants with a history of CVD. This may be explained by microvascular ischemia commonly observed in participants with CVD (4), thereby further highlighting the relevance of CVD on RNFL thinning, which should be considered by clinicians when detecting and monitoring glaucoma.

Across ethnic groups in our study, we observed that the association between CVD and RNFL thinning was particularly prominent in Indian eyes, with an average RNFL decrease of 1.92 μm. This observation may, in part, be due to the fact that Indians have thinner RNFL profiles compared to Malay and Chinese populations (13, 22). The inherently thinner RNFL profile in Indian eyes could potentially make them more vulnerable to the adverse effects of reduced systemic circulation caused by CVD.

Following stratification for the types of CVD (stroke, MI, angina), we observed a significant association between MI and RNFL thinning. This may be partly explained by the systemic impacts of

TABLE 2 Association between cardiovascular disease and peripapillary retinal nerve fiber layer thickness.

		Peripapillary RNFL thickness (μm)*									
		Average		Superior quadrant		Inferior quadrant		Temporal quadrant		Nasal quadrant	
	Number of eyes	Beta (95% CI)	*p*-value	Beta (95% CI)	*p*-value	Beta (95% CI)	*p*-value	Beta (95% CI)	*p*-value	Beta (95% CI)	*p*-value
No CVD	8,421	Ref		Ref		Ref		Ref		Ref	
Presence of CVD	767	−1.63 (−2.70 to −0.56)	**0.003**	−1.79 (−3.48 to −0.10)	**0.038**	−2.14 (−3.96 to −0.32)	**0.021**	−1.39 (−2.43 to −0.34)	**0.010**	−1.12 (−2.21 to −0.04)	0.043
Subtypes:											
Stroke	171	−1.37 (−3.38 to 0.63)	0.180	−0.97 (−4.09 to 2.14)	0.539	−2.33 (−5.95 to 1.30)	0.208	−1.61 (−3.75 to 0.53)	0.140	−0.44 (−2.43 to 1.54)	0.661
Myocardial infarction	465	−1.75 (−3.08 to −0.42)	**0.010**	−2.22 (−4.36 to −0.09)	**0.041**	−2.42 (−4.64 to −0.20)	**0.033**	−1.12 (−2.42 to 0.17)	0.090	−1.09 (−2.47 to 0.29)	0.120
Angina	230	−0.93 (−2.85 to 1.00)	0.345	−0.85 (−3.80 to 2.11)	0.575	−0.25 (−3.38 to 2.88)	0.877	−1.35 (−3.17 to 0.46)	0.144	−1.17 (−3.09 to 0.75)	0.232

CVD, cardiovascular disease; RNFL, retinal nerve fiber layer. *Model adjusted for age, gender, ethnicity, diabetes, hypertension, hyperlipidaemia, chronic kidney disease, body mass index, current smoking status, and intraocular pressure. Bold values indicate results that are statistically significant.

TABLE 3 Association between cardiovascular disease and macular ganglion cell inner plexiform layer thickness.

		Macular GCIPL thickness (μm)*					
		Average		Superior hemisphere		Inferior hemisphere	
	Number of eyes	Beta (95% CI)	*p*-value	Beta (95% CI)	*p*-value	Beta (95% CI)	*p*-value
No CVD	8,492	Ref		Ref		Ref	
Presence of CVD	778	−0.59 (−1.33 to 0.15)	0.118	−0.59 (−1.34 to 0.16)	0.124	−0.46 (−1.23 to 0.30)	0.237
Subtypes:							
Stroke	171	−1.34 (−2.83 to 0.14)	0.076	−1.42 (−2.94 to 0.10)	0.066	−1.19 (−2.73 to 0.35)	0.131
Myocardial infarction	475	−0.22 (−1.15 to 0.71)	0.641	−0.13 (−1.08 to 0.81)	0.786	−0.14 (−1.10 to 0.82)	0.774
Angina	233	−0.52 (−1.87 to 0.83)	0.450	−0.75 (−2.09 to 0.60)	0.278	−0.28 (−1.68 to 1.13)	0.700

CVD, cardiovascular disease; GCIPL, ganglion cell-inner plexiform layer. *Model adjusted for age, gender, ethnicity, diabetes, hypertension, hyperlipidaemia, chronic kidney disease, body mass index, current smoking status, and intraocular pressure.

TABLE 4 Association between cardiovascular disease with average peripapillary retinal nerve fiber layer and ganglion cell-inner plexiform layer thickness by ethnicity.

		Average RNFL (μm)*			Average GCIPL (μm)*	
	Number of eyes	Beta (95% CI)	*p*-value	Number of eyes	Beta (95% CI)	*p*-value
Malay:						
No CVD	2,223	Ref		2,249	Ref	
Presence of CVD	194	−1.31 (−3.09 to 0.48)	0.152	200	−0.26 (−1.42 to 0.90)	0.662
Subtypes						
Stroke	39	−1.37 (−4.55 to 1.81)	0.399	39	−1.13 (−3.48 to 1.22)	0.345
MI	137	−0.48 (−2.53 to 1.58)	0.649	143	0.01 (−1.33 to 1.36)	0.983
Angina	29	−4.25 (−9.27 to 0.77)	0.097	29	−0.04 (−3.14 to 3.06)	0.979
Indian:						
No CVD	2,838	Ref		2,865	Ref	
Presence of CVD	402	−1.92 (−3.52 to −0.33)	0.018	406	−0.88 (−1.99 to 0.23)	0.119
Subtypes						
Stroke	78	−1.43 (−4.80 to 1.95)	0.408	78	−2.46 (−4.94 to 0.03)	0.052
MI	246	−2.62 (−4.55 to −0.69)	0.008	249	−0.47 (−1.88 to 0.93)	0.510
Angina	154	−0.24 (−2.67 to 2.19)	0.846	157	−0.32 (−1.91 to 1.28)	0.696
Chinese:						
No CVD	3,360	Red		3,378	Red	
Presence of CVD	171	−1.62 (−3.89 to 0.65)	0.163	172	−0.26 (−1.93 to 1.41)	0.758
Subtypes						
Stroke	54	−1.29 (−4.95 to 2.38)	0.492	54	0.10 (−2.57 to 2.77)	0.942
MI	82	−1.69 (−5.14 to 1.76)	0.337	83	0.30 (−1.94 to 2.54)	0.793
Angina	47	−1.35 (−5.10 to 2.41)	0.482	47	−1.60 (−5.15 to 1.94)	0.376

CVD, cardiovascular disease; GCIPL, ganglion cell-inner plexiform layer; MI, myocardial infarction; RNFL, retinal nerve fiber layer. Model adjusted for age, gender, diabetes, hypertension, hyperlipidaemia, chronic kidney disease, body mass index, current smoking status, and intraocular pressure.

MI. MI results in ischaemic damage to the cardiac tissue, compromising cardiac ejection function and hence resulting in poorer perfusion of the optic nerve head and peripapillary region. On the other hand, the lack of association between stroke and angina with RNFL thinning in our study may potentially be due to the comparatively smaller sample size in the subgroups of stroke and angina (171 eyes with stroke and 230 eyes with angina, compared to 465 eyes with MI).

Coronary diseases and stroke are macrovascular processes associated with a limitation of blood supply to the heart or brain while retinal and retinal vasculature changes are microvascular processes (24). In macrovascular disease, the disease process is mainly due to atherosclerosis and atheroma formation (25). On the other hand, the disease process in microvascular disease involves multiple abnormalities in structure and function of the small vessels including reduced nitric oxide availability, reduced arteriolar diameter, and increased wall-to-lumen ratio of small arteries (24). Taken together, it is plausible that there are structural differences in the vasculature structures in the brain and heart, vs. the retina. However, the macrovasculature and microvasculature are an interconnected continuum, and changes in the macrovasculature circulation impacts the microvasculature circulation due to changes in blood delivery pace and flow. Nevertheless, among the CVD subtypes, we only observed a significant association between MI and RNFL thinning. To further elucidate the pathophysiological links between CVD subtypes and RNFL thinning, future studies utilizing OCT-angiography parameters or other CVD related biomarkers are warranted.

Contrary to our findings for RNFL thickness, a history of CVD showed no significant association with GCIPL thinning. We postulate that this may be due to the differential main blood supply of both layers. The RNFL layer receives its main vascular supply from the radial peripapillary capillary plexus, while the GCIPL is mainly perfused by the superficial vascular plexus (26). Given the difference in vascular supply, RNFL and GCIPL may also be differentially impacted by systemic circulatory changes, thus partially explaining the difference in association observed in this study.

The strengths of our study include a large sample size consisting of the three main ethnic groups (Malays, Indians, and Chinese) in Asia. Our comprehensive study protocol enabled us to consider an extensive list of potential confounding factors in our analysis. However, our study also has a few limitations. First, CVD status was based on participant's self-reported history of MI, angina, or stroke. Nevertheless, as previous occurrence of a MI, angina, or stroke are likely to have been significant clinical events, self-reported error was less likely in this regard. Second, as our study is a cross-sectional study, we are unable to infer causality on the observed associations. A further longitudinal study would help to validate on the causal association between CVD and RNFL thinning.

In conclusion, we observed significant association between CVD and RNFL thinning in a large multi-ethnic Asian population. This association remained consistently significant even after excluding eyes with a diagnosis of glaucoma.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, provided data access policy and ethics requirements are fulfilled.

Ethics statement

The studies involving humans were approved by SingHealth Centralized Institutional Review Board. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

SM, DQ, C-YC, and Y-CT conceived and designed the study. SM, DQ, MC, ZL, SN, Z-DS, ST, TR, and CS analyzed and interpreted the data. DQ, SM, MC, ZL, C-YC, and Y-CT wrote the manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmed.2023.1235309/full#supplementary-material

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Reduction of retinal vessel density in non-exudative macular neovascularization: a retrospective study

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Purpose: The purpose of this study is to identify predictive activation biomarkers in retinal microvascular characteristics of non-exudative macular neovascularization (MNV) and avoid delayed treatment or overtreatment of subclinical MNV. The main objective is to contribute to the international debate on a new understanding of the role of retinal vessel features in the pathogenesis and progression of non-exudative MNV and age-related macular degeneration (AMD). A discussion on revising-related clinical protocols is presented.

Methods: In this retrospective study, the authors included eyes with non-exudative MNV, eyes with exudative AMD, and normal eyes of age-matched healthy subjects. The parameters were obtained by optical coherence tomography (OCT) and optical coherence tomography angiography (OCTA).

Results: In total, 21 eyes with exudative AMD, 21 eyes with non-exudative MNV, and 20 eyes of 20 age-matched healthy subjects without retinal pathology were included. Vessel density (VD) of the deep vascular complex (DVC) in eyes with non-exudative MNV was significantly greater than that in eyes with exudative AMD ($p = 0.002$), while for superficial vascular plexus (SVP) metrics, no VD differences among sectors were observed between eyes with non-exudative MNV and eyes with exudative AMD.

Conclusion: The reduction in retinal vessel density, especially in the DVC, seems to be involved in or be accompanied by non-exudative MNV activation and should be closely monitored during follow-up visits in order to ensure prompt anti-angiogenic therapy. A discussion on applicable clinical protocols is presented aiming to contribute to new insights into ophthalmology service development which is directed to this specific type of patient and diagnosis.

KEYWORDS

retinal image, non-exudative macular neovascularization, retinal blood flow, age-related macular degeneration, optical coherence tomography

Introduction

Age-related macular degeneration (AMD) is the most common cause of visual impairment in industrialized countries (1–3). Macular neovascularization (MNV), the main characteristic of exudative AMD, leads to exudation, hemorrhage, and fibrosis formation and results in retinal damage and vision loss (1). João R. de Oliveira Dias et al. detected subclinical non-exudative MNV in 14.4% of non-exudative AMD eyes on OCT angiography (OCTA) among 160 patients with exudative AMD in one eye and non-exudative AMD in the fellow eye (4). It is known that the risk of developing exudation in eyes with non-exudative MNV was reported to be nearly 10 times higher than in eyes without these lesions (5). However, despite the higher risk of exudation, most experts recommended that prophylactic treatment before the exudation of non-exudative MNV should be avoided (6). Moreover, it has been suggested in protocols to preserve the potential protective and nutritional role of MNVs for the outer retina (7–9). Hence, to avoid delayed treatment or overtreatment, it is of great importance to find out the characteristics of non-exudative MNV that could serve as predictors of near-future exudation.

Some studies have tried to identify predictive activation biomarkers of subclinical non-exudative MNV, such as its size, shape, and growth rate (5, 10–12). However, to the best of our knowledge, there has not yet been any published study concerning retinal microvascular characteristics of non-exudative MNV on the risk of exudation.

In this study, we compared retinal vessel density and FAZ in non-exudative MNV and exudative AMD using OCTA to detect whether there is any difference in retinal blood flow between them and identify predictive activation biomarkers in retinal microvascular characteristics of non-exudative MNV, so as to ensure prompt anti-angiogenic therapy. This approach adds a new perspective on the role of retinal vessel density in the pathogenesis and progression of nonexudative MNV and AMD.

Methods

In this retrospective study, we reviewed the charts of patients affected by treatment-naïve non-exudative MNV in AMD and exudative AMD who presented to the Affiliated Eye Hospital of Nanjing Medical University in China between April 2020 and December 2021.

The records were reviewed meticulously, including fluorescein angiography (FA), indocyanine green angiography (ICGA), and structural spectral-domain OCT (Heidelberg Engineering, Heidelberg, Germany). Two masked retinal specialists (YG and SZ) classified MNVs into three subtypes (1, 2, or 3) and determined the MNV activity status (exudative vs. non-exudative).

We excluded eyes with polypoidal choroidal vasculopathy (PCV), eyes with previous treatments, and eyes with any disease potentially affecting the image interpretation. Patients who had diabetes mellitus, high myopia, and uveitis were excluded.

Image acquisition protocol for OCTA

A 3 mm × 3 mm OCTA macular scan was obtained using the Optovue RTVue XR Avanti with the software AngioVue OCTA (Optovue Inc., Fremont, California, United states). The software also included an artifact removal function. Images were analyzed with automated projection artifact removal. Images with weak signals (signal strength index <60) or an OCTA motion artifact score of 4 were excluded.

The image analysis of the superficial vascular plexus (SVP) and deep vascular complex (DVC) was performed with AngioAnalyticTM software. The SVP starts from the inner limiting membrane (ILM) and ends at 9 μm above the junction between the inner plexiform layer and the inner nuclear layer (IPL–INL), while the DVC comprises the section between 9 μm above the IPL–INL junction and 9 μm below the outer plexiform layer and outer nuclear layer (OPL–ONL) junction (13). Potential artifacts and segmentation errors due to the distortion of the retina were carefully inspected in each layer. The segmentation errors were manually corrected by an expert (GS) when there was intraretinal fluid in nAMD. The FAZ area, perimeter, and FD-300 were obtained with the software automatically. FD-300 shows the vessel density starting from ILM and ending at 9 μm below the OPL–ONL junction in a 300 μm wide region around FAZ.

Manual correction for the segmentation error was required in approximately half of the eyes. The correction was performed by a senior ophthalmologic resident (WHH) and confirmed by a retinal specialist (LY).

Statistical analysis

Statistical analyses were conducted using SPSS software (IBM Corp., NY, United states; version 26.0). Continuous variables were described as mean ± standard deviation. All best corrected visual acuities (BCVAs) were converted to logarithms of the minimal angle of resolution (logMAR) before data analyses. Student's *t*-test and one-way analysis of variance (ANOVA) were conducted for continuous variables among and between different groups after normal distribution confirmation using the Kolmogorov–Smirnov test. The Kruskal–Wallis tests were used for non-normally distributed data. Fisher's exact tests were used for categorical variables. The Kendall tau correlation coefficient was used to examine the correlations between the OCTA parameters and different groups. A p-value of <0.05 was considered statistically significant.

Results

In total, 42 eyes of 41 patients were included in this study. The mean age was 66.0 ± 7.3 years, and most patients (71.4%) were male. There were 21 eyes with exudative AMD and 21 eyes with non-exudative MNV. There were 16 eyes with type 1 MNV, 4 eyes with type 2 MNV, and 1 eye with type 3 MNV in exudative AMD eyes. In total, 20 eyes of 20 age-matched healthy subjects without retinal pathology were included as normal controls. All the subjects were Chinese and treatment naïve. Visual acuity in eyes with non-exudative MNV was superior to those with exudative AMD (logMAR BCVA 0.34 ± 0.20 vs. 0.81 ± 0.14, $p < 0.001$). There were no significant differences in age, sex, refractive error, axial length, lens status, or IOP between eyes with exudative AMD and eyes with non-exudative MNV and normal controls (Table 1).

For SVP metrics, no VD differences among sectors were observed between eyes with non-exudative MNV and exudative AMD. VD of the SVP was lower in eyes with non-exudative MNV and exudative AMD compared with normal eyes (all $p < 0.001$). Conversely, VD of the DVC in eyes with non-exudative MNV was significantly greater than that in eyes with exudative AMD ($p = 0.002$). VD of the DVC in eyes with non-exudative MNV was significantly lower than that in normal eyes ($p = 0.006$) (Figures 1, 2 and Table 2).

For the FAZ area, there was no significant difference between eyes with exudative AMD and non-exudative MNV. The FAZ area was significantly larger in eyes with exudative AMD compared with normal eyes ($p = 0.008$). It was also larger in eyes with non-exudative MNV than in normal eyes, although without statistical significance ($p = 0.075$). The FAZ perimeter was smaller in normal eyes than that in non-exudative MNV and exudative AMD eyes. There was no significant difference in perimeter between eyes with non-exudative MNV and eyes with exudative AMD. Regarding FD-300, there was no significant difference between eyes with non-exudative MNV and eyes with exudative AMD. FD-300 was lower in eyes with non-exudative MNV and exudative AMD than in normal eyes (all $p = 0.001$) (Figures 1, 2 and Table 2).

In Kendall tau correlation coefficient analysis, we observed significant correlations between different groups and OCTA parameters. Retinal vessel density measured in FD-300, SVP, and DVC decreased significantly from normal eyes to eyes with non-exudative MNV and then to eyes with exudative AMD (all $p < 0.001$). The FAZ area and perimeter showed a significant increase from normal eyes to eyes with non-exudative MNV and then to eyes with exudative AMD (FAZ area: $p = 0.016$, perimeter: $p = 0.003$) (Table 2).

TABLE 1 Demographic and clinical characteristics.

	Exudative AMD	Non-exudative MNV	Controls	p-value
Eyes, *n*	21	21	20	
Age (mean ± SD)	67.8 ± 6.3	64.2 ± 8.0	65.8 ± 6.7	0.368[a]
Sex (male)	75.0%	66.6%	70.0%	0.938[b]
BCVA (logMAR)	0.81 ± 0.14	0.34 ± 0.20	0.04 ± 0.05	<0.013[a]
Rx (diopters)	+0.30 ± 0.87	+0.14 ± 0.89	−0.07 ± 0.83	0.668[a]
AL (axial length)	23.21 ± 1.08	24.43 ± 0.99	23.42 ± 1.18	0.663[a]
Lens (phakic)	47.6%	61.9%	40.0%	0.395[b]
IOP (mmHg)	13.8 ± 2.7	14.9 ± 2.7	15.5 ± 2.8	0.587[a]

AMD, age-related macular degeneration; SD, standard deviation; BCVA, best-corrected visual acuity; Rx, refractive error; AL, axial length; IOP, intraocular pressure. [a]Kruskal–Wallis test.
[b]Fisher's exact test.

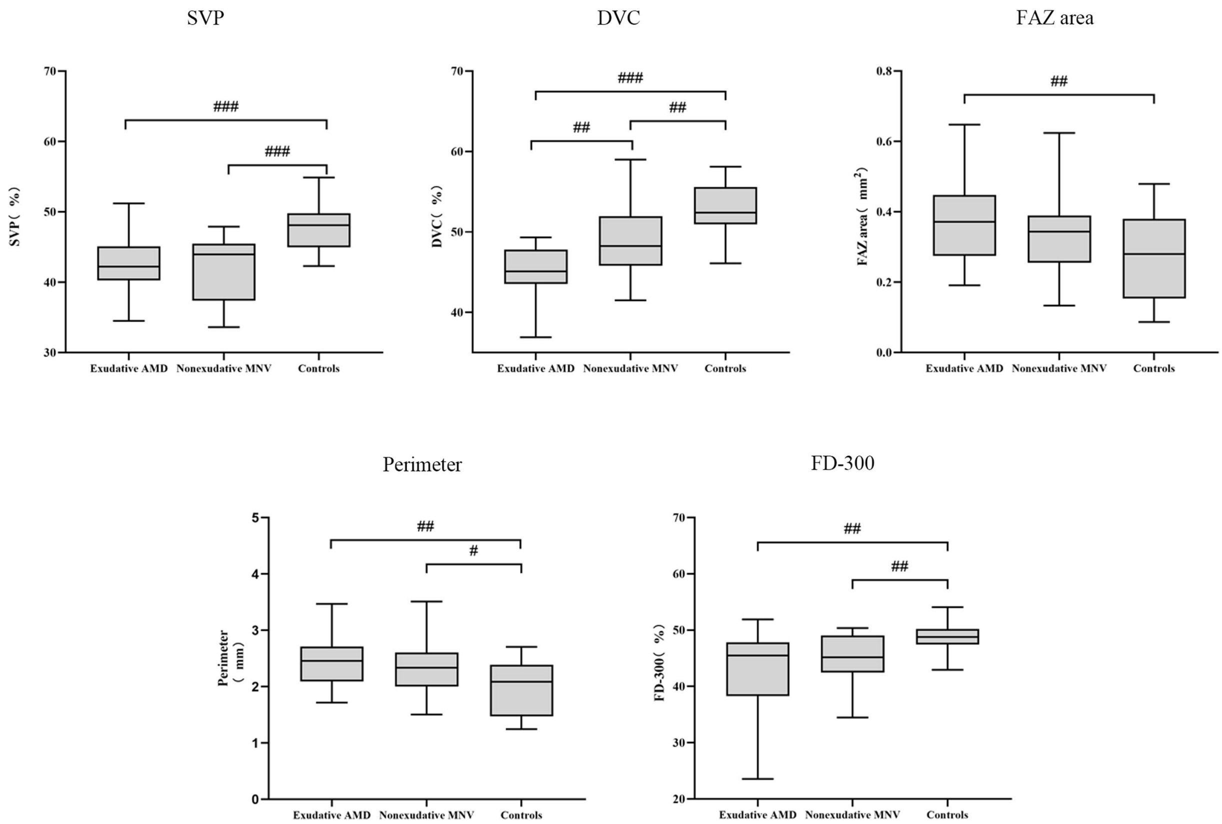

FIGURE 1
Box plot showing retinal vascular indexes in exudative AMD patients, non-exudative MNV patients, and healthy controls. #, $p < 0.05$; ##, $p < 0.01$; and ###, $p < 0.001$.

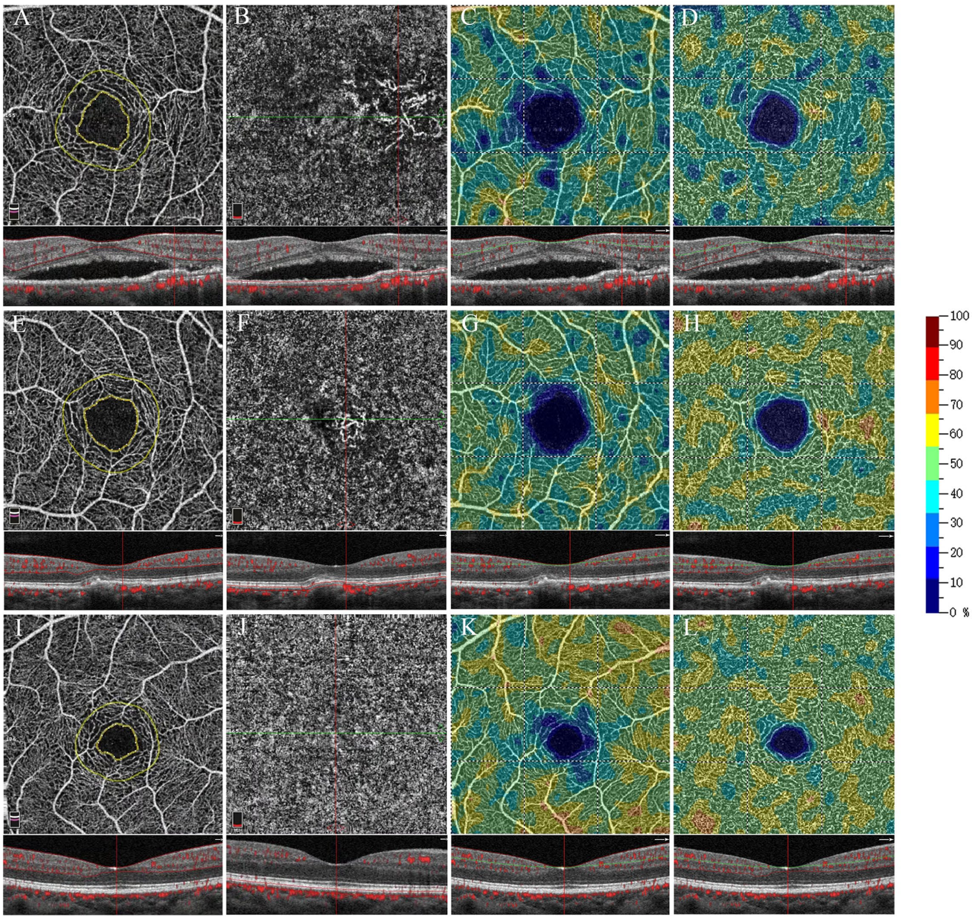

FIGURE 2
Optical coherence tomography angiography 3 × 3 mm scan of exudative AMD eyes **(A–D)**, non-exudative MNV eyes **(E–H)**, and healthy eyes **(I–L)**. The OCTA map shows the contour (inner yellow ring) of the FAZ and a 300 μm wide area (limited by the outer yellow ring) where the flow density (FD-300) was calculated **(A,E,I)**. En face OCTA and OCTA B-scan with flow marked in red **(B,F,J)**. En face OCTA angiograms with color-coded VD (color bar: warmer colors representing the higher VD) of the retinal vascular plexuses: SVP **(C,J,K)**, DVC **(D,H,L)**.

TABLE 2 Vessel density, FAZ area, and perimeter in exudative AMD patients, non-exudative MNV patients, and healthy controls.

	Exudative AMD (*n* = 21)	Non-exudative MNV (*n* = 21)	Controls (*n* = 20)	*p*-value[a]	*p*-value[b]	*p*-value[c]	Correlation coefficient	*p*-value
SVP VD (%)	42.52 ± 4.04	42.20 ± 4.48	47.76 ± 3.58	0.812	<0.001	<0.001	0.384	<0.001
DVC VD (%)	44.88 ± 3.40	49.07 ± 4.49	52.61 ± 3.11	0.002	<0.001	0.006	0.538	<0.001
FAZ area (mm^2)	0.37 ± 0.12	0.34 ± 0.12	0.27 ± 0.12	0.388	0.008	0.075	−0.245	0.016
Perimeter (mm)	2.47 ± 0.47	2.36 ± 0.49	1.98 ± 0.47	0.474	0.002	0.018	−0.303	0.003
FD-300 (%)	43.32 ± 6.54	44.70 ± 4.33	48.69 ± 2.45	0.452	0.001	0.001	0.340	<0.001

SVP, superficial vascular plexus; VD, vessel density; DVC, deep vascular complex; AMD, age-related macular degeneration; MNV, macular neovascularization. [a]Exudative AMD versus non-exudative MNV.
[b]Exudative AMD versus controls.
[c]Non-exudative MNV versus controls.

Discussion

In this retrospective study, we explored retinal vessel features in patients with non-exudative MNV using OCTA. Overall, we found the reduction in retinal vessel density, especially in the DVC, might be involved in or be accompanied by non-exudative MNV activation and should be closely monitored during follow-up.

Subclinical non-exudative MNV was reported first in cadaveric eyes with AMD in the 1970s. Its risk of developing exudation in eyes with non-exudative MNV was much higher compared with eyes without these lesions, especially when the fellow eye already suffered from exudative AMD (4, 5, 11). OCTA as a non-invasive tool can be used to detect and monitor non-exudative MNV at follow-up visits (4, 14–16). Previous studies have tried to identify predictive activation biomarkers of subclinical MNV, but mainly focusing on the feature of MNV itself (5, 10–12). To figure out whether the feature of retinal vessel density of non-exudative MNV is associated with the progression to exudations, we compared retinal vessel density and FAZ parameters in non-exudative MNV, exudative AMD, and normal eyes using OCTA. To the best of our knowledge, there have not been any formerly published studies comparing retinal microvascular characteristics of non-exudative MNV with that of exudative AMD and normal control.

In this study, VDs of the SVP and DVC were lower in eyes with exudative AMD compared with normal eyes. The results are consistent with the previous studies (17–19). Not only exudative AMD eyes, significant loss of superficial vessel density and a trend for deep vessel density were also reported in intermediate AMD patients (20, 21). The alteration of retinal vessels was also noticeable in early AMD eyes where the fellow eye developed exudative AMD (22). Furthermore, it was found that AMD eyes with GA present more rapid loss of retinal vessel density and FAZ enlargement over 2 years (23). These findings support the hypothesis that retinal change can be involved in or be accompanied by the progression of AMD. Thus, it is of great importance to compare retinal microvascular characteristics between non-exudative MNV and exudative AMD.

Our study demonstrates that the VD of the DVC in eyes with non-exudative MNV was significantly greater than that in eyes with exudative AMD and significantly lower than that in normal eyes. However, there was no statistical difference in SVP VDs between exudative AMD and non-exudative MNV eyes. In correlation coefficient analysis, retinal vessel density measured in the SVP and DVC decreased significantly from normal eyes to eyes with non-exudative MNV and then to eyes with exudative AMD. Colantuono et al. found that perfusion density in the DVC decreased over time, which was lower in non-exudative MNV eyes than that in the eyes of healthy controls and intermediate AMD with non-significant differences (24). It might be explained by the small sample size that led to a relatively low statistical power. According to the study by Toto et al., superficial vessel density decreased significantly in the intermediate AMD, while no significant difference in deep vessel density was found between early AMD, intermediate AMD, and controls (20). Therefore, we suppose that the decreased flow in SVP might be earlier than DVC in the AMD course, and the further decreased flow in DVC might be related to the exudation of non-exudative MNV.

Pathologists Grossniklaus and Green first proposed that type 1 MNV might be beneficial (25), and these vessels might supply oxygen to the ischemic outer retina and protect against the progression of geographic atrophy (7, 9, 12). Therefore, we suppose that non-exudative MNV may be a protective factor for the outer retina and DVC, while for the inner retina and SVP, it may be less protective. Then, the reduction in DVC and ischemic outer retina might induce the activation of non-exudative MNV, which may impair the outer and inner retina, and lead to the thinning of retinal layers and further decreased flow in retinal vessels eventually. Thus, the reduction in retinal vessel density, especially the VD of the DVC, might be involved in or be accompanied by non-exudative MNV activation and should be closely monitored during follow-up.

It was suggested that post-receptor retinal neuronal loss could have induced retinal vascular change in AMD (23). Relative sparing of the radial peripapillary capillary plexus and impairment of underlying retinal vasculature, supporting potential anterograde transsynaptic degeneration in intermediate AMD. These findings supported the hypothesis that decreased flow in retinal vessels may be a response to a reduced metabolic demand due to thinning of the IPL and ganglion cell layers (GCLs) in non-exudative AMD (26–28). Whether the activation of non-exudative MNV follows this hypothesis remains uncertain. In this study, the reduction in retinal vessel density, especially the VD of the DVC, might be involved in or be accompanied by near-future exudation, and a prospective study of non-exudative MNV should be performed to determine whether VD of DVC is the predictive factor for the activation of MNV. The main limitation of our study is that the retinal layer thickness was not obtained. Assessment of retinal layer thickness should be implemented in the future to determine the relationship between the reduction in retinal vessel density and the change in retinal layer thickness.

We found that the FAZ area and its perimeter in exudative AMD were significantly larger than that in normal eyes. A significant increase in perimeter and a trend in FAZ area were observed in eyes with non-exudative MNV compared with normal controls. It was reported that the area and perimeter of the FAZ in eyes with non-exudative AMD were larger than those in the normal controls (29). Qiu et al. reported that the FAZ area did not change much in exudative AMD eyes compared with the healthy controls. The possible reason for the disagreement is that OCTA was performed in different scan patterns. FD-300, as an OCTA biomarker, comprised segmentation of SVP and DVC, which in diabetic macular edema, branch retinal vein occlusion, and retinal arterial occlusion, was lower than the control group (30–32). To the best of our knowledge, this is the first study to investigate FD-300 in exudative AMD and non-exudative MNV. In our study, FD-300 was lower in eyes with non-exudative MNV and eyes with exudative AMD than that in normal eyes, and there was no significant difference between eyes with non-exudative MNV and eyes with exudative AMD. In correlation coefficient analysis, FD-300 decreased significantly from normal eyes to eyes with non-exudative MNV and then to eyes with exudative AMD. This evidence also supports that the reduction in retinal vessel density might be involved with or be accompanied by the progression of AMD and the activation of non-exudative MNV.

What is the current set of recommendations in protocols?

The diagnosis of symptomatic exudative MNV in AMD should be made on the basis of medical history and the use of multimodal imaging technologies, potentially including OCT, FA, and ICGA. Current expert consensus statements support the use of anti-angiogenic therapy as the first-line treatment of patients with nAMD. The benefits of intravitreal injections are not only to halt the progression of the neovascular component of the disease but also to improve visual acuity and quality of life.

Based on multimodal imaging technologies including OCT, FA, and ICGA, symptomatic exudative MNV in AMD was detected. The use of anti-angiogenic therapy as the first-line treatment of patients with nAMD has been fully supported by expert consensus statements (33–35). The utility of intravitreal injections is not only to halt the progression of the disease but also to increase visual acuity and quality of life as much as possible. Although no controlled clinical trial has been performed to provide definitive recommendations, for subclinical MNV which are asymptomatic in treatment-naïve eyes, the management of such lesions is not yet codified, and most of the authors agree not to treat them in the absence of fluid on OCT (6). They should be closely monitored to detect early signs of exudation that may affect visual function (4). To avoid delayed treatment or overtreatment, it is of great importance to find out the characteristics of non-exudative MNV that could serve as predictors of near-future exudation. Previous studies mainly focused on the features of MNV itself (5, 10–12). In this study, we found that the reduction in retinal vessel density, especially the VD of the DVC, might be involved in or be accompanied by near-future exudation and should be closely monitored during follow-up in order to ensure prompt anti-angiogenic therapy. Additionally, this study falls within recent recommended approaches to healthcare research (33–39).

Recommendations for evidence-based practice

One key insight into this study is that instead of prophylactic treatment, non-exudative MNV should be closely monitored to detect early signs of exudation. In this study, we found that the reduction in retinal vessel density, especially the VD of the DVC, might be involved in or be accompanied by near-future exudation. Future studies are necessary to test the hypothesis in a prospective manner. Assessment of retinal layer thickness should be implemented in the future to determine the relationship between the reduction in retinal vessel density and the change in retinal layer thickness.

In conclusion, this exploratory study investigated retinal microvascular characteristics of non-exudative MNV, wherein the presence of this condition was associated with a reduction in retinal vessel density, especially in the DVC, and that further reduction in the vascular density of the DVC may be associated with neovascular exudation. Consequently, monitoring of DVC vessel density may help with risk stratification and determination of appropriate follow-up intervals, thereby ensuring prompt access to anti-angiogenic therapy.

Limitations

Our study has several limitations. First, despite the retrospective study, the study is exploratory, and the resources to undertake a clinical trial were not available. In addition, further studies are necessary to test the hypothesis in a prospective manner. The second limitation is that the retinal layer thickness was not obtained. Assessment of retinal layer thickness should be implemented in the future to determine the relationship between the reduction in retinal vessel density and the change in retinal layer thickness. The third one is that approaches to enhance the quality of OCTA images and reduce noise were not used because it is a retrospective study. Future studies should reduce noise in OCTA images. Another limitation was that the effect of intraretinal fluid on measurements of VD is not well understood.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

YG and SZ conceptualized and wrote the article. YZ, TY, and GS undertook the activities associated with the review and meta-analysis. PM revised the whole article and methodology. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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Glossary

MNV	macular neovascularization
AMD	age-related macular degeneration
OCTA	optical coherence tomography angiography
VD	vessel density
SVP	superficial vascular plexus
DVC	deep vascular complex
FAZ	foveal avascular zone
CNV	choroidal neovascularization
FA	fluorescein angiography
ICGA	indocyanine green angiography
ILM	inner limiting membrane
IPL	inner plexiform layer
INL	inner nuclear layer
OPL	outer plexiform layer
ONL	outer nuclear layer
BCVAs	best corrected visual acuities
logMAR	logarithm of the minimal angle of resolution
ANOVA	one-way analysis of variance

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Epidemiological and clinical characteristics of open globe injuries in Southwest China

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Background: Open globe injuries (OGIs) are one of the leading causes of monocular vision loss, and the clinical characteristics of OGIs are region specific. The features and patterns of OGIs in Southwest China are poorly known and not well studied. Our study aimed to review the epidemiological and clinical characteristics of patients hospitalized for OGIs in Southwest China.

Methods: A retrospective study of OGI patients admitted to the West China Hospital from January 1st, 2015, to December 31st, 2019, was performed. Demographic characteristics and injury details were recorded. The Birmingham Eye Trauma Terminology system and the ocular trauma score (OTS) were used.

Results: A total of 3,014 patients were included. The male-to-female ratio was 5.2:1, and the mean age was 35.6 ± 19.1 years. 15.2% of patients were from the ethnic groups. The highest-risk occupation was the farmer (30.3%), followed by the worker (28.5%). OGIs occurred more frequently in people with middle (37.0%) and primary school (33.1%) education levels. Types of injuries included 46.8% penetration, 21.2% rupture, 2.9% perforation, and 29.1% intraocular foreign body (IOFB). The injuries types differed between age and occupation groups ($p < 0.001$). IOFBs had a higher risk of causing endophthalmitis, retinal detachment, and traumatic cataracts ($p < 0.001$). The most common injuries resulted from sharp objects (72.7%). The causes of the injuries were significantly associated with age, ethnicity, and occupation ($p < 0.001$). Explosion injuries and attacks by animals were more common among people of Tibetan and Yi ethnicities. Blunt trauma, vehicle crashes, falls and age older than 60 years were risk factors for a lack of light perception and lower OTS scores prognosis.

Conclusion: OGIs in Southwest China mainly affected working-aged males, especially workers or farmers. Severe vision loss and IOFBs are more common findings. OGIs in older patients and ethnic minorities requires additional attention.

KEYWORDS

open globe injuries, injuries types, intraocular foreign body, Southwest China, ethnic minorities

Introduction

Ocular trauma is one of the common causes of vision loss which results in a major economic problem for societies worldwide (1). Open globe injury (OGI), defined as a full-thickness wound of the eye wall, is among the severe types of ocular trauma that can cause irreversible visual impairment and blindness (2). Therefore, OGI imposes a serious financial burden to both individuals and governments due to the additional family care, high medical costs, long-term treatment follow-up and vision rehabilitation, and possible job loss (3). Over the past 15 years, the incidence of OGI has been approximately 2.5–27.7 per 100,000 people worldwide, showing a large variation among countries in which Western countries have a lower incidence than China (4–6). The clinical characteristics of OGI are region specific, for instance, in southeastern Spain, approximately 50% of OGI cases were wire induced (7), while in the midlands of England, more cases were assault-related injuries (8). Since more than 90% of ocular trauma cases are preventable (9), the epidemiological investigation of a given region is very important for the prevention, treatment, and prognosis of OGIs.

Although several previous studies have analyzed the epidemiology of ocular trauma in China (10–14), most data used were collected 10 years ago with few studies specifically investigating the epidemiological characteristics of OGIs in Southwest China. More than 200 million people live in this part of China, and many of them belong to ethnic minorities, including Tibetans. The economic development in this region is not as high as that in the southeastern coastal regions. Therefore, a survey of the epidemiological and clinical characteristics of OGI will provide essential information for OGI management in this region.

West China Hospital of Sichuan University is the largest trauma center in Southwest China, and approximately 7,500 ophthalmic emergencies each year are treated at the hospital. Severely injured ophthalmic events originally occur in Sichuan, Tibet, Qinghai, and Yunnan, and the patients are usually transferred to our hospital. This study aimed to evaluate the common injury causes, associated injuries, and high-risk population groups of OGIs in Southwest China.

Methods

This was a cross-sectional retrospective study with all data collected from hospitalized patients admitted to the Department of Ophthalmology, West China Hospital from January 1, 2015, to December 31, 2019. All patients had discharged diagnoses of OGI. Our study was approved by the Ethics Committee of West China Hospital and was conducted in adherence with the Declaration of Helsinki and its laws. Because the analyses were performed retrospectively on the deidentified data, informed consent was not required.

The inclusion criteria were an admission diagnosis of OGI according to the International Classification of Diseases, Tenth Revision (ICD-10). Patients who had previously received treatment for OGIs at other hospitals and subsequently presented to West China Hospital due to complications were excluded. All data used in this study were copied from the electronic medical records system, including general information such as age, sex, nationality, occupation, education, delays in presentation, and causes and locations of ocular trauma, and clinical data such as the classification and distribution of ocular trauma, visual acuity (VA) at admission, and accompanying symptoms. In cases of bilateral eye involvement, we collected data selectively from one eye, prioritizing the eye with more comprehensive information, accurate medical records, and a clearer description of the injury status. According to the Birmingham Eye Trauma Terminology system (15), OGI types were subdivided into four categories: penetrating injuries, perforating injuries, intraocular foreign bodies (IOFBs), and ruptures. Based on the location of the globe opening, all OGIs were identified in three zones where injuries occurred. Zone I is involved in an opening of the cornea or corneoscleral limbus, Zone II included injuries taking place at the anterior 5 mm of the sclera, and Zone III covered the full-thickness injuries that extended more than 5 mm posterior to the corneoscleral limbus (16). The ocular trauma score (OTS) was applied to calculate the extent of eye injury and to evaluate the prognosis (17).

Abbreviations: OGI, Open globe injuries; OTS, ocular trauma score; IOFB, Intraocular foreign body; VA, visual acuity; NLP, No light perception.

Statistical analysis

All statistical analyses in the present study were performed using SPSS (version 22.0, IBM Corporation, Armonk, NY, United States). Descriptive statistical results were presented as numbers (percentages) for categorical variables and meant for continuous variables. Pearson's chi-square tests were used to assess correlations between each pair of categorical variables. Cramer's V and adjusted residuals were used to describe the correlations. All p values were nominal and 2-sided, and statistically significant differences were considered at $p \leq 0.05$.

Results

Demographic and baseline characteristics

A total of 3,014 patients were hospitalized with OGIs during the 5-year study period (2015–2019) and included in our analyses. Each year, approximately 7,500 patients with ocular diseases were admitted to the ophthalmic emergency department, and OGIs accounted for 8.04% of ophthalmic emergencies. The baseline data are shown in Table 1.

Among all patients, 2,527 (83.8%) were male and 487 (16.2%) were female, yielding a male-to-female ratio of 5.2:1. The mean age of the patients was 35.6 ± 19.1 years, ranging from 2 months to 86 years old. There were significant differences in age between sexes, with an average age of 36.6 ± 17.9 years for males and 30.0 ± 23.7 years for females ($F = 50.7$, $p < 0.001$). The general age distributions of the patients were found in 35–60 years (47.4%), 17–35 years (24.0%), and 0–6 years (11.5%). Regarding the highest sex-specific proportion, 90.4% of cases among males occurred in the 17–35 age group, and 36.8% of cases among female occurred in the 0–6 age group (Figure 1A).

The patients were of ethnicities including Han (84.8%), Tibetan (9.2%), Yi (4.5%), and others (1.5%). The age distribution between the combined minorities and those people of Han ethnicity significantly differed ($X^2 = 180.2$, $p < 0.001$). Among the 3,014 patients, the highest-risk occupation was farmer (30.3%), followed by worker (28.5%). OGIs occurred more frequently in people with middle school (37.0%) and primary school (33.1%) education levels.

The delay time from injury happening to hospitalization varied from 1 h to 42 days. Only 17.4% of patients received timely medical treatment in the hospitals within 6 h, 29.1% arrived at the hospitals in 6 to 12 h, and 19.4% arrived in 12 to 24 h, respectively (Figure 2). Unfortunately, only 3.5% of minority patients were provided the medical care within 6 h. The vast majority of minority patients (38.3%) arrived at the hospital in 1 to

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TABLE 1 Demographics and characteristics of patients for open globe injuries over a 5-year period at the West China hospital of Sichuan university.

Classifications	Cases (*n*)	Percentage
Gender		
Male	2,527	83.8%
Female	487	16.2%
Age groups		
0–6	348	11.5%
7–16	272	9.0%
17–35	722	24.0%
36–60	1,428	27.4%
>60	244	8.1%
Nationality		
Han	2,557	84.8%
Tibetan	276	9.2%
Yi	137	4.5%
Others	44	1.5%
Education level		
Illiteracy	198	6.6%
Preschool period	331	11.0%
Primary school	998	33.1%
Middle school	1,114	37.0%
High school	250	8.3%
University	123	4.1%
Occupation		
Unemployment	299	9.9%
Children	286	9.5%
Student	255	8.5%
Worker	859	28.5%
Farmer	914	30.3%
Non-manual work	401	13.3%
Time of arrival at hospital		
<6h	523	17.4%
6-12h	876	29.1%
12-24h	576	19.1%
1-3d	646	21.4%
3-7d	228	7.6%
>7d	165	5.5%
Total patients	3,014	100%

3 days. Compared to the low ratio of 10.0% of farmers, 25.8% of workers were able to be hospitalized 6 h after injury.

Clinical characteristics of OGIs

The various classifications of all OGIs, including the types and locations of the wounds, VA, and concomitant ocular diagnosis, are presented in Table 2. A total of 3,014 eyes were included.

The types of injuries were different between age groups, and this difference was statistically significant ($X^2 = 405.1$, $p < 0.001$). In patients under 16 years old, penetrating injuries accounted for 78.1%, which was much higher than the proportion in people (38.7%) over 16 years old. IOFBs occurred most frequently in the ages of 17–35 (36.7%) and 35–60 (35.9%) age groups. The rate of rupture was the highest among patients over 60 years of age (44.7%). Between job types, the type of injury significantly differed ($X^2 = 361.6$, $p < 0.001$). Workers and farmers experienced the most IOFBs (41.8 and 33.5%, respectively; Figure 1B).

No light perception (NLP) was the most severe visual impairment, and 23.1% of patients older than 60 years suffered NLP after OGI. Different injury types were correspondingly related to typical eye complications. The results of *post hoc* testing among the groups are shown in Table 3. The OTS scores, an index of effective reorganization and evaluation for the prognosis of OGI, were correlated with age, hospital arrival time, and education level. Among those patients older than 60 years, 33.1% had an OTS score of 0–44, while only 0.4% had an OTS score of 91–100. Among patients with an OTS score of 0–44, the arrival time at the hospital was approximately 1–3 days (26.6%), and this rate decreased when arrival time to the hospital was less than 6 h (adjusted residuals was −4.2). The proportion of patients with an OTS score of 91–100 was relatively high (10.1%) for patients who had been hospitalized for more than 7 days. Regarding OTS scores, 30.8% of illiterate patients had a low count of 0–44, while 35.4% of illiteracy had a medium count of 45–65.

Causes of injury

Overall, the most common injury resulted from sharp objects (72.7%), followed by blunt injury (13.3%). The causes of injuries were significantly associated with age, ethnicity, and occupation ($p < 0.001$). The rates of sharp injuries were the highest among workers and farmers, at 80.8 and 74.2%, respectively. Among sharp injuries, most were caused by metal materials, with a 7:3 ratio of metal objects to nonmetal objects. Sharp injuries were moderately correlated with the age (Cramer's $V = 0.324$, $p < 0.001$) and weakly correlated with occupation (Cramer's $V = 0.293$, $p < 0.001$). The results of *post hoc* testing among the groups in this study are shown in Table 4.

Blunt trauma was most likely to occur in people over 60 years old, accounting for 22.5% of cases in this category. The highest rate of OGIs from traffic accidents was found among nonmanual workers. A few blunt force injuries (10.9%) were due to being beaten by a fist. For the 0–6 and > 60 age groups, the proportions of injuries caused by falls were 13.5 and 11.9%, respectively, while for the 17–60 age group, this proportion decreased to approximately 3%. Explosion injuries occupied 7.6 and 11.7% of all cases among Tibetans and Yi ethnicities, respectively, and only 4.4% of cases among Han ethnicities (Figure 3). Explosion injuries caused by fireworks accounted for 38.4%. Two patients suffered eye injuries resulting from gunshots, and the other blast injuries were due to items such as detonators, lighters, gas tanks, light bulbs, and pressure gages. Among all injuries, 3.1% of patients explicitly stated that the injury was related to violent attacks. Twenty-eight patients were attacked by animals, and the proportion of OGIs from animal attacks in ethnic minorities was significantly higher than that in Han people ($\chi 2 = 16.852$, $p < 0.001$).

Differences in causes of injury could lead to different types of damage, initial VA, and prognoses. Seventy percent of binocular OGIs were

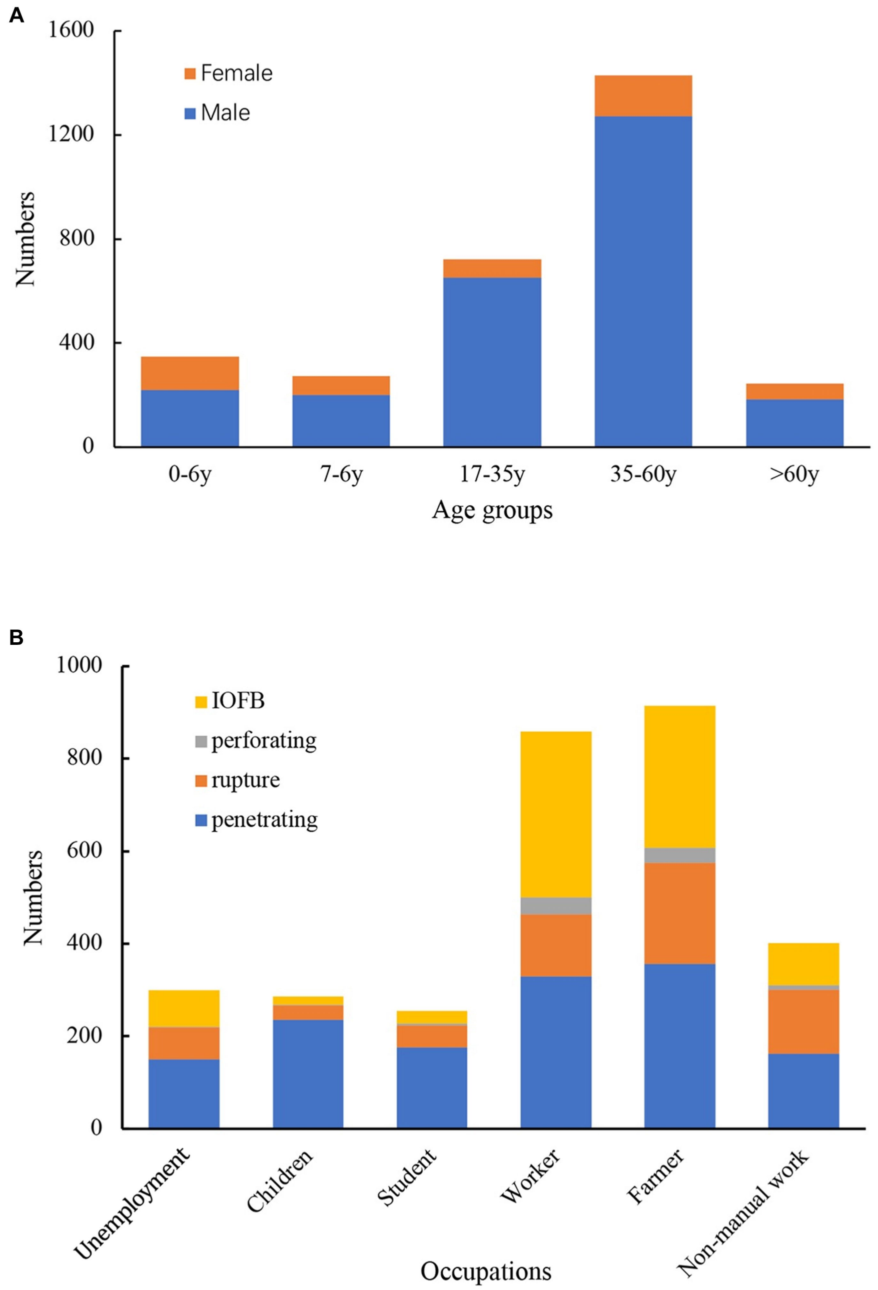

FIGURE 1
Numbers of OGIs by different classifications. **(A)** Numbers of OGIs by age and sex. **(B)** Numbers of OGIs by occupations and types.

attributed to blast injuries. Sharp trauma was correlated with a better initial VA of 20/200–20/50 and>20/50 (adjusted residuals were 7.1 and 4.2, respectively). Blunt trauma (33.7%), vehicle crashes (34.7%), and falls (31.3%) were relative risk factors for NLP (adjusted residuals were 13.7, 6.9, and 7.1, respectively), as well as a lower OTS score prognosis (adjusted residuals were 16.2, 6.2, and 5.4, respectively).

Discussion

This was a retrospective analysis of OGIs in the last 5 years before the coronavirus disease 2019 epidemic era. The patients included in this study lived in Sichuan Province, the Tibetan Autonomous Region, and Yunnan Province in Southeastern China. The results reflect the characteristics of OGIs under the nonepidemic condition in this region.

Consistent with previous studies, our study confirmed that OGIs occurred mainly in the 17 to 60 working-aged group, and the majority of patients were males (18, 19), probably due to more males being engaged in manual labor-related jobs and paying less attention than females to trauma protection. Compared with other regions in China (20), the injured population in the southwestern region had lower educational levels, with 70.1% of patients just having a junior and primary school education level. This may result from the lower

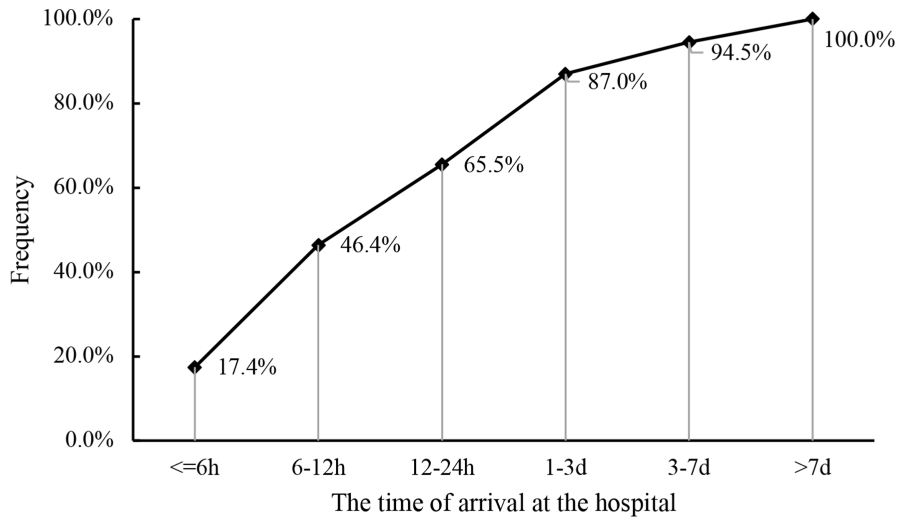

FIGURE 2
Cumulative proportion of patients at the time of arrival at the hospital.

economic and educational developments in the southwestern region. Our study demonstrated that the occupations that suffered the most OGIs were farmers and workers because Southwest China is an important agricultural and industrial region. Many studies have shown that ocular trauma could be effectively reduced through enhancing education and improving protective measures (21, 22). Therefore, eye protection training and equipment configuration for workers and farmers will help decrease the incidence rate of OGI.

Timely treatment is very important to minimize eye trauma. Previous studies, as well as our study, have shown that the earlier the medical care is carried out, the better the visual prognosis is (23, 24). However, only 17.4% of patients were able to arrive at the hospital within 6h for medical intervention in our study. Among these patients, the ratio of workers was significantly higher than that of farmers and other occupations. Among those patients who arrived at the hospital within 1–3 days, farmers and ethnic minorities accounted for a relatively larger proportion because these people lived in areas far from the trauma center or in remote mountainous areas where transportation was inconvenient. These patients have low education levels and poor personal health awareness. Nevertheless, 26.6% of the patients who arrived at the hospital within 1–3 days had OTS scores of only 0–44, which indicated a poor visual prognosis. Therefore, for farmers and ethnic minorities, improving the transportation system, promoting the local medical level, and strengthening education on the dangerous awareness of eye trauma is essential for better visual prognoses.

Compared with other domestic and international data, our study showed the highest incidence rate of IOFBs, up to 29.1% (10, 11, 19, 25). The situation might be attributed to uneven medical resource distributions in Southwest China (26), resulting in a few local ocular trauma centers that can perform vitrectomy or other surgical treatments for IOFBs. Therefore, most patients in this area were forced to concentrate in the West China Hospital. The occurrence of IOFBs is often associated with work-related injuries (1, 12). Most people who are injured in the work environment not only disregard the use of protective eye equipment but also lack safety consciousness and risk awareness. Almost all patients we interviewed did not use protective measures such as goggles while knocking or working with tools. This finding is consistent with those of many studies conducted in areas with poor development levels (27, 28). A study in Taiwan indicated that eye protection devices could reduce the risk of work-related eye injury by up to 60% (29). IOFBs were closely related to severe blinding ocular complications: endophthalmitis, retinal detachment, and traumatic cataracts. Therefore, corresponding laws and regulations should be formulated to force employers to equip each high-risk worker with protective measures.

In the elderly population older than 60, the rate of rupture injuries was as high as 44.7% (the rate of rupture injuries in the general population was 21.2%). Because of poor visual contrast sensitivity, poor depth perception, impaired cognitive function, and high incidence of bone and cardiovascular and cerebrovascular diseases (30), elderly people have a higher risk of severe falls and injuries while moving heavy objects. Moreover, our study showed that 23.1% of the elderly people had NLP after injury, and 33.1% had an OTS score of only 0–44 points. Visual outcomes from the ocular trauma are worse in older adults (31). Rupture injuries are more often accompanied by orbital facial fractures, eyelid or lacrimal ductule laceration, etc., which require greater expenditures and multiple treatments. With the aging of society as a whole, more attention should be given to ocular trauma in elderly individuals, and targeted protection will help avoid serious visual impairments and economic burdens.

Different causes of injury also lead to different visual outcomes, such as blunt trauma, vehicle accident injuries, and falls, which are associated with severe visual impairment. Understanding the cause of injury is crucial to preventing and controlling OGIs. Sharp object injuries were the main cause of OGIs in Southwest China, and the proportion of this cause was higher than that in previous studies (32, 33). Among those sharp injury cases, OGIs in children were usually related to the use of scissors, knives, and other tools, while OGIs in the school-age population were mainly due to pencils. Nails were a common cause of injuries for workers, especially when nail guns were involved. Notably, nail guns often hit the posterior segment of the

TABLE 2 The injury and ocular characteristics of open globe injuries.

Classifications	Subtype	Cases (*n*)	Percentage (%)
Type	Penetration	1,411	46.8%
	Rupture	639	21.2%
	Perforation	87	2.9%
	Intraocular foreign body	877	29.1%
Zone	I	1757	58.3%
	II	642	21.3%
	III	615	20.4%
Laterality of eyes	OD	1,501	49.80%
	OS	1,493	49.50%
	OU	20	0.70%
Visual acuity	NLP	348	12.3%
	LP/HM	1,464	51.7%
	1/200–19/200	471	16.6%
	20/200–20/50	355	12.5%
	>20/50	191	6.8%
	Missing data	185	6.1%
Complications	Endophthalmitis	607	20.1%
	Retinal detachment	319	10.6%
	Choroidal hemorrhage	97	3.2%
	Hyphtma	988	32.8%
	Vitreous hemorrhage	1,063	35.3%
	Traumatic cataract	1788	59.3%
	Lens dislocation	306	10.2%
	Facial or orbital fracture	175	5.8%
	Eyelid and lacrimal duct laceration	439	14.6%
OTS scores	I(0–44)	586	19.4%
	II(45–65)	961	31.9%
	III(66–80)	881	29.2%
	IV(81–91)	228	7.6%
	V(92–100)	137	4.5%
	missing data	221	7.3%

eyeball, which can irreparably damage vision (34). Except for sharp metal objects, ocular trauma in farmers was associated with sharp objects in nature, such as stones, twigs, and bamboo. Blast injuries are unique cases in China because there is a tradition of setting off fireworks and firecrackers on holidays. However, explosive injuries accounted for only 5% of all injury causes in our study, far lower than the 11.1–24.5% in previous studies. Among explosive injury causes, fireworks and firecrackers accounted for only 38.4% of blast trauma, which was the lowest proportion in the Chinese population (10, 12). It is likely that the low rate of injury directly results from the gradual implementation of fireworks and firecracker safety management regulations in China in 2015. Laws and regulations have played an effective role in reducing special types of eye injuries.

According to the seventh national census of China in 2020, there are 125 million people who belong to an ethnic minority, accounting for 8.89% of the population. Sichuan Province and Southwest China are the main areas where Tibetan and Yi people live. Therefore, the proportion of ethnic minorities with OGI cases was relatively high (15.5%). Compared with Han patients, Tibetan and Yi patients were injured at younger ages, took longer to reach the hospital, and had more falls and explosion damage. Since the lifestyle of ethnic minorities is dominated by agriculture and animal husbandry, there were more animal injuries compared with the Han population. This is the first study to include OGI data on ethnic minority populations in China. The results suggest that for ethnic minorities, multiple steps should be considered, such as enhancing local medical levels, advertising the hazards of ocular trauma and medical care knowledge in daily life, and especially educating children and adolescents on how to prevent OGIs.

TABLE 3 Injury type related to concomitant ocular diagnosis.

	Penetrating		Rupture		Perforating		IOFB		χ^2	*P*
Endophthalmitis	283	(−0.1)	24	(−11.6)	16	(−0.4)	284	(10.7)	188.558	<0.001
Retinal detachment	70	(−9.4)	63	(−0.7)	21	(4.2)	165	(9.4)	127.154	<0.001
Choroidal hemorrhage	29	(−3.4)	30	(2.4)	9	(3.8)	29	(0.2)	24.808	<0.001
Hyphtma	338	(−9.7)	468	(24.5)	38	(2.2)	144	(−12.3)	635.808	<0.001
Vitreous hemorrhage	258	(−18.3)	432	(19.3)	70	(9.0)	303	(−0.5)	548.981	<0.001
Traumatic cataract	900	(4.7)	204	(−15.9)	62	(2.3)	622	(8.3)	264.469	<0.001
Lens dislocation	92	(−6.2)	168	(15.2)	6	(−1.0)	40	(−6.5)	233.930	<0.001
Facial or orbital fracture	24	(−9.0)	131	(17.9)	4	(−0.5)	16	(−6.0)	321.426	<0.001
Eyelid and lacrimal duct laceration	130	(−7.8)	239	(18.4)	8	(−1.4)	62	(−7.5)	341.898	<0.001

Adjusted residuals appear in parentheses to the right of observed numbers.

TABLE 4 Crosstabulations of sharp instrument type and age, occupation groups.

	Age groups (χ^2 = 907.786, *P* < 0.001)					Occupation groups (χ^2 = 930.400, *P* < 0.001)					
Type of Sharp instrument	0-6 y	7-6 y	17-35 y	35-60 y	>60 y	Unemploy-ed	Child	Student	Worker	Farmer	Others
Nail	5 (−6.8)	7 (−5.0)	106 (2.1)	241 (7)	8 (−3.5)	20 (−3)	3 (−6.3)	5 (−4.9)	193 (9.3)	116 (0.4)	30 (−1.6)
Scissors, knife and needle	94 (17.4)	31 (4.3)	33 (−2.1)	19 (−10.9)	5 (−2)	27 (2.5)	84 (17.5)	24 (3)	12 (−7.7)	16 (−6.7)	19 (0)
Other metal instrument	46 (−9.2)	27 (−8.5)	272 (3.5)	561 (7.6)	60 (0)	66 (−4)	36 (−8.3)	31 (−6.9)	387 (7.3)	339 (3.9)	107 (0.9)
Stone, wood and bamboo	48 (1.1)	43 (2.7)	54 (−4.5)	158 (−1.8)	52 (7.2)	50 (3.1)	36 (0.4)	35 (1.8)	57 (−7)	154 (5.6)	23 (−2.7)
Ceramic, glass and plastic	38 (3.2)	30 (3.4)	57 (1.2)	72 (−4.1)	7 (−1.7)	29 (2.3)	31 (2.9)	28 (3.5)	41 (−3.8)	35 (−4.4)	40 (4.5)
Pen and pencil	21 (4.9)	43 (16.5)	2 (−4.2)	2 (−7.7)	0 (−2.2)	13 (2.7)	13 (2.7)	38 (15.3)	1 (−5.5)	0 (−5.6)	3 (−1.7)
Limbs or animals	4 (1.1)	2 (0.2)	6 (0.6)	6 (−1.7)	2 (0.7)	4 (1.6)	4 (1.6)	2 (0.4)	0 (−3.1)	6 (−0.1)	4 (1.4)

Adjusted residuals appear in parentheses below observed numbers.

This study has several potential limitations that can be topics for future studies. First, all data included were collected from the West China Hospital, which cannot fully represent the whole region. Second, since the electronic medical records system had changed, we were unable to conduct the long-term follow-up of visual outcomes, and instead, the OTS scores were used to estimate prognoses. In practice, many studies have shown the validity of the OTS score for visual prognostic assessment (35, 36). Meanwhile, because most of the patients could not provide prognosis information, we were unable to analyze the straightforward link between OGIs and socioeconomic parameters. Last, the relevant descriptions, parameters, and signs recorded in the old documents may not be accurate. For example, some children were unable to comply with the instructions to achieve an accurate measure of initial VA. In addition, the judgment of relative afferent pupillary defect was inaccurately or unclearly recorded, resulting in a lack of the corresponding OTS score. However, even if relative afferent pupillary defect could not be precisely evaluated, the OTS was still a reliable prognostic tool for ocular trauma (37).

In summary, our study analyzed the epidemiological trends, ocular characteristics, and causes of injury among 3,014 patients with OGIs in Southwest China. Ocular trauma in this region mainly affected working-aged males, especially workers or farmers. The proportion of IOFBs was higher than in the eastern parts of China, and severe vision loss was more frequently found. The OGI characteristics of elderly patients and ethnic minorities showed unique patterns. According to our results, improving local medical care, increasing public awareness of ocular trauma prevention, and formulating personalized prevention and control plans for different

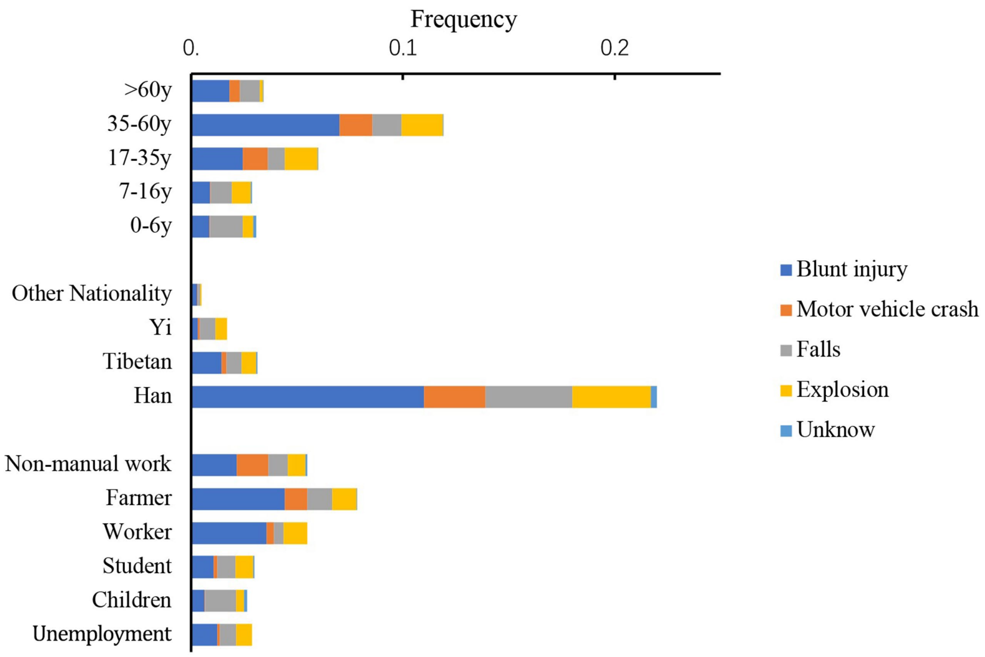

FIGURE 3
Incident frequency of OGI is categorized by age, nationalities, occupation, and causes of injury (except sharp injury).

groups of people can effectively reduce the incidence and severity of ocular trauma.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by Medical Ethics Committee of Sichuan University. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation was not required from the participants or the participants' legal guardians/next of kin in accordance with the national legislation and institutional requirements.

Author contributions

QC: Writing – original draft, Writing – review & editing. LL: Data curation, Investigation, Writing – original draft. YS: Data curation, Investigation, Writing – original draft. FL: Supervision, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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Trends in the global burden of vision loss among the older adults from 1990 to 2019

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Purpose: To quantify the global impact of vision impairment in individuals aged 65 years and older between 1990 and 2019, segmented by disease, age, and sociodemographic index (SDI).

Methods: Using the Global Burden of Diseases 2019 (GBD 2019) dataset, a retrospective demographic evaluation was undertaken to ascertain the magnitude of vision loss over this period. Metrics evaluated included case numbers, prevalence rates per 100,000 individuals, and shifts in prevalence rates via average annual percentage changes (AAPCs) and years lived with disability (YLDs).

Results: From 1990 to 2019, vision impairment rates for individuals aged 65 years and older increased from 40,027.0 (95% UI: 32,232.9-49,945.1) to 40,965.8 (95% UI: 32,911-51,358.3, AAPC: 0.11). YLDs associated with vision loss saw a significant decrease, moving from 1713.5 (95% UI: 1216.2–2339.7) to 1579.1 (95% UI: 1108.3–2168.9, AAPC: −0.12). Gender-based evaluation showed males had lower global prevalence and YLD rates compared to females. Cataracts and near vision impairment were the major factors, raising prevalence by 6.95 and 2.11%, respectively. Cataract prevalence in high-middle SDI regions and near vision deficits in high SDI regions significantly influenced YLDs variation between 1990 and 2019.

Conclusion: Over the past three decades, there has been a significant decrease in the vision impairment burden in individuals aged 65 and older worldwide. However, disparities continue, based on disease type, regional SDI, and age brackets. Enhancing eye care services, both in scope and quality, is crucial for reducing the global vision impairment burden among the older adults.

KEYWORDS

older adults, vision loss, average annual percentage changes, sociodemographic index, years lived with disability

1 Introduction

The global population has experienced a rapid aging trend in recent decades, largely due to socioeconomic development. This demographic shift has resulted in an increasing burden of disease on healthcare systems worldwide, particularly regarding certain types of diseases and injuries. According to World Population Prospects 2019 (1), the number of people aged

65 years and older is projected to rise from 1 in 11 people worldwide in 2019 to 1 in 6 people by 2050. Furthermore, population aging has been associated with a significant increase in global disability-adjusted life years (2), highlighting the need for increased medical resources to meet the healthcare needs of the older adults. As a result, many healthcare systems will require reforms to cope with the health impact of population aging.

While previous studies have examined specific aspects of the health impact of population aging (3, 4), few have explored the relationship between population aging and vision loss on a global scale. Some studies have focused on specific regions (5–8) or diseases (9–11), making it difficult to draw generalized conclusions. Additionally, some studies have not separated the effects of population aging from population growth (12, 13), leading to inaccurate estimates of the net effect of population aging. Furthermore, traditional decomposition methods used in previous studies are sensitive to decomposition order and choice of reference group, leading to inconsistent results (3, 14).

To address these limitations, we present a systematic analysis of the health impact of global population aging and vision loss between 1990 and 2019. We utilized a decomposition method that is not influenced by decomposition order or choice of reference group, allowing for accurate estimation of the net effect of population aging on vision loss (3). Our study aims to provide valuable information for policymakers and researchers to better understand and address the healthcare needs of the aging population, especially regarding vision loss.

2 Methods

2.1 Overview

The data source on population aging and vision loss during 1990–2019 were acquired from the GBD 2019 (15), which provided estimates of health outcomes and related measures for countries and territories worldwide. The data included prevalence of vision loss by sex, age group, and country from 1990 to 2019. In this study, the definition and diagnosis of vision loss adhered strictly to the criteria set forth by the GBD 2019 (16). Specifically, our classification utilized the Snellen chart standards to define moderate vision impairment as presenting visual acuity (PVA) of greater than or equal to 6/60 and less than 6/18, severe vision impairment as PVA of greater than or equal to 3/60 and less than 6/60, and blindness as PVA less than 3/60 or a visual field around central fixation of less than 10 degrees. GBD 2019 used multiple data sources, including surveys, censuses, and administrative records to estimate the prevalence of vision loss. The study classified the countries and territories into high-income, upper-middle-income, lower-middle-income, and low-income categories based on the World Bank's income classifications in 2019.

2.2 Frontier analysis method

To assess the correlation between the burden of vision loss and socio-demographic development, we utilized a quantitative methodology known as frontier analysis. This approach aimed to identify the lowest achievable age-standardized YLDs rate based on the Socio-demographic Index (SDI), which serves as a measure of development status. The YLDs frontier represents the minimum YLDs that each country or territory could potentially attain given its specific SDI value. The effective difference, which measures the distance from the frontier, indicates the extent to which there may be unrealized opportunities for improvement (reduction in YLDs) based on a country or territory's position on the development spectrum. To construct the frontier for age-adjusted vision loss YLDs by SDI, we employed a data envelope analysis method called the free disposal hull, which allows for non-linear frontiers (17, 18). Data from 1990 to 2019 were utilized, and to address uncertainty, we generated 1,000 bootstrapped samples by randomly selecting data points with replacement from all countries and territories across the years. The mean YLDs attributed to vision loss was calculated for each Socio-demographic Index (SDI) value based on the bootstrapped samples. Subsequently, a smoothed frontier was generated using LOESS regression with a local polynomial degree of 1 and a span of 0.2. Outliers were excluded during the frontier generation process to mitigate their influence (17). To examine the relationship between age-standardized vision loss YLDs rates and the frontier in 2019, we calculated the effective difference, which represents the absolute distance from the frontier, using the 2019 SDI and age-standardized vision loss YLDs rate data point for each country or territory. Countries or territories with lower YLDs than the frontier were assigned a zero distance, indicating that they had achieved or surpassed the minimum YLDs level established by their SDI value.

2.3 Decomposition method

In our study, we sought to analyze the shifts in vision loss prevalence from 1990 to 2019 by attributing these changes to three primary factors: population aging, population growth, and variations in age-specific prevalence rates. To accomplish this, we embarked on a detailed comparative analysis of several decomposition methods that have been documented in existing research (3, 4, 14, 19, 20). These methods, each offering unique insights into the breakdown of health outcome changes, often face common challenges, notably in the selection of decomposition order and reference groups, leading to possible inconsistencies in outcomes.

After an exhaustive evaluation and comparison of these methodologies, we adopted a specific decomposition approach that effectively addresses the noted challenges, ensuring a consistent and clear framework for attributing changes in vision loss prevalence (14). This selected method employs a comprehensive set of formulas to systematically calculate the impact of population aging, growth, and changes in mortality rates on vision loss variation. It stands out for its methodological robustness and consistency, making it particularly suitable for our analysis. For our data analysis, we utilized R version 4.2.3, leveraging the "maps" package to create detailed visualizations that complement our findings. For our data analysis, we utilized R version 4.2.3, leveraging the "maps" package to create detailed visualizations that complement our findings. To conduct the decomposition analysis, we employed the easyGBDR package, version 1.0.0.1.

Using the aforementioned decomposition method, we computed the absolute and relative contributions of population aging, population growth, and changes in age-specific prevalence rates to the disparity in vision loss prevalence between 1990 and each subsequent year from 1991 to 2019. These calculations encompassed the global population as well as individual countries and territories considered in our study. The absolute contribution represents the number of vision loss cases attributed to each factor, while the relative contribution ("attributed proportion") is expressed as a percentage, representing the attributed cases of vision loss divided by the total number of cases in 1990. A positive contribution indicates an increase in the prevalence of vision loss, while a negative contribution indicates a decrease.

2.4 Statistical analysis

We employed visualizations to illustrate the absolute contributions of the three components to changes in vision loss prevalence. Additionally, we graphically depicted the relative contributions of population aging by sex for the global population and various income categories as classified by the World Bank. Moreover, we compiled tables showcasing the top five causes of vision loss (including glaucoma, cataracts, AMD, refractive disorders, and near vision loss) with the most substantial increases and decreases in attributed cases related to population aging, categorized by sex. Furthermore, we estimated the relative contributions of population aging from 1990 to 2019, stratified by country, sex, and specific causes of vision loss.

To further deepen our understanding of the interplay between population aging and changes in vision loss prevalence, we calculated the ratio of vision loss cases attributed to changes in age-specific prevalence rates to those attributed to population aging. This analysis focused on countries where population aging corresponded to an increase in vision loss prevalence between 1990 and 2019. By utilizing this ratio, we assessed the comparative impact of changes in age-specific prevalence rates versus population aging on alterations in vision loss prevalence. Notably, all analyses were stratified by sex, recognizing the divergent effects of population aging on vision loss prevalence between males and females.

Our analysis strategy was finalized in March 2023, and involved exploring patterns in the prevalence of vision loss attributed to population aging, variation in the number of attributed cases, and changes in the number of attributed cases by sex, country income category, and cause of vision loss. We also compared the effect of changes in age-specific prevalence rates to the effect of population aging. All data analyses were conducted between April 2023 and May 2023. We followed the Guidelines for Accurate and Transparent Health Estimates Reporting (GATHER) statement (21) to ensure transparency and accuracy in our research.

3 Results

3.1 Overview of the global burden

Globally, there has been a significant upward trend in the prevalence and AAPC of global vision loss (Figure 1 and Table 1). The age-standardized prevalence rate (ASPR) increased from 40,027.0 (95% uncertainty interval [UI] = 32,232.9–49,945.1) in 1990 to 40,965.8 (95% UI = 32,911–51,358.3) in 2019. The AAPC for prevalence showed an increase of 0.11 (95% confidence interval [CI]: 0.07 to 0.14). Conversely, the number of YLDs and its average annual percentage change exhibited a declining trend, with an AAPC of −0.12 (95% CI: −0.23 to −0.01) (Figure 2 and Table 1). Overall, the YLDs of vision loss decreased for all age groups (age ≥ 65 years) and SDI groups from 1990 to 2019. In terms of vision loss due to specific eye diseases, age-standardized prevalence rate per 100,000 population increased for vision loss due to cataract and near vision loss; it decreased for vision loss due to glaucoma, age-related macular degeneration (AMD), refraction disorders and other causes (Table 2). YLD rate per 100,000 population increased during the monitoring period for near vision loss; it decreased for glaucoma, cataract, AMD, refraction disorders and other causes (Table 3). Notably, the high SDI group showed a significant upward trend in the age-standardized rate and YLD rate of near vision loss from 1990 to 2019, while the other SDI groups showed significant decreases in both rates.

3.2 Distribution of prevalence and YLDs by age and sex

In terms of sex, the global prevalence and YLD rates were all lower among males than among females (Table 1). For males, the prevalence rates remained relatively stable, while the YLD rates exhibited a significant decline with an AAPC of −0.28. In contrast, among females, the prevalence rates showed a slight increase with an AAPC of 0.19, while the YLD rates did not show any significant changes. Supplementary Tables S1–S7 showed the distribution of prevalence and YLDs of overall vision loss and specific causes of vision loss by gender and age subgroup. The prevalence of cataract and near vision loss among different age subgroups exhibited a consistent distribution pattern similar to the overall vision loss, with distinct upward trends among females in the age groups of 65–69 years, 70–74 years, 75–79 years, 80–84 years, and 85–89 years. Additionally, there was a distinct increasing trend in near vision loss among females in the 90–94 years age group. Regarding YLDs by age subgroup, there was no significant increase in overall vision loss across all age groups among females. However, cataract demonstrated an increase specifically in the 75–79 years age group, while near vision loss exhibited an elevated trend in the 65–69 years, 75–79 years, 80–84 years, and 90–94 years age groups. In contrast, the YLDs associated with the remaining specific causes of vision loss either experienced a significant decrease or showed no significant increase when examined by gender and age subgroup.

3.3 Burden trends by region

Among 21 GBD regions by SDI in 2019, East Asia had the highest vision loss prevalence, while Southern Sub-Saharan Africa had the highest ASPR per 100,000 population (67931.4, 95% UI: 51008.7–87105.2; Table 1). The North Africa and Middle East region experienced the most rapid decline in prevalence rates (AAPC = -0.34; 95% CI: −0.41 to −0.28). Regarding the YLDs due to overall vision loss, East Asia ranked first. Southern Sub-Saharan Africa had the highest ASPR per 100,000 population (3143.5; 95% UI: 2236.8–4268.4; Table 1). Southeast Asia exhibited the most rapid decrease rate in prevalence rates (AAPC = −1; 95% CI: −1.12 to −0.88). However, despite a significant downward trend in prevalence and YLDs observed in most regions, the High-income Asia Pacific region

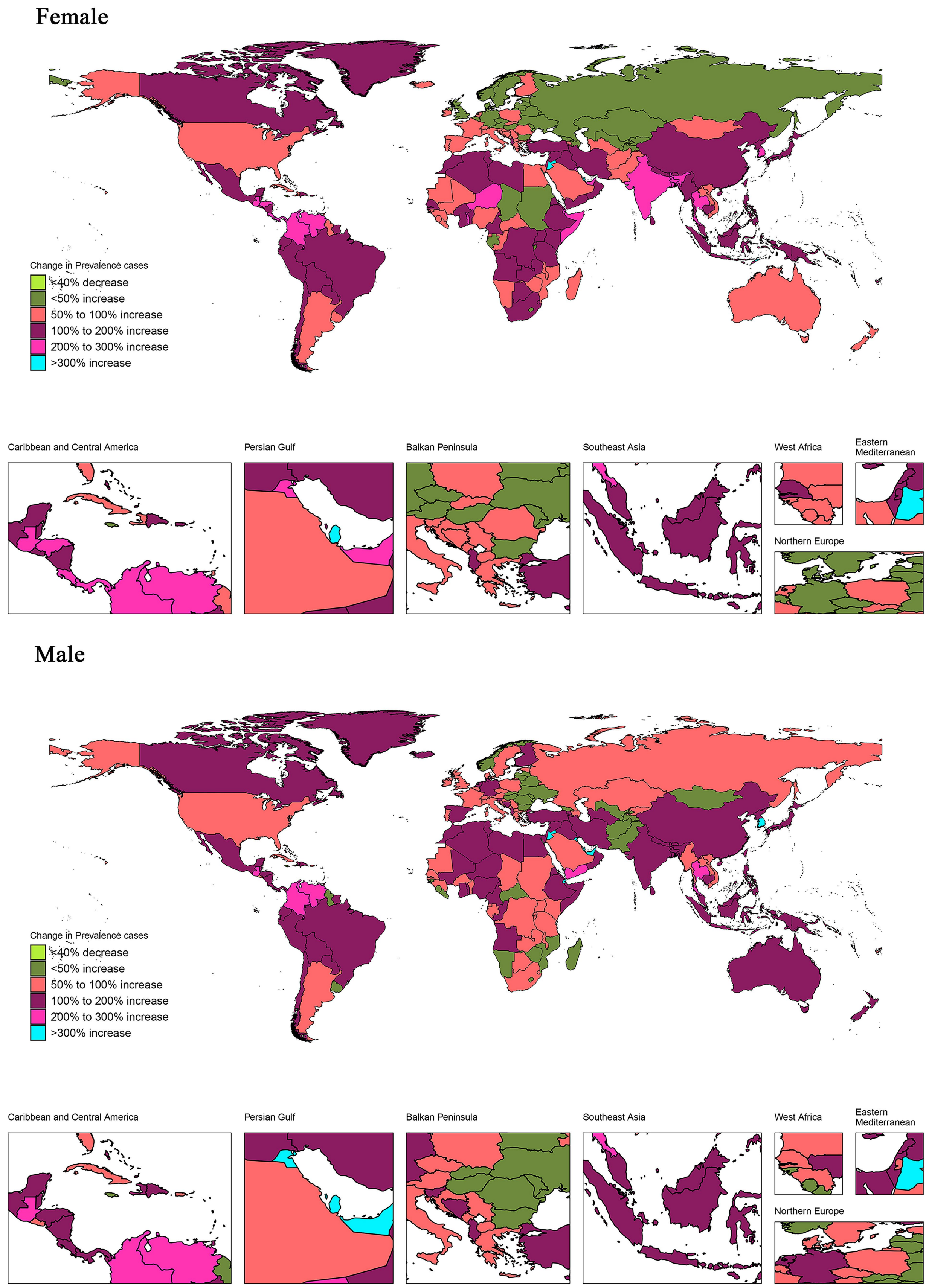

FIGURE 1
Proportion of changes in prevalence number associated with vision loss between 1990 and 2019 in 204 countries and regions. The proportion of change in prevalence number was calculated as the change in prevalence number between 1990 and 2019 divided by prevalence number in

(Continued)

FIGURE 1 (Continued)
1990 × 100%. Countries and regions with negative proportions were treated as a single category. Countries and regions with positive proportions were classified into 5 categories according to quintiles of positive proportions. The maps were drawn using the R package "maps," which was based on the data from the Natural Earth project.

showed a significant increase in prevalence (AAPC = 0.2; 95% CI: 0.12 to 0.28; $p < 0.001$), while YLDs did not change significantly ($p = 0.482$).

3.4 Burden trends of overall vision loss by SDI

Vision loss epidemiology is driven by population growth, aging, and epidemiological changes. Globally and within each SDI quintile, there was a significant increase in YLDs attributed to vision loss over the past 30 years. The most substantial increase in YLDs was observed in the Middle and Low-middle SDI quintiles (Figure 3). YLDs contributed most to aging in the Middle SDI quintile, while declining in the High SDI, High-middle SDI, Low-middle SDI, and Low SDI quintiles. A significant amount of changes in vision loss YLDs between SDI quintiles were associated with shifts in age and population, with population growth playing a larger role in Low-SDI and Low-middle-SDI countries.

In order to gain a better understanding of the YLD rates of vision loss and a country's development status, we built a frontier analysis based on age-standardized YLDs rates and SDI using data from 1990 to 2019 (Figure 4). The trends in vision loss YLDs and epidemiological changes varied across different GBD regions, with some regions experiencing decreases in age-standardized YLD rate and others showing increasing trends. Frontier lines indicate the areas with the lowest YLD rates (optimal performers) based on their SDI. A country's effective distance from the frontier is defined as the gap between a country's observed and potentially achievable YLDs; this gap can be reduced or eliminated based on the country or region's sociodemographic resources. In 2019, the SDI and YLDs were used to calculate the effective difference between each country and region (Figure 4 and Supplementary Table S6). As SDI increased, the effective difference tended to be smaller and less variable.

3.5 Burden trends of specific causes of vision loss by SDI

Based on the predominant causes of vision loss related to population aging, we conducted a decomposition analysis and frontier analysis focusing on six key factors: glaucoma, cataracts, AMD, refractive disorders, near vision loss and other causes. Decomposition analysis of YLDs in specific causes of vision loss was shown in Supplementary Figure S1. Trends in the burden of cataract and near vision loss by SDI quintiles were consistent with trends in the burden of overall causes of vision loss, both showing the greatest contribution of YLDs to the aging of middle SDI quintiles with a gradual decrease on either side. Additionally, glaucoma and refraction disorders showed the greatest contribution of YLDs to the aging of high SDI quintiles, while AMD and other causes had the highest contribution in high-middle SDI quintiles, with a gradual decrease on either side. The frontier analysis demonstrates consistent characteristics of the frontier line, revealing that as SDI increases, the effective differences tend to decrease in size and become less variable (Supplementary Figure S2).

4 Discussion

This study comprehensively analyzed the prevalence rates and YLDs related to vision loss among individuals aged 65 years and older from 1990 to 2019. The research explored various factors, including the specific types of vision loss, different age groups, geographical regions, countries, and SDI quintiles. Our findings shed light on the complexities of vision loss in the geriatric population and underscore potential areas for targeted interventions across different demographics.

In 2019, there were 293.67 million cases of vision loss and 11.18 million YLDs worldwide. The prevalence increased and the YLD rate decreased, with AAPCs of 0.11 and − 0.12, respectively. Our findings are consistent with those of a previous report that conducted a systematic review and meta-analysis of population-based surveys on global vision impairment and blindness (22). Evaluating the increase in life expectancy during the study period, our analysis indicates a substantial increase in the number of cases of vision loss globally. This increase coincides with a notable rise in the global older adults population, indirectly reflecting the rising life expectancy and its implications on health system demands, including the need for enhanced vision care services. While our study did not directly analyze changes in life expectancy, the growing number of older adults individuals experiencing vision loss mirrors the implications of increased life expectancy on public health and vision care needs.

The rise in the prevalence of vision impairment can be attributed to a range of factors. A primary driver is the escalating demand for vision care services stemming from demographic shifts and changes in lifestyle (23). With the global population continuing to expand and age, the incidence of age-related vision conditions like cataracts, AMD and near vision loss is on the rise. Improved diagnostic capabilities and advancements in healthcare infrastructure have contributed to better detection and reporting of vision disorders in various regions. High-income and high-middle SDI regions are often home to populations with longer life expectancies (24, 25), leading to a greater number of individuals reaching an age where vision disorders are more prevalent. Additionally, lifestyle factors such as smoking (26–28) and exposure to sunlight (29–31) have been shown to increase the risk of cataracts and AMD, particularly in high-middle SDI regions like Eastern Europe and High-income Asia Pacific (32). In high SDI regions, shifts in lifestyles and habits such as prolonged screen time can contribute to an increased prevalence rate of near vision loss (33). Access to advanced healthcare systems in high SDI regions also plays a role in the higher prevalence rates. Individuals in these regions have better options for vision correction, such as eyeglasses, contact lenses, or refractive surgeries, which can result in more individuals seeking and receiving appropriate treatment for refractive error. Presbyopia, which occurs due to the natural age-related decline in the eyes'

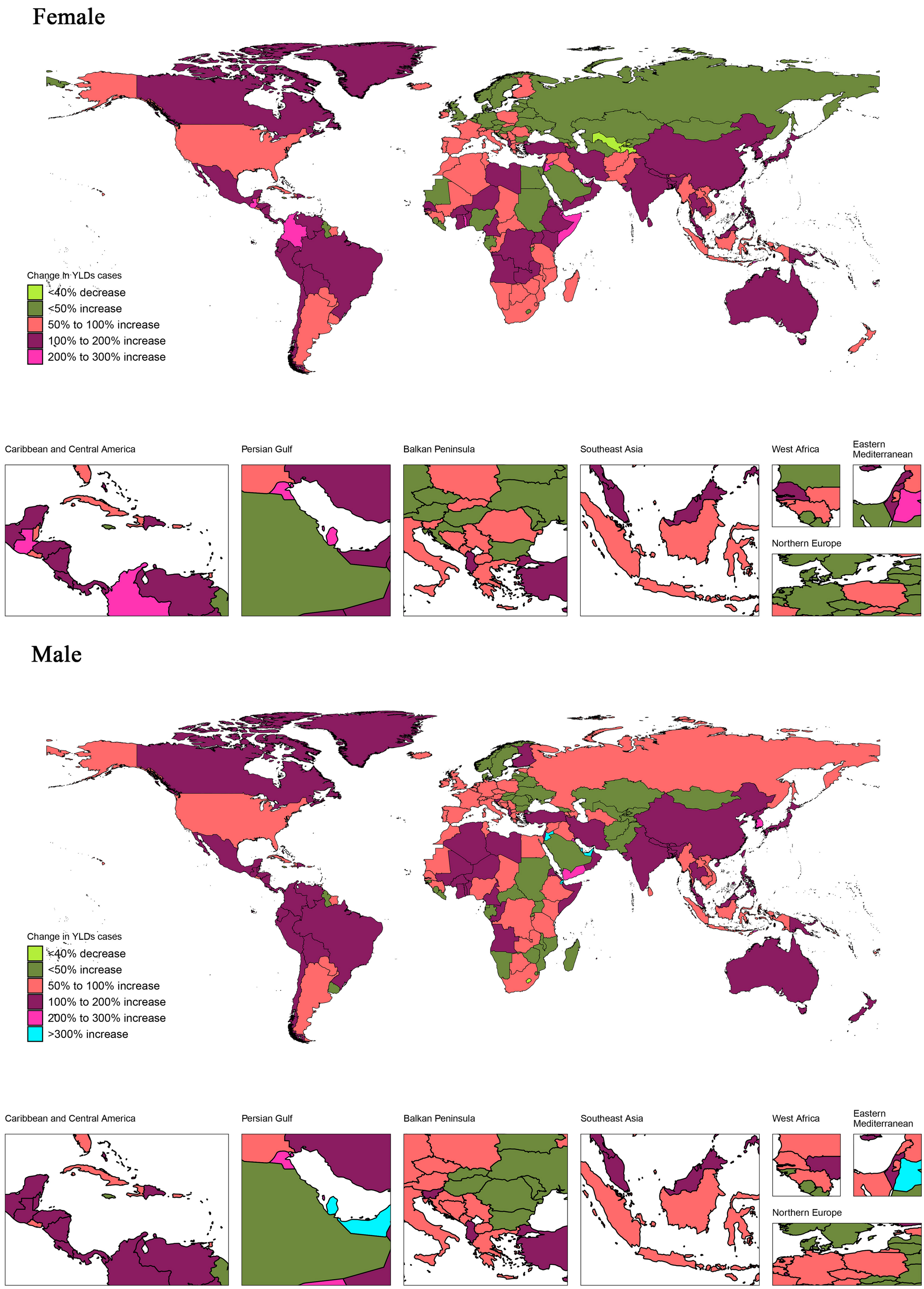

FIGURE 2
Proportion of changes in YLDs associated with vision loss between 1990 and 2019 in 204 countries and regions. The proportion of change in YLDs was calculated as the change in YLD between 1990 and 2019 divided by YLD in 1990 × 100%. Countries and regions were categorized into a single group with negative proportions, while those with positive proportions were divided into five categories based on quintiles. YLDs, years lived with disability.

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TABLE 1 Prevalence and years lived with disability (YLDs) for overall vision loss in global and regional populations (age ≥ 65 years) from 1990 to 2019.

	Prevalence						YLDs					
	1990		2019		AAPC,1990–2019	*p*-value	1990		2019		AAPC,1990–2019	*p*-value
	cases (n)	ASPR (per 100,000 population)	cases (n)	ASPR (per 100,000 population)			cases (n)	ASYR (per 100,000 population)	cases (n)	ASYR (per 100,000 population)		
Global	127,849,966	40027.0 (32232.9–49945.1)	293,674,327	40965.8 (32911–51358.3)	0.11 (0.07 to 0.14)	<0.001	5,322,245	1713.5 (1216.2–2339.7)	11,187,620	1579.1 (1108.3–2168.9)	−0.12 (−0.23 to −0.01)	**0.035**
Sex												
Male	53,164,877	39287.2 (31570.5–49178.7)	125,601,695	39027.5 (31281.6–49128.1)	0.01 (−0.06 to 0.08)	0.734	2,185,399	1691.6 (1202.3–2,309)	4,677,036	1492.2 (1045.1–2053.1)	−0.28 (−0.38 to −0.18)	**<0.001**
Female	74,685,089	40606.3 (32681.8–50553.7)	168,072,632	42567.6 (34208.9–53315.5)	0.19 (0.17 to 0.21)	<0.001	3,136,846	1733.9 (1232.2–2369.7)	6,510,584	1,651 (1160.4–2266.8)	−0.05 (−0.16 to 0.07)	0.43
Age group, years												
65–69	42,101,113	34093.1 (26388.3–43397.7)	92,267,021	35681.7 (27642–45,366)	0.15 (0.09 to 0.2)	<0.001	1,492,096	1208.3 (839.3–1696.6)	2,926,040	1131.6 (776.1–1603.7)	−0.2 (−0.31 to −0.09)	**<0.001**
70–74	33,638,614	39802.7 (32000.2–49428.2)	74,687,619	39921.3 (32083–49895.1)	0.03 (−0.02 to 0.07)	0.23	1,363,851	1613.8 (1151.3–2210.4)	2,719,515	1453.6 (1017.5–2000.2)	−0.25 (−0.39 to −0.11)	**0.001**
75–79	26,224,165	42773.6 (34876.7–53931.8)	55,748,941	43878.2 (35758.5–55360.9)	0.09 (0 to 0.18)	0.042	1,148,318	1873.0 (1341.1–2562.5)	2,259,834	1778.6 (1262.7–2443.9)	−0.15 (−0.24 to −0.06)	**0.001**
80–84	16,073,570	45638.1 (37659.8–56516.7)	39,704,725	47031.1 (38616.8–58925.7)	0.17 (0 to 0.35)	0.055	775,072	2200.7 (1569.6–2,952)	1,728,723	2047.7 (1450.5–2758.2)	−0.06 (−0.36 to 0.25)	0.706
85–89	7,175,646	47619.5 (39848.7–57464.6)	20,851,596	47955.8 (39776–58380.2)	0.04 (−0.04 to 0.12)	0.294	382,115	2535.8 (1821.1–3366.8)	993,074	2283.9 (1629.1–3039.1)	−0.24 (−0.46 to −0.02)	**0.029**
90–94	2,124,299	48213.7 (40977.2–56546.7)	8,135,642	48261.0 (40534.5–57555.6)	−0.01 (−0.06 to 0.05)	0.784	126,645	2874.4 (2049–3778.9)	426,615	2530.7 (1795.4–3350.5)	−0.42 (−0.5 to −0.34)	**<0.001**
95+	512,559	49789.8 (41592.1–58369.7)	2,278,781	47741.1 (39223.2–57022.1)	−0.14 (−0.18 to −0.09)	<0.001	34,145	3316.8 (2336.7–4428.6)	133,820	2803.6 (1983.4–3792.5)	−0.55 (−0.58 to −0.52)	**<0.001**
Sociodemographic index												
High	13,179,895	13451.5 (10971.5–16493.9)	25,520,118	13412.5 (10898.5–16543.5)	0.04 (0 to 0.09)	0.069	535,161	550.0 (384–754.2)	983,828	507.9 (352.6–700.4)	−0.15 (−0.22 to −0.09)	**<0.001**
High-middle	37,221,322	42877.7 (33641.2–54823.5)	77,614,558	42228.3 (33190.1–53974.5)	−0.03 (−0.06 to 0)	0.09	1,225,703	1465.5 (1016.5–2035.6)	2,459,535	1353.7 (929.3–1897.8)	−0.07 (−0.15 to 0.02)	0.118
Middle	39,984,412	54459.6 (43650.1–68235.1)	102,118,249	51049.5 (40809.1–64436.2)	−0.19 (−0.24 to −0.13)	<0.001	1,745,223	2524.4 (1788.8–3429.6)	3,959,525	2046 (1440.9–2804.7)	−0.51 (−0.76 to −0.25)	**<0.001**

(Continued)

TABLE 1 (Continued)

	Prevalence						YLDs					
	1990		2019		AAPC,1990–2019	p-value	1990		2019		AAPC,1990–2019	p-value
	cases (n)	ASPR (per 100,000 population)	cases (n)	ASPR (per 100,000 population)			cases (n)	ASYR (per 100,000 population)	cases (n)	ASYR (per 100,000 population)		
Low-middle	26,830,514	63909.8 (52799.9–77,796)	65,087,888	59989.6 (48880.1–74110.3)	−0.18 (−0.21 to −0.14)	<0.001	1,347,089	3391.7 (2427.6–4574.6)	2,818,977	2688.2 (1900.9–3671.3)	−0.66 (−0.77 to −0.54)	**<0.001**
Low	10,570,892	64551.3 (52595.5–78745.1)	23,202,944	62630.6 (51024.7–76932.4)	−0.08 (−0.16 to −0.01)	0.032	466,193	3055.8 (2183.3–4134.7)	960,346	2717.8 (1928.6–3,714)	−0.29 (−0.42 to −0.16)	**<0.001**
Region												
Andean Latin America	762,685	48675.6 (39871.5–60332.6)	2,164,611	45651.5 (36650.4–57073.9)	−0.25 (−0.32 to −0.18)	<0.001	762,685	2535.4 (1775.6–3490.8)	2,164,611	1934.8 (1337.1–2,673)	−0.88 (−1.08 to −0.68)	**<0.001**
Australasia	265,990	12422.6 (10523.7–14595.4)	558,935	11331.1 (9215.5–13,898)	−0.25 (−0.4 to −0.1)	0.001	265,990	511.8 (355.6–698.3)	558,935	472.6 (328.2–645.3)	−0.1 (−0.26 to 0.07)	0.238
Caribbean	957,101	42820.3 (33227.6–55719.4)	1,833,112	39842.1 (30782.5–51781.5)	−0.21 (−0.23 to −0.19)	<0.001	957,101	1649.8 (1142.7–2293.5)	1,833,112	1362.4 (932.9–1903.1)	−0.59 (−0.61 to −0.56)	**<0.001**
Central Asia	1,900,830	55285.9 (43144.1–70434.6)	2,545,400	53161.6 (41152–68593.7)	−0.14 (−0.2 to −0.08)	<0.001	1,900,830	1946.3 (1336.9–2727.4)	2,545,400	1697.3 (1153–2,393)	−0.51 (−0.62 to −0.4)	**<0.001**
Central Europe	5,909,295	46852.7 (34413–63,050)	9,458,374	44670.3 (32795.2–60137.9)	−0.06 (−0.1 to −0.01)	0.014	5,909,295	1022.4 (654.2–1549.7)	9,458,374	938.3 (590.7–1,439)	−0.16 (−0.23 to −0.09)	**<0.001**
Central Latin America	3,117,808	49724.8 (39478.6–63094.1)	9,387,270	47618.2 (37079.5–61068.8)	−0.11 (−0.14 to −0.08)	<0.001	3,117,808	2,158 (1515.4–2954.8)	9,387,270	1702 (1178.1–2359.8)	−0.72 (−0.85 to −0.58)	**<0.001**
Central Sub-Saharan Africa	834,794	57028.3 (42104.4–75112.5)	1,803,244	54942.6 (40808.1–73074.3)	−0.1 (−0.24 to 0.04)	0.158	834,794	1481.8 (983.6–2159.1)	1,803,244	1379.3 (906.4–2031)	−0.07 (−0.25 to 0.11)	0.462
East Asia	34,284,300	52953.3 (40390.4–69197.6)	89,049,826	49475.8 (38057.9–64,462)	−0.17 (−0.27 to −0.07)	0.001	34,284,300	1694.8 (1166.3–2375.1)	89,049,826	1486.1 (1002.6–2103.4)	−0.19 (−0.78 to 0.41)	0.536
Eastern Europe	12,730,806	55123.3 (42491.1–70967.3)	18,022,574	56232.3 (43032.7–72855.4)	0.06 (0.02 to 0.11)	0.003	12,730,806	1574.1 (1056.4–2265.4)	18,022,574	1,460 (960–2154.9)	−0.19 (−0.28 to −0.11)	**<0.001**
Eastern Sub-Saharan Africa	3,364,901	64,271 (50586.8–80,276)	6,654,041	60,133 (47150.5–76049.8)	−0.22 (−0.27 to −0.17)	<0.001	3,364,901	2738.5 (1934.7–3727.8)	6,654,041	2388.6 (1687.5–3277.7)	−0.45 (−0.58 to −0.32)	**<0.001**
High-income Asia Pacific	1,592,137	9667.9 (8015.8–11621.9)	4,687,725	9480.7 (7816–11449.3)	0.2 (0.12 to 0.28)	<0.001	1,592,137	484.2 (338.7–660.4)	4,687,725	450.3 (312.2–618.5)	0.07 (−0.12 to 0.25)	0.482

(Continued)

TABLE 1 (Continued)

	Prevalence						YLDs					
	1990		2019		AAPC,1990–2019	*p*-value	1990		2019		AAPC,1990–2019	*p*-value
	cases (n)	ASPR (per 100,000 population)	cases (n)	ASPR (per 100,000 population)			cases (n)	ASYR (per 100,000 population)	cases (n)	ASYR (per 100,000 population)		
High-income North America	3,748,514	10868.7 (8784.5–13500.7)	6,571,011	10716.5 (8651–13330.8)	−0.05 (−0.12 to 0.02)	0.178	3,748,514	427.3 (300.5–582.1)	6,571,011	406.6 (285.5–554.9)	−0.17 (−0.26 to −0.07)	**0.001**
North Africa and Middle East	5,400,635	44883.5 (37856.3–53947.6)	12,279,852	39775.1 (33147.4–48189.7)	−0.34 (−0.41 to −0.28)	<0.001	5,400,635	2747.3 (1943.8–3730.4)	12,279,852	2018.6 (1421.8–2744.5)	−0.96 (−1.05 to −0.86)	**<0.001**
Oceania	104,332	55621.9 (45526.5–68218.6)	231,532	54142.2 (44062.8–66668.9)	−0.07 (−0.23 to 0.09)	0.413	104,332	2327.4 (1619.3–3205.1)	231,532	2115.5 (1466.1–2924.9)	−0.29 (−0.58 to 0.01)	0.061
South Asia	27,196,147	71820.5 (60767.3–85211.9)	74,805,014	66778.6 (55349.7–81070.5)	−0.21 (−0.24 to −0.18)	<0.001	27,196,147	4087.6 (2937.6–5478.9)	74,805,014	3143.5 (2236.8–4268.4)	−0.76 (−0.88 to −0.63)	**<0.001**
Southeast Asia	9,833,193	55732.9 (47128.6–66380.4)	22,442,888	50644.9 (42552.2–61298.2)	−0.31 (−0.37 to −0.24)	<0.001	9,833,193	3607.5 (2573.5–4844.8)	22,442,888	2680.3 (1908.7–3,614)	−1 (−1.12 to −0.88)	**<0.001**
Southern Latin America	592,537	15296.7 (12836.4–18084.1)	1,125,434	14479.5 (12086.1–17191.8)	−0.03 (−0.08 to 0.01)	0.125	592,537	816.8 (568.5–1118.1)	1,125,434	708.3 (489.9–974.5)	−0.27 (−0.33 to −0.22)	**<0.001**
Southern Sub-Saharan Africa	1,540,857	71661.6 (54521.1–89290.9)	2,939,557	67931.4 (51008.7–87105.2)	−0.18 (−0.2 to −0.15)	<0.001	1,540,857	2453.2 (1704.7–3,392)	2,939,557	2016.4 (1390.2–2845.9)	−0.7 (−0.85 to −0.54)	**<0.001**
Tropical Latin America	2,838,342	42423.8 (34591.6–52836.7)	7,955,527	39029.6 (31453.8–49169.8)	−0.12 (−0.31 to 0.06)	0.19	2,838,342	2135.3 (1514.9–2886.4)	7,955,527	1745.5 (1230.4–2383.6)	−0.51 (−0.79 to −0.23)	**<0.001**
Western Europe	7,066,664	12659.2 (10610.2–15053.4)	11,553,114	12050.1 (10056.4–14401.6)	0 (−0.08 to 0.08)	0.931	7,066,664	678.1 (474.4–924.1)	11,553,114	611.6 (426.6–836.1)	−0.14 (−0.23 to −0.05)	**0.003**
Western Sub-Saharan Africa	3,808,095	58971.4 (46872.9–74301.8)	7,605,285	59534.8 (47715.7–74207.8)	0.06 (−0.03 to 0.16)	0.185	3,808,095	2888.4 (2052.2–3923.7)	7,605,285	2686.5 (1898–3,677)	−0.19 (−0.42 to 0.04)	0.104

YLD, years lived with disability; ASPR, age-standardized prevalence rate; ASYR, age-standardized YLD rate; AAPC, average annual percentage changes. *P*-values less than 0.05 are considered statistically significant and are highlighted in bold.

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TABLE 2 Global and sociodemographic index (SDI) quintile data on numbers for overall vision loss and age-standardized rates for specific causes of vision loss in 2019, with percentage changes from 1990 (age > =65 years).

	Prevalence number		Due to glaucoma		Due to cataract		Due to age-related macular degeneration		Due to refraction disorders		Due to near vision loss		Due to other causes	
Location	Number (UI)	Percentage change from 1990	Rate (UI)	Percentage change from 1990	Rate (UI)	Percentage change from 1990	Rate (UI)	Percentage change from 1990	Rate (UI)	Percentage change from 1990	Rate (UI)	Percentage change from 1990	Rate (UI)	Percentage change from 1990
Global	293674326.1 (235534978.8–368549406.2)	129.70%	874.8 (688–1087.1)	−15.76%	9729.4 (7970.1–11751.9)	6.95%	827.3 (645.3–1037.1)	−2.62%	6093.9 (4817–7,602)	−5.55%	29491.1 (19148.1–42899.6)	2.11%	2844.9 (2259–3566.2)	−5.43%
High SDI	25520118.3 (20798851.9–31388714.4)	93.60%	488 (381.9–612.6)	−9.19%	3003.2 (2313.9–3843.4)	−1.01%	446.4 (344.9–562.7)	−14.66%	2,743 (2106.6–3525.9)	−3.52%	6710.6 (4316.8–9,969)	3.59%	1096.4 (799.5–1478.5)	−5.3
High-middle SDI	77614557.5 (60904484.0–99308023.0)	108.52%	769.7 (605.4–959.4)	−18.74%	7624.4 (6062–9445.5)	14.81%	925.7 (718.7–1166.1)	4.22%	5620.8 (4394.7–7088.4)	−6.84%	31,571 (20604.6–45735.2)	−2.63%	2,986 (2355.9–3760.1)	−19.81%
Middel SDI	102118249.3 (81303185.5–129165833.6)	155.40%	1066.4 (840.6–1328.2)	−24.31%	12972.3 (10744–15456.2)	−5.94%	958.8 (747.2–1204.7)	−3.49%	6785.9 (5369.3–8,450)	−11.32%	37250.9 (23976.5–54705.5)	−7.93%	3796.9 (3066.3–4670.9)	−10.60%
Low-middle SDI	65087888.2 (52871879.6–80566062.5)	142.59%	1119.4 (881.7–1393.2)	−27.24%	17774.8 (14825–21077.8)	−10.86%	895.1 (699.6–1117.1)	−18.00%	10302.4 (8234.4–12694.1)	−18.44%	44487.8 (28774–65057.8)	−6.68%	3784.4 (3005.8–4,734)	−3.41%
Low SDI	23202943.7 (18818980.4–28578866.8)	119.50%	1753.6 (1378.2–2181.8)	−18.09%	15921.4 (13308–18866.7)	−1.23%	1145.0 (902.2–1423.1)	−1.72%	8239.6 (6593.5–10133.2)	−6.28%	49526.2 (33624.7–69192.3)	−4.84%	3680.3 (2906.1–4623.6)	5.01%

SDI, sociodemographic index.

TABLE 3 Global and sociodemographic index (SDI) quintile data on numbers of years lived with disability (YLDs) for overall vision loss and age-standardized rate for specific causes of vision loss YLDs in 2019, with percentage changes from 1990 (age > =65 years).

	Prevalence number		Due to glaucoma		Due to cataract		Due to age-related macular degeneration		Due to refraction disorders		Due to near vision loss		Due to other causes	
	Number (UI)	Percentage change from 1990	Rate (UI)	Percentage change from 1990	Rate (UI)	Percentage change from 1990	Rate (UI)	Percentage change from 1990	Rate (UI)	Percentage change from 1990	Rate (UI)	Percentage change from 1990	Rate (UI)	Percentage change from 1990
Global	11187620.2 (7845107.2–15390016.3)	110.21%	88.7 (58.3–129.9)	−25.40%	648.0 (451.4–890.2)	−7.72%	60.5 (40.3–86.7)	−14.79%	284.2 (188.9–405.3)	−8.29%	284.7 (121.9–565.8)	2.30%	212.9 (146–300.1)	−8.70%
High SDI	983828.4 (683795.4–1353356.3)	83.84%	50.5 (33.4–73.7)	−15.13%	162.1 (107.8–229.2)	−6.79%	38.8 (25.4–56.6)	−22.24%	121.6 (78.7–178.2)	−5.00%	64.6 (27.5–129.6)	3.69%	70.3 (46.5–101.1)	−8.10%
High-middle SDI	2459534.9 (1686538.8–3452585.7)	100.66%	78.2 (51.4–114.7)	−29.68%	440.9 (304–611.8)	1.08%	66.6 (44.4–95.3)	−12.14%	254.4 (167.3–367.7)	−5.39%	306.3 (130.6–610)	−2.17%	207.4 (142.6–289.9)	−20.32%
Middel SDI	3959524.8 (2781266.2–5452397.5)	126.88%	106.1 (69.8–156.2)	−35.58%	882.2 (616–1210.8)	−22.55%	65.1 (43.2–93)	−13.89%	329.8 (219.9–468.1)	−14.78%	359.5 (152.6–713.1)	−7.82%	303.3 (207.2–429.3)	−17.58%
Low-middle SDI	2818977.1 (1988172.2–3866223.9)	109.26%	110.5 (72.7–161.7)	−34.42%	1314.8 (920.5–1795.1)	−23.64%	64.5 (43.4–91.7)	−24.83%	479.6 (320.3–678.7)	−24.46%	425.2 (180.8–847.1)	−6.55%	293.5 (201.2–413.8)	−9.83%
Low SDI	960346.3 (679488.9–1320247.3)	106.00%	201.0 (130.4–296.7)	−22.69%	1230.7 (859.9–1695.8)	−13.46%	84.7 (57.2–120.1)	−9.41%	400.9 (269.1–564.6)	−10.85%	476.3 (207.2–926.8)	−4.61%	324.2 (219.7–468.3)	−2.17%

SDI, sociodemographic index; YLDs, years lived with disability.

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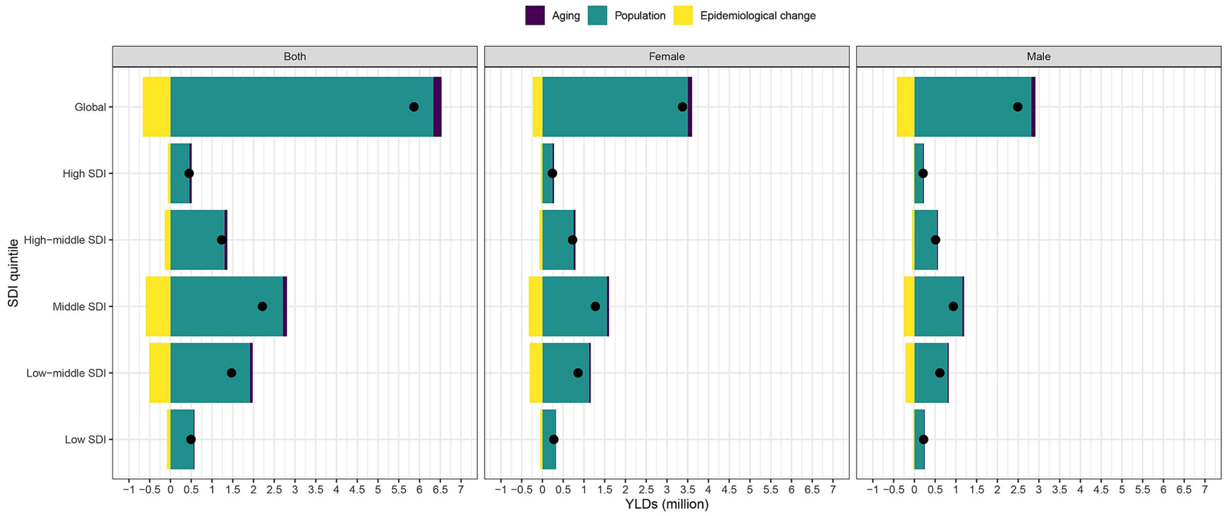

FIGURE 3
Changes in overall vision loss YLDs according to population-level determinants of population growth, aging and epidemiological change from 1990 to 2019 at the global level and by SDI quintile. The black dot represents the overall value of change contributed by all three components. For each component, the magnitude of a positive value indicates a corresponding increase in vision loss YLDs attributed to the component, and the magnitude of a negative value indicates a corresponding decrease in vision loss YLDs attributed to the related component. YLDs, years lived with disability, SDI, socio-demographic index.

focusing ability, manifests when the clarity of near vision becomes insufficient despite optimal correction for distance vision. To effectively address these challenges, we propose the integration of vision care into broader healthcare strategies aimed at the aging population, emphasizing the importance of preventive measures and accessible corrective solutions, such as eyeglasses and contact lenses.

Our analysis highlights a significant global increase in the prevalence of vision loss due to cataracts, with a 6.95% rise from 1990 to 2019. This trend underscores that, even with marked improvements in cataract surgery techniques and earlier interventions, the total cases of vision loss attributable to cataracts have climbed. This phenomenon can primarily be attributed to the surge in the global aging population, which has expanded more rapidly than the rate of medical advancements in treating cataracts. Additionally, our study reveals notable differences across various SDI quintiles, with high-middle SDI regions experiencing a 14.81% increase in cataract-related vision loss, highlighting substantial global disparities in the accessibility to and execution of modern cataract surgery techniques. In contrast, low SDI regions demonstrated a decrease of −1.23%, suggesting a critical role of broader factors such as healthcare access and diagnostic capabilities in managing cataract-related vision impairment. These findings illustrate the intricate relationship between demographic shifts, progress in medical technologies, and healthcare access in addressing the challenge of cataract-induced vision loss. Despite advancements in surgical methods facilitating earlier diagnoses and treatments, the overall rise in cataract cases emphasizes the urgent need for comprehensive public health strategies. Such strategies should extend beyond merely enhancing surgical access to include a wider spectrum of eye care services, ensuring they are accessible and affordable for the aging population worldwide. The increase in vision loss due to cataracts, despite the evolution of surgical interventions, necessitates policy initiatives aimed at augmenting global access to cataract surgery, particularly focusing on enhancing healthcare infrastructure in lower SDI regions. This approach is vital for mitigating the burden of vision loss on the aging demographic, ensuring equitable healthcare access, and fostering a healthier global community.

Notably, the GBD 2019 findings highlight that women exhibit higher prevalence rates and YLDs of vision loss compared to men. The increase in both prevalence and YLD rates of vision loss was greater among females than males. Possible factors contributing to this discrepancy include the postmenopausal decline in estrogen, which can thin the nerve fiber layer (34) and an elevated risk of cataracts (35), thereby increasing susceptibility to vision loss in women. The decline in estrogen levels may also have implications for ocular surface tissues and tear secretion (36), exerting additional effects on vision.

The study also highlights the significant burden of near vision impairment in the older population. In 2015, an estimated 666.7 million people aged 50 years or older experienced this condition (37). Additionally, a 2018 meta-analysis estimated that 826 million people had near vision impairment due to no or inadequate presbyopic correction (38). Based on the analysis from GBD 2019, it was estimated that there were approximately 250.2 million individuals aged 65 years and older who experienced near vision loss in 2019. It is noteworthy that both the prevalence of near vision loss and YLDs associated with it have been on the rise, particularly among women. Our analysis reveals a nuanced picture of vision loss due to refractive disorders, including near vision loss, which directly relates to the necessity for glasses. Globally, we observed a slight increase of 2.11% in the prevalence of vision loss due to near vision impairment from 1990 to 2019. This increase suggests that, despite advances in vision care and the availability of corrective lenses, the demand for and access to glasses has not fully mitigated the burden of vision loss attributable to refractive errors in the older adults population. The lack of a definition for near vision impairment in the International Classification of Diseases until 2019 limited the ability to provide a

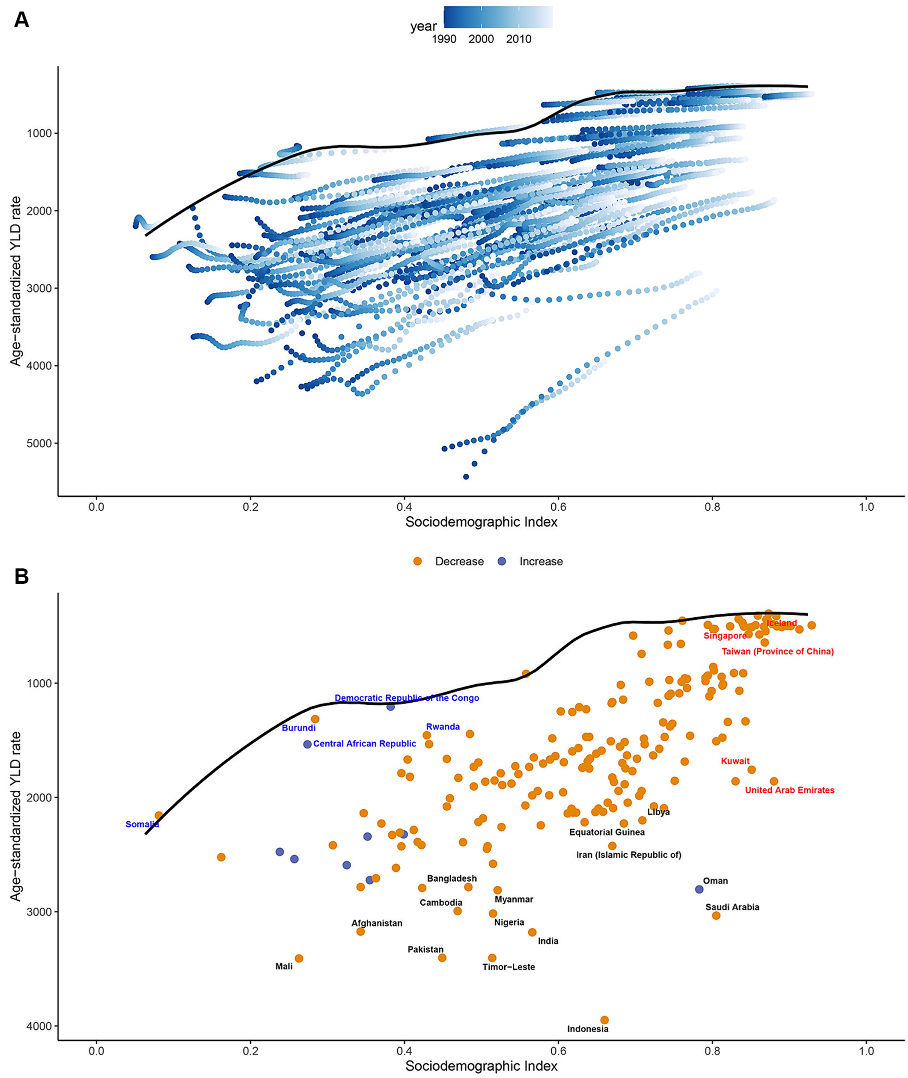

FIGURE 4
(A) Frontier analysis based on SDI and age-standardized overall vision loss YLDs rate from 1990 to 2019. The frontier is delineated in solid black color; countries and territories are represented as dots. **(B)** Frontier analysis based on SDI and age-standardized overall vision loss YLDs rate in 2019. The top 15 countries with the largest effective difference (largest overall vision loss YLDs gap from the frontier) are labeled in black; examples of frontier countries with low SDI (<0.5) and low effective difference are labeled in blue (e.g., Democratic Republic of the Congo, Rwanda, Burundi, Central African Republic and Somalia); and examples of countries and territories with high SDI (>0.85) and relatively high effective difference for their level of development are labeled in red (e.g., Iceland, Singapore, Taiwan, Kuwait and United Arab Emirates). Red dots indicate an increase in overall vision loss YLDs rate from 1990 to 2019; blue dots indicate a decrease in age-standardized overall vision loss YLDs rate between 1990 and 2019. YLDs, years lived with disability; SDI, socio-demographic index.

comprehensive analysis of temporal changes in the prevalence of vision impairment due to uncorrected presbyopia. Nonetheless, this underscores the importance of conducting surveys that incorporate a near vision component to gain better insights into future trends in this area.

Several limitations should be acknowledged in our study. Firstly, the reliance on the GBD 2019 dataset, while comprehensive, imposes constraints on our study's granularity regarding specific causes of vision loss not classified within the main categories. Data availability varied across different world regions, leading to significant data gaps as previously described. Secondly, many studies were not conducted at a national level, and regional assessments were predominant for several countries. This may affect the uniformity and standardization of diagnostic tools and criteria used across different studies, given the diversity of healthcare systems and practices worldwide. Policy-making regarding vision impairment typically occurs at a national level, making national-level data more relevant. Furthermore, our study's definitions and categorization of vision loss were aligned with the GBD 2019 criteria, which categorize vision impairment based on visual acuity in the better-seeing eye. This approach allowed us to cover a broad spectrum of vision impairment, from mild vision loss to complete blindness. However, it also meant that other significant causes of vision loss, such as diabetic retinopathy, stroke, and retinal detachment, were not included as primary focus areas due to their classification under "other causes" in the GBD framework. The issue of under-corrected presbyopia has often been overlooked, even in major ophthalmology studies, resulting in less precise estimates. Additionally, variations in measurement methods, such as objective versus functional presbyopia, test distance, and font size, further contribute to limitations in studies involving uncorrected presbyopia. In light of these concerns, we emphasize the need for future research to explore these other significant causes of vision loss more deeply, utilizing datasets that may offer more detailed categorization and diagnostic clarity. We are committed to enhancing the understanding of our study's methodological rigor and the reliability of its findings, contributing valuable insights into the global burden of vision loss and its determinants.

Overall, this study provides valuable insights into the prevalence and impact of vision loss in the aging population, highlighting the need for comprehensive vision care services and interventions targeting different age groups and genders. Moreover, our discussion identifies future research directions focusing on lifestyle changes, early screening for age-related vision conditions, and the development of interventions tailored to mitigate identified risk factors.

5 Conclusion

The past three decades have witnessed remarkable advancements in mitigating the impact of blindness and vision loss among individuals aged 65 years and above worldwide. This encouraging trend is a testament to the progress made in eye care and public health initiatives. However, it is crucial to acknowledge that significant variations persist in the burden of these conditions, influenced by factors such as the type of impairment, a country's SDI, and specific age groups.

The presence of age-specific variations in the burden of vision loss underscores the necessity for targeted interventions. Older adults often exhibit distinct risk profiles and have specific eye health needs compared to younger age groups. Tailoring screening programs, treatment protocols, and rehabilitation services to address the unique challenges faced by older adults can further reduce the burden of vision loss and enhance their overall quality of life.

In conclusion, while significant progress has been made in reducing the burden of blindness and vision loss among older adults, there is still work to be done. By implementing strategies that focus on improving screening coverage, ensuring quality control, addressing specific impairments like uncorrected presbyopia, and targeting interventions based on country SDIs and age groups, we can continue to make strides in reducing the burden of vision loss among older adults globally.

Data availability statement

Data are available on the Global Health Data Exchange GBD 2019 website (https://ghdx.healthdata.org/gbd-2019). Both the statistical code and detailed region-or country-specific decomposition results of vision loss are available upon request from YW at wangyb35@csu.edu.cn.

Author contributions

JY: Writing – review & editing, Investigation, Visualization. BJ: Data curation, Methodology, Writing – review & editing. TZ: Data curation, Methodology, Writing – review & editing. XG: Data curation, Methodology, Writing – review & editing. YT: Conceptualization, Data curation, Methodology, Visualization, Writing – review & editing. YW: Conceptualization, Formal analysis, Investigation, Project administration, Supervision, Writing – original draft.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2024.1324141/full#supplementary-material

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The global burden of cataracts and its attributable risk factors in 204 countries and territories: a systematic analysis of the global burden of disease study

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Introduction: The global distribution and trends in the attributable burden of cataract risk have rarely been systematically explored. To guide the development of targeted and accurate cataract screening and treatment strategies, we analyzed the burden of cataract disease attributable to known risk factors.

Method: This study utilized detailed cataract data from the Global Burden of Disease e 2019, and we analyzed disability-adjusted life years (DALYs) e each risk factor from 1990 to 2019. Additionally, we calculated estimated annual percentage changes (EAPCs) during the study period.

Results: The results revealed that from 1990–2019, the global age-standardized DALYs of e attributable to particulate matter pollution, smoking, high fasting glucose plasma and high BMI showed steady downward trends (1990–2009: EAPC = −0.21 [−0.57 −0.14]); 2000–2009: EAPC = −0.95 [−1.01 −0.89]; 2010–2019: EAPC = −1.41 [−1.8 −1.02]). The age-standardized DALYs and mortality caused by each risk factor were highest in the low-middle sociodemographic index (SDI) region (EAPC = −1.77[(−2.19−−1.34)]). The overall disease burden of cataracts is lower in males than in females. When analyzing the EAPCs of cataract disease burden for each risk factor individually, we found that the age-standardized disability-adjusted life years caused by particulate matter pollution and smoking decreased (PMP1990-2009: EAPC = −0.53 [−0.9−−0.16]; 2000–2009: EAPC = −1.39 [−1.45--1.32]; 2010–2019: EAPC = −2.27 [−2.75−−1.79]; smoking 2000 to 2009: EAPC = −1.51 [−1.6−−1.43], 2009 to 2019: EAPC = −1.34 [−1.68−−1])), while high fasting plasma glucose and high body mass index increased annually (HFPG1990 to 1999: EAPC = 1.27 [0.89–1.65], 2000 to 2009: EAPC = 1.02 [0.82–1.22], 2010–2019: EAPC = 0.44 [0.19–0.68]; HBMI 1990 to 1999: EAPC = 1.65 [1.37–1.94], 2000 to 2009: EAPC = 1.56 [1.43–1.68], 2010–2019: EAPC = 1.47 [1.18–1.77]).

Disscussion: The burden of cataracts caused by ambient particulate matter and smoking is increasing in low, low-middle SDI areas, and specific and effective measures are urgently needed. The results of this study suggest that reducing particulate matter pollution, quitting smoking, controlling blood glucose, and lowering BMI could play important roles in reducing the occurrence of cataracts, especially in older people.

KEYWORDS

cataract, risk factors, global burden of disease study 2019, particulate matter pollution, smoking, high fasting plasma glucose, high body mass index

1 Introduction

Cataract is defined as the loss of transparency of the lens, resulting in changes in refractive properties and increased light scattering, resulting in blurred vision or blindness (1). Cataracts are one of the leading causes of blindness worldwide (1, 2). The impact of cataracts on vision loss, particularly in older age groups, can significantly impact an individual's quality of life (3) by exacerbating the possibility of dementia (4), falls (5) and road traffic accidents (6).

Although cataracts can be treated with simple and cost-effective surgery, one of the e challenges facing global ophthalmology today remains the high risk of operable cataract blindness, especially in developing countries (7, 8).

The 2017 Global Burden of Disease (GBD) study reported that cataracts are the second largest burden of eye disease (8 million) resulting in disability-adjusted life years (DALYs), just behind near vision loss (9.8million) (9).

Globally, the number of DALYs due to cataracts increased by 91.2% globally from 1990 to 2019. Previous study also approved that aging, female sex, and lower socioeconomic status were associated with a higher cataract burden (10). Previous studies have shown that areas with a low sociodemographic index (SDI) have a greater burden of cataracts (11).

However, detailed information about cataract disease burden by region, sex, and age group at the specific risk factor level remains elusive, hampering cataract prevention and control. GBD research data from 1990 to 2019 show that the prevalence of risk factors has changed significantly over the past 30 years. Summary exposure values (SEVs) for household air pollution from smoking and solid fuels decreased in all SDI quintiles. In contrast, the SEV of environmental particulate matter pollution increased significantly (10). Findings from a UK Biobank study revealed a correlation between higher ambient exposure to PM 2.5 and an increased likelihood of future cataract surgery (12). The number of deaths and DALYs caused by high body mass index (BMI) increased significantly globally. A pattern of a temporary increase in disease burden is associated with a high BMI in areas with the lowest SDI (13). Previous Mendelian randomization studies have associated genetically higher BMI and susceptibility to type 2 diabetes with an increased likelihood of age-related cataracts (14). High fasting plasma glucose (HFPG), also occurs in males and in areas with lower SDI, is an important factor in increasing global and regional disease burden (15).

Changes in these risk factors that contribute to cataract disease burden are primarily influenced by economic development and demographic changes. Therefore, in addition to delineating the overall pattern of cataract burden, timely studies are needed to comprehensively examine the impact of various risk factors on cataract burden. In this study, we analyzed the burden of cataracts attributable to four risk factors from 1990 to 2019 by SDI, age, and sex to reveal the different trends and distribution characteristics of the burden caused by each risk factor.

2 Materials and methods

2.1 Data sources and definitions

The GBD study established a freely accessible database containing data on estimated attributable burdens obtained through standardized methods for various risk factors in all countries. GBD 2019 includes more than 3.5 billion estimates for 369 diseases and injuries, 286 causes of death, and 87 behavioral, environmental, occupational, and metabolic risk factors in 204 countries and territories from 1990 to 2019.

The GBD 2019 estimates the global burden by age and sex of 369 diseases and injuries and 87 risk factors in 204 countries and territories between 1990 and 2019 by quantifying the health costs of premature death and nonfatal disability (16).

The sociodemographic index (SDI) was developed by GBD researchers and calculated as the geometric mean of these indices: total fertility rate in those under 25 years old, mean education for those aged 15 years or older, and lag-distributed income *per capita*. The global countries and territories were categorized into five super regions according to the quintiles of country-level estimates of SDI for the year 2019: low-SDI (0 ~ <0.455), low-middle-SDI (0.455 ~ <0.608), middle-SDI (0.608 ~ <0.690), high-middle-SDI (0.690 ~ <0.805), and high-SDI (0.805–1).[1]

The particulate matter pollution in GBD 2019 included both outdoor and indoor PM 2.5 pollution. PM 2.5 refers to particulate matter with an aerodynamic diameter ≤ 2.5 μm. GBD 2019 identified different sources of PM 2.5: outdoor PM 2.5 pollution, also known as ambient particulate matter pollution (APMP), due to exposure to PM 2.5 in outdoor air, and indoor PM 2.5 pollution, also known as solid particulate matter pollution (HAP) fuel, which refers to exposure to PM 2.5 due to the use of solid cooking fuels (wood, coal, charcoal, agricultural residues and manure). The theoretical minimum risk exposure levels for APMP and HAP are evenly distributed between 2.4 $\mu g/m^3$ and 5.9 $\mu g/m^3$ and represent the level that minimizes risk at the population level or captures the maximum attributable burden (17).

According to the GBD Project, a current smoker is an individual who currently uses any smoked tobacco product on a daily or occasional basis. Ex-smokers included individuals who had quit smoking for at least 6 months when possible or according to the definition used in the survey (18).

High fasting plasma glucose was defined as any level of FPG above the theoretical minimum-risk exposure level (TMREL), which is 4.8–5.4 mmol/L in the GBD study (16).

A high BMI is defined as a BMI greater than or equal to 25 kg/m2 for people over 20 years old, and a BMI of 20–25 kg/m2 is considered the theoretical minimum risk exposure level (19).

This study of cataract burden and its risk factors did not involve human subjects, and data were taken from the Global Health Data Exchange GBD Results Tool (See Footnote 1). This study complies with the Guidelines for Accurate and Transparent Reporting of Health Estimates (GATHER) guidelines for reporting health estimates (20). The detailed diagnostic and estimation methods for GBD 2019 have been published previously (16). In our study, we obtained publication estimates of DALYs with "cataracts" from the "all cause" category of the GBD website across 204 countries and territories. The statistical code used for GBD estimation is publicly available on the internet.

The GDB study was approved by the institutional review board of the University of Washington. Original data were collected with

1 http://ghdx.healthdata.org/gbd-results-tool

informed consent from the study participants or with a waiver from the institutional review board. As this was a secondary analysis of publicly available data, no further review by an institutional review board was required following the data use agreement of The Institute for Health Metrics and Evaluation.

2.2 Statistical analysis

The number of deaths or DALYs, age-standardized rates (ASRs) and estimated annual percentage change (EAPC) with a 95% uncertainty interval (UI) were adopted to quantify the cataract burden attributable to risk factors. The ASR, as a weighted mean of the age-specific rates, was considered necessary when comparing populations from different locations or for the same population over time in which the age profiles changed accordingly. The ASR was calculated as:

$$ASR = \frac{\sum_{i=1}^{A} a_i w_i}{\sum_{i=1}^{A} a_i} \times 100{,}000$$

a_i: specific age ratio, w_i: number of people (or weight).

of selected standard population, 100,000: per 100,000 population (21). The EAPC, which is widely accepted to reflect the annual change in rate over a specific period, was calculated based on the linear regression model $y = \alpha + \beta x + \varepsilon$, where $y = \ln(ASR)$ and x = calendar year. Then, the EAPC can be obtained from $100 \times (\exp(\beta) - 1)$, as well as its 95% UI (22). If both the EAPC estimation and the lower limit of the 95% UI were positive, then the ASR showed a non-decreasing trend. Conversely, if both the EAPC estimation and the upper limit of the 95% UI were negative, the ASR exhibited a non-increasing trend. Under other conditions, the ASR was considered stable. A locally weighted regression analysis was applied to identify the association between the EAPC and the SDI. Z score hierarchical cluster analysis and Pearson's test were performed to assess the patterns of ASR of risk factor-related DALYs in 204 countries and territories and 21 GBD regions and their temporal trends. Linear regression analysis is used to identify best-fit points and evaluate trends between these consecutive points.

Furthermore, we evaluated the relationship between the SDI and cataract disease burden. A two-sided p value of less than 0.05 was considered to indicate statistical significance. All the statistical analyses were performed using R version 4.3.1 (23).

3 Results

3.1 Overall impact of risk factors on cataract burden

From 1990 to 2019, the global age-standardized DALYs of cataracts attributable to risk factors showed steady decreasing trends (Figure 1A).

In 2019, among the five SDI quintiles, the age-standardized DALYs of cataracts due to risk factors were highest in low-middle-SDI areas (135.47 [82.97–196.56]), followed by low-SDI areas (113.23 [67.61–165.67]). High-SDI areas had the lowest disease burden (6.39 [4.08–9.52]; Supplementary Tables S1–S3). This trend was similar among males and females, as shown in Figure 1, with males having a lower overall disease burden of cataracts than females.

Figures 1B,C shows scatter plots of the SDI and DALYs among cataract patients in 22 countries/regions and 204 countries/regions. Age-standardized rates of cataract-related DALYs were lower in regions with SDIs larger than 0.6 (Figure 1B). The age-standardized rate of cataract-related DALYs was greater in low-SDI areas and decreased with increasing SDI. Figure 1C shows the association between age-standardized DALY rates and the SDI across countries in 2019. Across countries, age-standardized DALY rates increased with increasing SDI up to an SDI of approximately 0.38 but then declined with increasing SDI.

3.2 Cataract burden stratified by age and sex

From the perspective of age distribution, cataract DALYs increase with age, and the growth rate after the age of 60 years in low-middle- and low-SDI countries/regions seems to be higher than that in other SDI countries/regions (Figure 2A).

Subsequent analysis of the male/female ratio revealed that after the age of 20, the male/female ratio continued to approach 1, peaking at the age of 50–54 and then declining with age (Figure 2B).

By comparing the 1990 data with the 2019 data (Figure 2C), we found that overall, global cataract DALYs declined significantly among people over 60 years old, with almost no significant change in high-SDI countries/regions. As the SDI decreases, the changes gradually become apparent until middle-low-SDI countries. The change in DALYS of cataract burden in low-SDI countries from 1990 to 2019 was smaller than that in low-medium-SDI and medium-SDI countries/regions.

3.3 Contributions of risk factors to cataract burden by SDI, sex and age

From 1990 to 2019, the DALYs attributed to risk factors for cataracts showed a steady downward trend. In terms of overall risk factors, the age-standardized rate of cataract EAPC caused by risk factors decreased significantly from 2010 to 2019, and with the continuous development of society, the decrease in the EAPC continued to accelerate (1990–2009: EAPC = −0.21 [− 0.57–0.14]; 2000 to 2009: EAPC = −0.95 [−1.01–−0.89]; 2010–2019: EAPC = −1.41 [−1.8–−1.02]; Table 1).

As shown in Figure 3, from a global perspective, the main risk factor leading to cataract disease burden in 2019 was particulate matter pollution, followed by smoking, high fasting plasma glucose (HFPG) and high body mass index (BMI).

From the perspective of population age, as age increases, the burden of cataract disease caused by any type of risk factor increases (Figure 4A).

It is important to note that when analyzing the EAPC for cataract disease burden for each risk factor separately, we found a downward trend in age-standardized disability-adjusted life years due to particulate matter pollution and smoking, while high fasting plasma glucose and high body mass index increased over time.

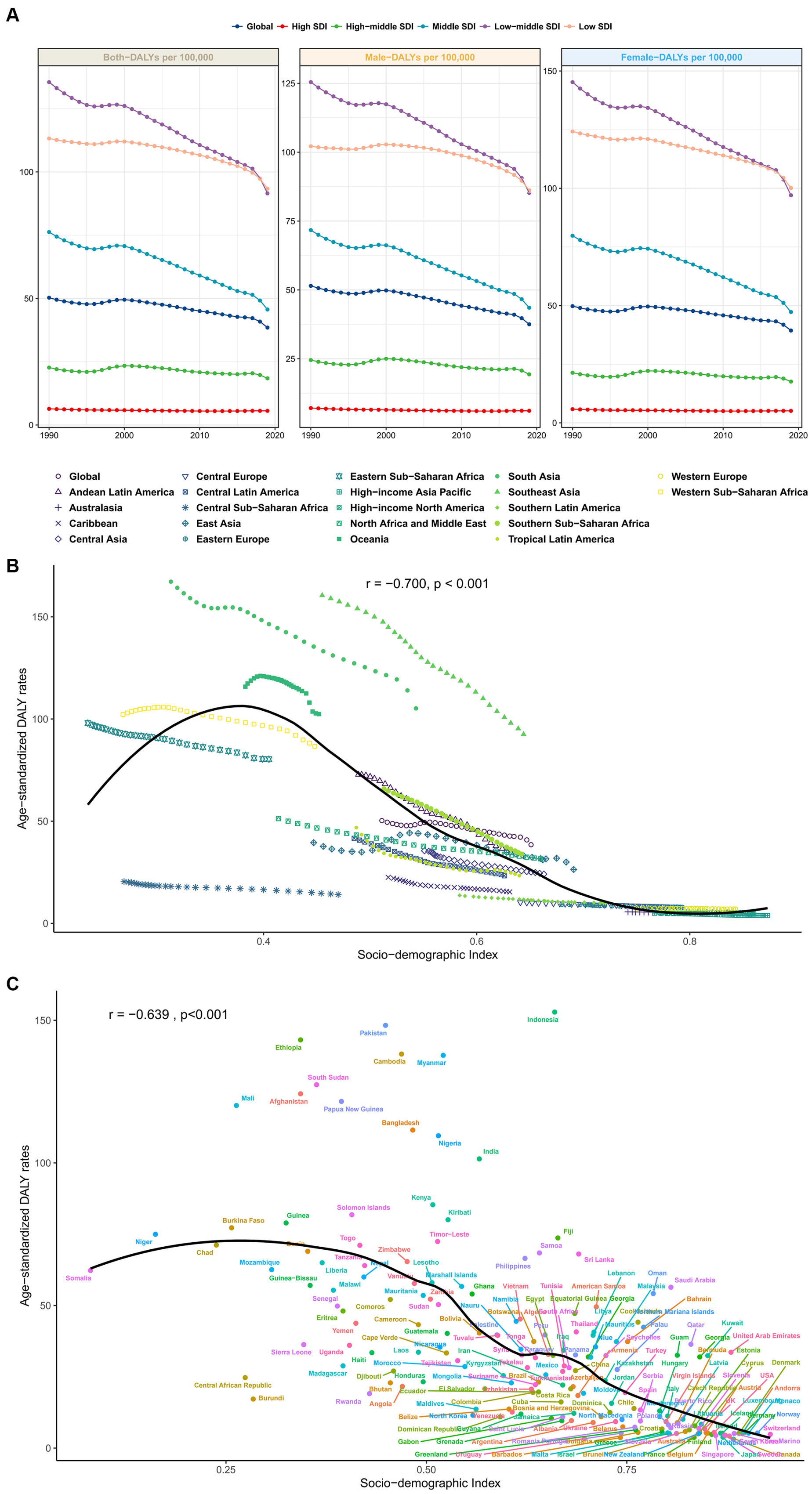

FIGURE 1
(A) From 1990 to 2019, the global age-standardized DALYs of cataracts attributable to risk factors showed steady downward trends in males, females and both sexes. **(B)** Changes in the SDI age-standardized DALY rates by region from 1990 to 2019. Areas above the solid black line have a greater

(Continued)

FIGURE 1 Continued
burden than expected (based on the SDI), while those below the line have a lower burden than expected. **(C)** Association between age-standardized DALY rates and SDI across countries in 2019. DALYs, disability-adjusted life years; SDI, sociodemographic index.

3.4 Particulate matter pollution

Globally, particulate matter pollution is the leading risk factor responsible for the burden of cataracts (Figure 4B). Almost all SDI regions showed a downward trend in DALYs. The largest decreases in age-standardized disability-adjusted life years due to particulate matter pollution occurred in low-middle-SDI regions. From the perspective of regional classification, particulate matter pollution causes cataract disease burden in low-middle-SDI and low-SDI regions, which is much greater than that in other SDI regions. With the continuous development of society, the decrease in the EAPC continued to accelerate (1990–2009: EAPC = −0.53 [−0.9–−0.16]; 2000–2009: EAPC = −1.39 [−1.45–−1.32]; 2010–2019: EAPC = −2.27 [−2.75–−1.79]).

In terms of sex, females are more likely to suffer from cataracts due to particulate matter pollution than males are. In 2019, the age-standardized DALY for cataracts due to particulate matter pollution was slightly greater in females than in males.

Moreover, among all age groups (Figure 4A), particulate matter pollution had a greater impact on cataracts among DALYs. In particular, for the population over 60 years old, those aged 70–74 years had the highest DALY rate, while a lighter burden appeared for those under 50 years old.

3.5 Smoking

In terms of regional classification, the regions with the largest decreases in age-standardized disability-adjusted life years due to smoking were low-middle-SDI regions and middle-SDI regions (Figure 3). The decrease in the EAPC due to smoking in other regions slowed in the past decade (2000 to 2009: EAPC = −1.51 [−1.6–−1.43], 2009 to 2019: EAPC = −1.34 [−1.68–−1]; Table 1).

Additionally, the impact of smoking on cataracts was much greater in men than in women (Figure 4B). In 2019, the disease burden attributable to smoking was greater in men than in women across all age groups and SDI regions. The global cataract DALY rate due to smoking increased with age, peaked among those aged 70–74 years, and then decreased (Figure 4A).

3.6 High fasting plasma glucose

From the perspective of regional classification, HFPG leads to smaller differences in age-standardized disability-adjusted life years in different countries/regions (Figure 3). The greatest burden of cataract disease was in low-middle-SDI regions, followed by low-SDI regions. It should be noted that from 1990 to 2019, the age-standardized disability-adjusted life-year rate for cataracts caused by HFPG showed an increasing trend (1990 to 1999: EAPC = 1.27 [0.89–1.65], 2000 to 2009: EAPC = 1.02 [0.82–1.22], 2010–2019: EAPC = 0.44 [0.19–0.68]; Table 1).

3.7 High body mass index

From the perspective of regional classification, a high BMI leads to smaller differences in age-standardized disability-adjusted life years in different SDI countries/regions (Figure 3). From 1990 to 2019, the age-standardized disability-adjusted life-year rate of cataracts caused by high BMI also showed an upward trend (1990 to 1999: EAPC = 1.65 [1.37–1.94], 2000 to 2009: EAPC = 1.56 [1.43–1.68], 2010–2019: EAPC = 1.47 [1.18–1.77]; Table 1). In terms of sex, we found that a high BMI had a stronger impact on cataract burden in females than in males, and a high BMI caused a greater difference in cataract DALYs among females in different SDI areas than among males in different SDI areas (Figure 4B).

4 Discussion

In this study, we comprehensively analyzed the current burden, trends, and risk factors for cataract DALYs at the global and regional levels from 1990 to 2019 based on the GBD 2019 study. This study provides further evidence for the implementation of relevant policies and strategies to prevent and control the increase in cataract burden in the future by longitudinally and cross-sectionally comparing risk factor exposure levels and the disease burden that each risk factor can cause.

This study revealed that, in terms of overall risk factors, the age-standardized rate of cataracts caused by risk factors decreased from 2010 to 2019, and with the continuous development of society, the decline in the EAPC continued to accelerate. When analyzing the EAPC of cataract disease burden for each risk factor separately, we found that the age-standardized disability-adjusted life years caused by particulate matter pollution and smoking showed a downward trend, while high fasting plasma glucose and high body mass index increased annually.

The age-standardized incidence of cataracts is decreasing globally. However, the incidence of cataracts varies greatly in different SDI regions, and the burden of cataracts caused by major risk factors, especially particulate matter pollution and smoking, varies greatly among SDI regions. Research shows that in areas with higher SDI levels, the burden of disease caused by risk factors is relatively small. In contrast, the cataract burden caused by risk factors is relatively high in low-SDI areas. SDI levels are directly related to population health, and the large wealth gap in many parts of the world has implications for health equity.

Previous studies have shown that in areas with lower SDI and lower health literacy, inadequate medical resources and preventive measures may lead to a greater burden of cataract disease. Moreover,

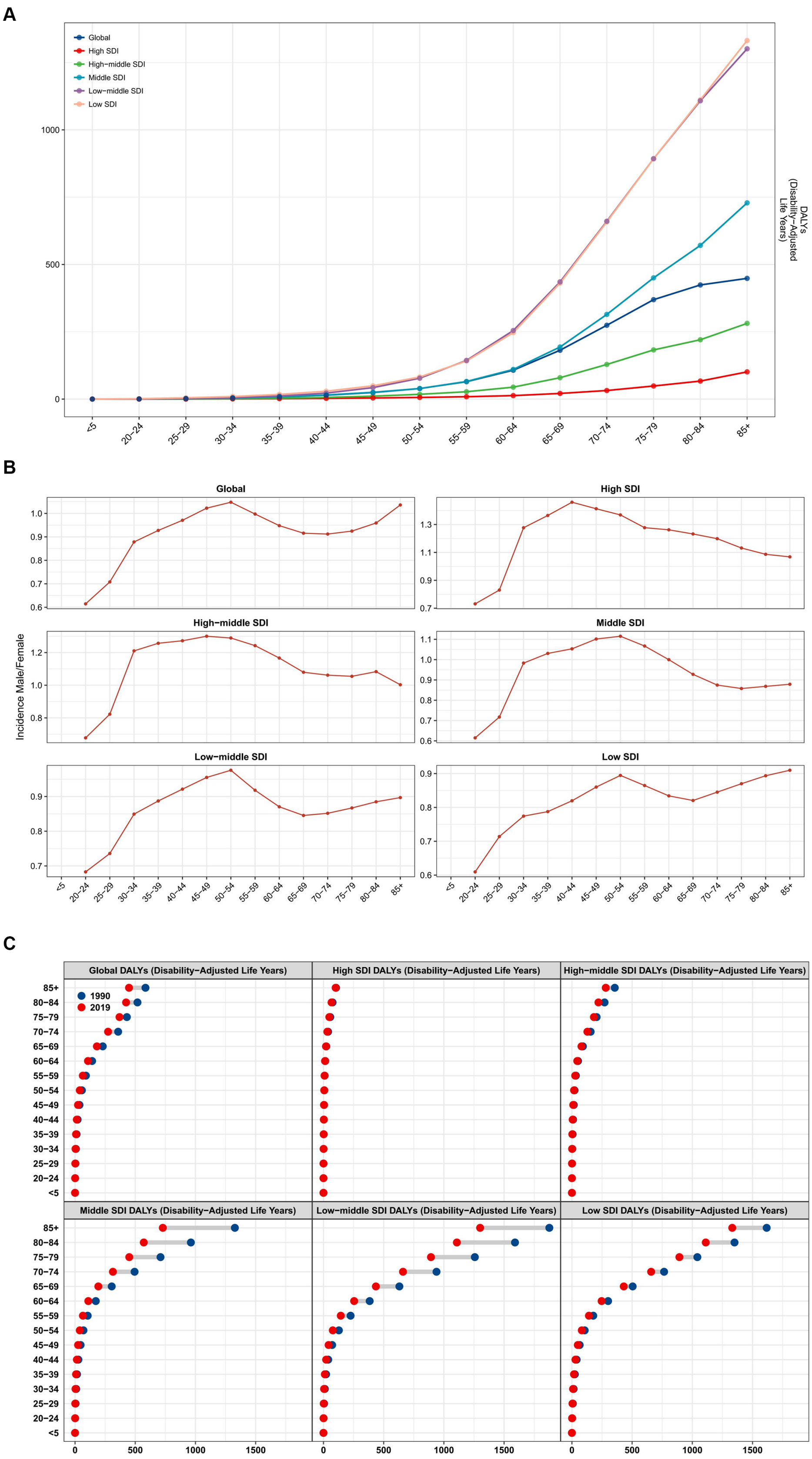

FIGURE 2
(A) Cataract DALY age distribution in SDI countries/regions, analysis of the **(B)** male/female ratio and **(C)** comparison between 1990 and 2019. EAPC, estimated annual percentage change; SDI, sociodemographic index.

TABLE 1 The temporal trends of cataract age-standardized DALYs attributed to risk factors across different SDI regions from 1990 to 2019.

EAPC	Years	All risk factors	High fasting plasma glucose	High body-mass index	Particulate matter pollution	Smoking
Global EAPC (95% CI)	1990–1999	−0.21 (−0.57–0.14)	1.27 (0.89–1.65)	1.65 (1.37–1.94)	−0.53 (−0.9--0.16)	0 (−0.3–0.3)
	2000–2009	−0.95 (−1.01--0.89)	1.02 (0.82–1.22)	1.56 (1.43–1.68)	−1.39 (−1.45--1.32)	−1.51 (−1.6--1.43)
	2010–2019	−1.41 (−1.8--1.02)	0.44 (0.19–0.68)	1.47 (1.18–1.77)	−2.27 (−2.75--1.79)	−1.34 (−1.68--1)
High SDI EAPC (95% CI)	1990–1999	−0.93 (−1.13--0.74)	−0.25 (−0.68–0.18)	0.93 (0.91–0.94)	−4.84 (−5.31--4.37)	−1.23 (−1.29--1.18)
	2000–2009	−0.6 (−0.62--0.58)	1.57 (1.49–1.65)	0.36 (0.32–0.39)	−6.09 (−6.18--6.01)	−1.52 (−1.57--1.48)
	2010–2019	0.22 (0.13–0.3)	1.28 (1.21–1.34)	0.99 (0.9–1.08)	−3.52 (−3.98--3.07)	−0.79 (−0.91--0.67)
High-middle SDI EAPC (95% CI)	1990–1999	0.19 (−0.57–0.95)	1.54 (0.96–2.13)	1.16 (0.85–1.48)	−0.47 (−1.47–0.55)	0.76 (0.24–1.29)
	2000–2009	−1.19 (−1.34--1.04)	1.52 (1.1–1.94)	0.87 (0.83–0.91)	−2.74 (−2.95--2.54)	−1.34 (−1.45--1.22)
	2010–2019	−0.85 (−1.35--0.34)	−0.14 (−0.53–0.25)	1.17 (0.88–1.46)	−2.68 (−3.44--1.92)	−0.17 (−0.63–0.29)
Middle SDI EAPC (95% CI)	1990–1999	−0.83 (−1.23--0.42)	0.93 (0.56–1.3)	1.65 (1.33–1.97)	−1.36 (−1.78--0.93)	0.12 (−0.26–0.5)
	2000–2009	−1.77 (−1.85--1.7)	0.25 (0.07–0.44)	1.33 (1.23–1.43)	−2.42 (−2.51--2.33)	−1.92 (−2.03--1.81)
	2010–2019	−2.48 (−2.89--2.07)	−0.37 (−0.63--0.11)	1.11 (0.79–1.43)	−3.86 (−4.39--3.33)	−1.89 (−2.23--1.54)
Low-middle SDI EAPC (95% CI)	1990–1999	−0.76 (−1.02--0.49)	0.68 (0.41–0.96)	1.89 (1.49–2.29)	−0.9 (−1.16--0.63)	−1.05 (−1.24--0.86)
	2000–2009	−1.3 (−1.34--1.25)	0.46 (0.28–0.63)	2.11 (1.75–2.48)	−1.5 (−1.54--1.46)	−2.19 (−2.26--2.11)
	2010–2019	−1.77 (−2.19--1.34)	0.39 (0.19–0.6)	1.75 (1.28–2.21)	−2.23 (−2.7--1.75)	−2.22 (−2.58--1.85)
Low SDI EAPC (95% CI)	1990–1999	−0.13 (−0.25--0.02)	1.07 (0.93–1.22)	1.43 (1.21–1.66)	−0.22 (−0.33--0.11)	−0.42 (−0.48--0.36)
	2000–2009	−0.47 (−0.5--0.44)	0.74 (0.59–0.88)	2.31 (2.15–2.47)	−0.59 (−0.62--0.56)	−0.98 (−1.01--0.95)
	2010–2019	−1.3 (−1.58--1.01)	0.13 (−0.01–0.26)	1.24 (1.11–1.38)	−1.49 (−1.8--1.17)	−2.24 (−2.49--1.99)

DALYs, disability-adjusted life years; EAPC, estimated annual percentage change; CI, certainty interval; SDI, Sociodemographic Index.

residents of more socioeconomic areas are more likely to have greater health literacy, better access to medical care, healthier diets and regular exercise, which may help reduce disease burden (24). A previous study suggested that lower income may be associated with an increased risk of a variety of vision-threatening diseases and may adversely affect ophthalmologists' professional diagnostic and treatment approaches (25).

Interestingly, we found that the cataract disease burden was greater in low-middle-SDI regions (135.47 [82.97–196.56]) than in low-SDI regions (113.23 [67.61–165.67]). This may be due to socioeconomic development, as cataract risk factors such as high body mass index (BMI), unhealthy diet, low physical activity, environmental pollutants, and smoking have increased significantly, but the health system has failed to keep up with the relevant population health needs (26, 27).

In addition, another possible explanation is that there are fewer medical institutions and health resources in low-SDI areas, which may lead to the underreporting of cataract data. In terms of sex, this study

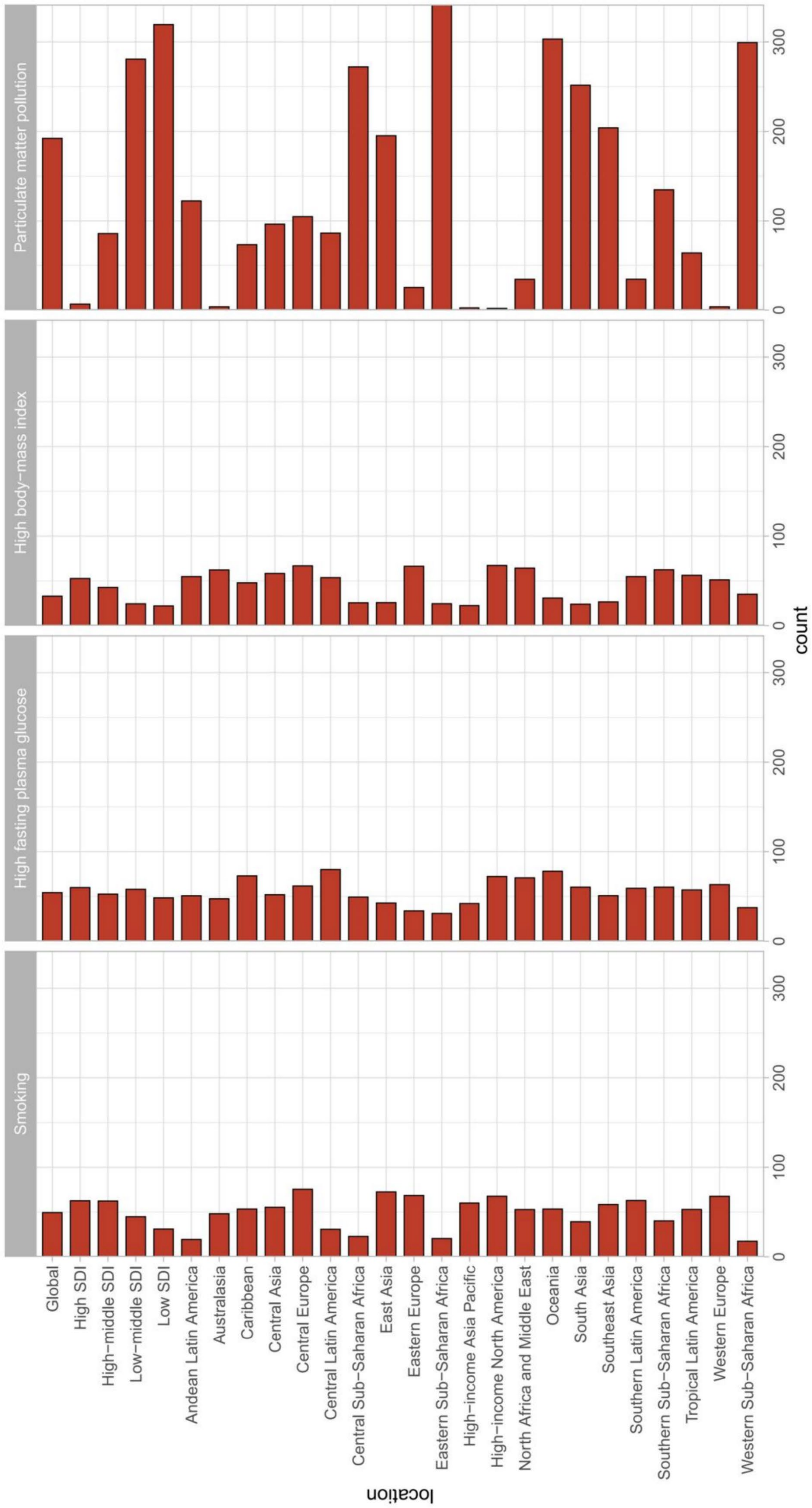

FIGURE 3
EAPC in DALYs attributable to risk factors for cataracts between 1990 and 2019 globally among different SDI quintiles and regions. EAPC, estimated annual percentage change; DALYs, disability-adjusted life years.

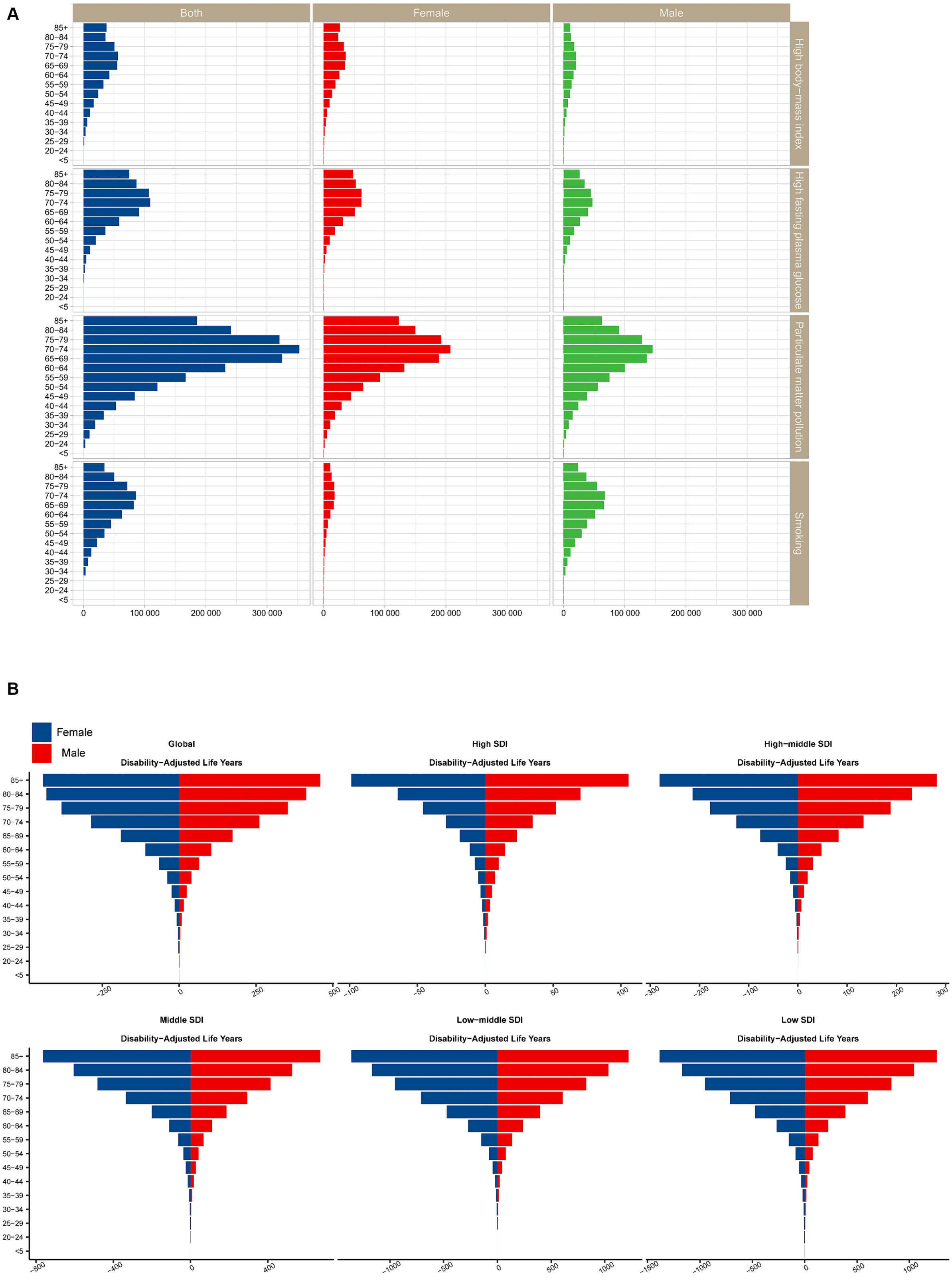

FIGURE 4
(A) Proportions of cataract risk across age groups in both sexes. **(B)** Trends in cataract risk across SDI countries/regions stratified by sex. SDI, sociodemographic index.

revealed that in most regions and age groups, the disease burden of cataract patients was slightly greater for females than for males. One possible explanation is that women have a greater incidence of cataracts and a longer life expectancy (28, 29). Another explanation may relate to gender inequality, with evidence that women are disadvantaged in areas such as education, employment opportunities, income distribution and health care (28). Previous research revealed that although 60% of cataract patients are female, males are 1.39 times more likely to undergo cataract surgery than females are (30). Women possess less family support and less control over their finances than men, which may prevent them from undergoing cataract surgery. For children with bilateral cataracts, girls are also less likely to undergo surgery than boys in low-income countries (31). Therefore, more emphasis should be placed on eye care services for women, and eliminating gender inequality is an important component in combating the global burden of cataracts.

In terms of risk factors, this study revealed that particulate matter pollution causes a greater disease burden for cataracts globally than smoking does, as previously recognized (2010–2019: EAPC = −2.27[−2.75–−1.79] vs. −1.34[−1.68–−1]). This may be attributed to two assumptions: first, the global population-weighted PM 2.5 concentration continued to increase rapidly from 2010 to 2015, reaching 44.2 μg/m3 in 2015 (32); second, population growth and aging, which led to increased air pollution and increased disease burden (33).

For males, in addition to particulate matter pollution, smoking is a major risk factor for cataract burden. Approximately 25% of men and 5.4% of women globally are smokers, posing a significant obstacle to tobacco control (34). Smoking not only affects the health of smokers but also has a greater impact on the health of people in the surrounding areas. In 2019, secondhand smoke was the sixth leading risk factor for death from cataracts. In addition, tobacco has a substantial negative impact not only on cataracts but also on cardiovascular disease, lung tumors, and fertility (35, 36). Many countries have adopted various approaches to reduce tobacco consumption with positive results, but this study indicated that more practical efforts are still needed (37).

For the HFGP (2010–2019: EAPC = 0.44 [0.19–0.68]) and high BMI (2010–2019: EAPC = 1.47 [1.18–1.77]), the associated increase in DALYs cannot be entirely attributed to population growth and aging. Other factors also contribute to the exacerbation of risk factors for HFPG and high BMI, and the two are correlated. The prevalence of overweight or obesity, physical inactivity, and unhealthy diet has been reported to be associated with an increased burden of hyperglycemia in recent decades (38, 39).

As the world is facing a serious situation of preventing and treating blindness, the World Health Organization (WHO) launched the global action "VISION 2020" (40). Over the span of 1990 to 2010, the number of individuals afflicted with cataract-induced blindness decreased by 11.4%, and the corresponding blindness rate decreased from 38.6 to 33.4% (41, 42).

Taken together, these results suggest the need to strengthen early cataract screening in specific groups (women in medium-low and low-SDI countries/regions). Furthermore, efforts to reduce cataract risk must be combined with comprehensive control strategies, including efforts to support early diagnosis and effective treatment. The results of this study suggest that reducing particulate matter pollution, quitting smoking, controlling blood sugar, and lowering BMI play important roles in reducing the occurrence of cataracts, especially in the older population.

To the best of our knowledge, this is the first study to use the latest data from GBD 2019 to comprehensively assess the disease burden of cataracts by calendar year, age, sex, location, socioeconomic status, and risk factors, which will be useful to the public as well as health policy makers. However, some potential limitations of our study should not be overlooked. First, based on GBD 2019, few data on the prevalence, incidence, and subtypes of cataracts are available, which limits the analysis of the results to a certain extent. Second, predictions rely heavily on the quality of registration data based on the original population. The sparsity of cataract data, especially in low-SDI regions, may affect the accuracy of the estimates. However, the GBD 2019 study utilized a number of powerful statistical tools to reduce this effect. Third, as a population epidemiological study, we were unable to obtain individual-level data, which are inevitably affected by confounding factors when calculating correlation coefficients. However, our results provide clinical scientists and socioeconomists with updated big data and a more comprehensive analysis of the burden of cataracts.

5 Conclusion

Our study delineates the overall pattern of cataract burden and emphasizes the need to bolster prevention and management efforts focused on reducing particulate matter pollution, quitting smoking, controlling blood sugar, and lowering BMI, especially for older people. More targeted and effective global public health strategies should be developed and implemented to control cataracts and their associated risk factors.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding authors.

Ethics statement

As the data were freely available, no ethical approval or informed consent was obtained.

Author contributions

DW: Conceptualization, Writing – original draft. TT: Methodology, Software, Writing – review & editing. PL: Data curation, Formal analysis, Investigation, Writing – original draft. JZ: Writing – review & editing. BS: Supervision, Writing – review & editing. MZ: Funding acquisition, Supervision, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2024.1366677/full#supplementary-material

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Causal relationships between height, screen time, physical activity, sleep and myopia: univariable and multivariable Mendelian randomization

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Background: This study aims to investigate the independent causal relation between height, screen time, physical activity, sleep and myopia.

Methods: Instrumental variables (IVs) for exposures and outcome were obtained from the largest publicly available genome-wide association studies (GWAS) databases. First, we performed a bidirectional univariate MR analysis using primarily the inverse variance weighted method (IVW) with height, screen time, physical activity and sleep as the exposure and myopia as the outcome to investigate the causal relationship between exposures and myopia. Sensitivity analysis was used to demonstrate its robustness. Then the multivariable MR (MVMR) and MR-based mediation approach was further used to estimate the mediating effect of potential confounders (education and time outdoors) on causality.

Results: The results of univariate MR analysis showed that taller height (OR = 1.009, 95% CI = 1.005–1.012, $p = 3.71 \times 10^{-7}$), longer time on computer (OR = 1.048, 95% CI = 1.029–1.047, $p = 3.87 \times 10^{-7}$) and less moderate physical activity (OR = 0.976, 95% CI = 0.96–0.991 $p = 2.37 \times 10^{-3}$) had a total effect on the increased risk of developing myopia. Meanwhile our results did not have sufficient evidence to support the causal relationship between chronotype ($p = 0.637$), sleep duration ($p = 0.952$) and myopia. After adjusting for education, only taller height remains an independent risk factor for myopia. After adjusting for education, the causal relationship between height, screen and myopia still had statistical significance. A reverse causal relationship was not found in our study. Most of the sensitivity analyses showed consistent results with those of the IVW method.

Conclusion: Our MR study revealed that genetically predicted taller height, longer time on computer, less moderate physical activity increased the risk of myopia. After full adjustment for confounders, only height remained independently associated with myopia. As a complement to observational studies, the results of our analysis provide strong evidence for the improvement of myopia risk factors and provide a theoretical basis for future measures to prevent and control myopia in adolescents.

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Mendelian randomization, myopia, risk factors, height, screen time, physical activity, sleep

Introduction

Myopia has become a growing public health concern worldwide, especially in some East and Southeast Asian regions with increasing incidence in recent decades (1). It is estimated that more than half of the world's population will be affected by myopia by 2050 (2). High myopia (over −6.0 D) can even lead to pathological complications, such as cataracts, open-angle glaucoma and retinal detachment (3). Data from Asian populations show that myopia increases rapidly in childhood, affecting 80–90% of high school students, of whom 10–20% are high myopia (4). Myopia is a multifactorial disease related to genetic and environmental factors (5). We currently have strong evidence for a causal link between education and time outdoors and myopia (6). However, evidence remains weak and inconsistent on whether some highly concerned modifiable risk factors, such as height (7–10), screen time (11, 12), physical activity (13–16) and sleep (17–21), affect the development of myopia. Therefore, it is very important to further investigate the risk factors for myopia in order to propose feasible measures that can reduce the incidence of myopia and slow down the progression of myopia. Because the results of observational studies are inevitably affected by potential confounding factors and reverse causality. Randomized controlled trials (RCT) are also difficult to conduct due to the limitations of human and financial resources and ethics. In recent years, the genetics of myopia has flourished, with genome-wide association studies (GWAS) in particular successfully identifying many common genetic variants associated with myopia and refractive error (22). Genetic variation accounts for at least 12%, and possibly as much as 30% or more, of the variance in mean spherical equivalent refraction in populations of European ancestry at present (6). Under the circumstances, a well-designed mediation analysis and Mendelian randomization analysis would be particularly useful.

Mendelian randomization (MR) analysis employs genetic variations to evaluate the causality between exposures and outcomes and has the advantage of minimizing bias due to confounding factors and reverse causality (23). The study design is similar to randomized controlled trial (RCT) since genes are transferred from parents to offspring randomly (24). In this study, we conducted a MR analysis to thoroughly investigate about the causal effects of some highly discussed, clinically instructive and changeable personal factors, including height, screen time, physical activity, sleep on myopia using univariate MR and multivariate MR methods. Furthermore, we used MR-based mediation analysis to investigate whether education and time outdoors mediate the effects of exposures.

Materials and methods

Study design and MR assumptions

In this study, we selected instrumental variables for the MR analysis using height, screen time, physical activity and sleep as 'exposures' and myopia as 'outcome.' Then, we conducted a two-sample bidirectional univariable MR analysis to evaluate the bidirectional causal relationships between exposures and myopia. Meanwhile sensitivity analysis was used to demonstrate its robustness. Next, we performed a multivariate MR analysis to assess whether the causal effect of exposures on myopia was mediated by education and time outdoors. Finally, a mediation analysis was calculated to assess the proportion of exposures' effect on myopia mediated by education and time outdoors. Three assumptions must be satisfied in this MR analysis: (1) the genetic variant used in MR is associated with exposures (relevance assumption); (2) associations of the genetic variant with exposures and myopia must not be confounded (independence assumption); and (3) the genetic variants must have an association with myopia only through the effect associated with exposures (exclusion restriction assumption) (Figure 1A).

Data source

The MR study was performed using publicly published studies or shared datasets. No additional ethics statement or consent was needed. Genetic instruments of height (standing height, $N = 336{,}474$), screen time (time spent using computer, $N = 261{,}987$) and physical activity (number of days/week of moderate physical activity 10+ minutes, $N = 321{,}309$) were derived from the Neale Lab consortium's summary data from the UK Biobank. Genome-wide association study (GWAS) of chronotype ($N = 413{,}343$) and sleep duration ($N = 460{,}099$) extracted from the UK Biobank, a large cohort study with deep genetic and phenotypic data collected on more than 500,000 individuals from across the United Kingdom (25). Chronotype refers to an individual's tendency for earlier or later sleep times, also known as circadian rhythm preference.

For the first assumption, the instrumental variables (IVs) for MR analyses were selected at a threshold of genome-wide significance ($p < 5 \times 10^{-8}$). Furthermore, the IVs for MR analyses were selected based on the following criteria: (1) To meet the MR assumptions, we performed a linkage disequilibrium (LD) analysis ($R^2 < 0.001$, clumping distance = 10,000 kb) based on European-based 1,000 Genome Projects and removed the SNPs that did not meet the requirements. (2) Palindromic SNPs with intermediate allele frequencies were removed when harmonizing exposure and outcome data. (3) Proxy SNPs with $r^2 > 0.9$ according to LDlink[1] were used when the original SNPs were not available for the outcome. At the same time, we estimated the F-statistics to evaluate the instrument strength. $F < 10$ indicates weak instrument strength (26).

Myopia data integrated by the MRC IEU ("Phenotype: Reason for glasses/contact lenses: For short-sightedness, i.e., only or mainly for distance viewing such as driving, cinema etc., [called 'myopia']") were used as an outcome, including 37,362 cases of myopia and 423,174 cases of population controls.

1 https://ldlink.nci.nih.gov/

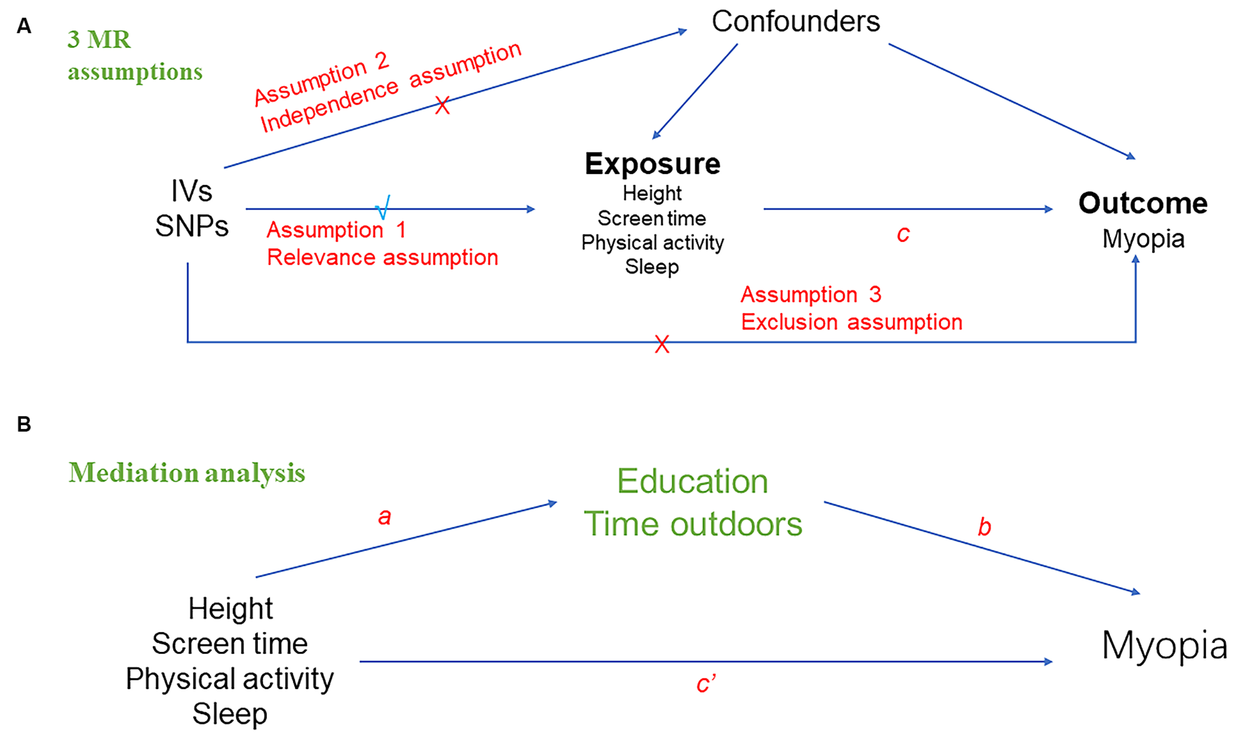

FIGURE 1
Overall design of Mendelian randomization analyses in the present study. **(A)** Schematic diagram of the three major assumptions of Mendelian randomization. **(B)** Mediation analysis diagram applied in this study.

MR analysis and sensitivity analysis

The principal method of two-sample MR conducted in this study was inverse variance weighted (IVW) (27), followed by MR-Egger and weighted median (WM) (28). If the assumption that all included SNPs can be used as valid IVs is met, the IVW method provides an accurate estimate (29). MR Egger's results remained valid if SNPs with pleiotropy exceed 50%, but the estimation accuracy produced by this method is very low (30). WM analysis calculates the median of an empirical distribution of MR association estimates weighted for their accuracy, providing consistent estimates when more than half of the instruments are valid (28). Then, we performed reverse MR analysis with myopia as exposure. We adopted methods and settings that were consistent with the forward MR. Next, to investigate the direct effects of exposures on myopia, we performed multivariable MR (MVMR) analysis by multivariate random-effects IVW method, which is an extension of univariable MR that allows detecting causal effects of multiple risk factors jointly (31). Finally, we calculated the proportional effect of exposures on outcomes mediated by potential confounders (educations and time outdoors). A graphical summary of the analyses is given in Figure 1. First, we performed univariable two-sample MR to estimate the total effect of each exposure on myopia (c in Figure 1A) and the effect of each exposure on education and time outdoors (a in Figure 1B). We then used MVMR to estimate the effect of education and time outdoors on myopia (b in Figure 1B), adjusting for each exposure. Therefore, the indirect effect of each exposure on myopia, through education and time outdoors, was obtained by multiplying the effect of each exposure on each mediator and the effect of each mediator on myopia ($a \times b$ in Figure 1B). MR effect was considered significant at a Bonferroni-corrected p value of $0.05/5 = 0.01$ (five exposure and one outcome). A p value between 0.01–0.05 was considered a suggestive association. The results were presented in odds ratios (OR) and 95% confidence intervals (CI).

Given that the traditional IVW MR method is susceptible to unbalanced horizontal pleiotropy (32). To assess comprehensive sensitivity, the heterogeneity estimated by Cochran's Q test was used to appraise whether any single IV was driving the results and to check for consistency of the analyses with MR assumptions. The MR-Egger regression test intercept evaluates the evidence for directional pleiotropy, where intercepts that are significantly different from zero suggest directional pleiotropy (30) ($p < 0.05$). If the MR-PRESSO analysis indicated that significant outliers exist, we would remove the outlier variants and conduct the MR analysis again. Finally, we used leave-one-out plots for IVW estimates to confirm that the effects were not unduly influenced by outliers potentially representing pleiotropic pathways. All analyses are performed using the TwoSampleMR v0.5.7 package in the R software (Version 4.2.1), except for the MR-PRESSO model, which is performed using the MRPRESSO package v1.0.

Results

Univariable and bidirectional Mendelian randomization

After removing palindromic sequences, the number of SNPs included as IVs for exposures in MR analysis is shown in Figure 2.

The detailed information for each SNP selected as IVs were shown in Supplementary Table 1. F-statistic for all exposures ranges from 15 to 667, indicating the absence of weak instrumental variables. The main IVW method shows that the taller height (OR = 1.009, 95%CI = 1.005–1.012, $p = 3.71 \times 10^{-7}$) and time spent on computer (OR = 1.048, 95%CI = 1.029–1.047, $p = 3.87 \times 10^{-7}$) may increase the risk of the onset of myopia and more physical activity is a protective factor against myopia (OR = 0.976, 95%CI = 0.96–0.991, $p = 2.37 \times 10^{-3}$). No significant causal relationships were found between sleep duration (OR = 1.006, 95%CI = 0.981–1.031, $p = 0.652$), chronotype (OR = 1, 95%CI = 0.99–1.009, $p = 0.927$) and myopia. More detailed results are shown in Figure 2. These associations are consistent across WM and MR-Egger methods, with similar causal estimates in direction and magnitude. Although the Cochran's *Q* test on height, screen time, sleep duration and chronotype showed heterogeneity ($p < 0.05$), because we used random-effects IVW as the primary method, heterogeneity was acceptable and would not invalidate the estimate (33) (Supplementary Table 2). Meanwhile the causal relationship between exposures and myopia remained after excluding outliers using MR-PRESSO (Figure 2). The *p*-values of the intercepts were > 0.05 with the MR Egger pleiotropy test, indicating that there is no pleiotropic bias in the assessment of causal relationships with the IVW method. Leave-one-out analysis shows that all SNPs are evenly distributed on the same side of 0 and the causality is not driven by any single SNP. In the reverse MR analysis, we found no reverse causality between myopia and exposures.

Multivariable Mendelian randomization and mediation analysis

Since the causal relationship between exposures and myopia might be partially mediated by education and time outdoors, we used MVMR analysis to assess the direct effect of exposure on myopia. According to the results of MVMR analysis, height can be considered an independent risk factor, because it still has a significant causal relationship with myopia after adjusting for education and outdoor time. Whereas physical activity does not appear to have a direct effect on myopia, as the significance disappears after adjustment. Meanwhile the causal relationship between screen time and myopia is largely mediated by education. Detailed data are shown in Table 1.

Finally, we further calculated the proportional effect of height, screen time and physical activity on myopia mediated by education

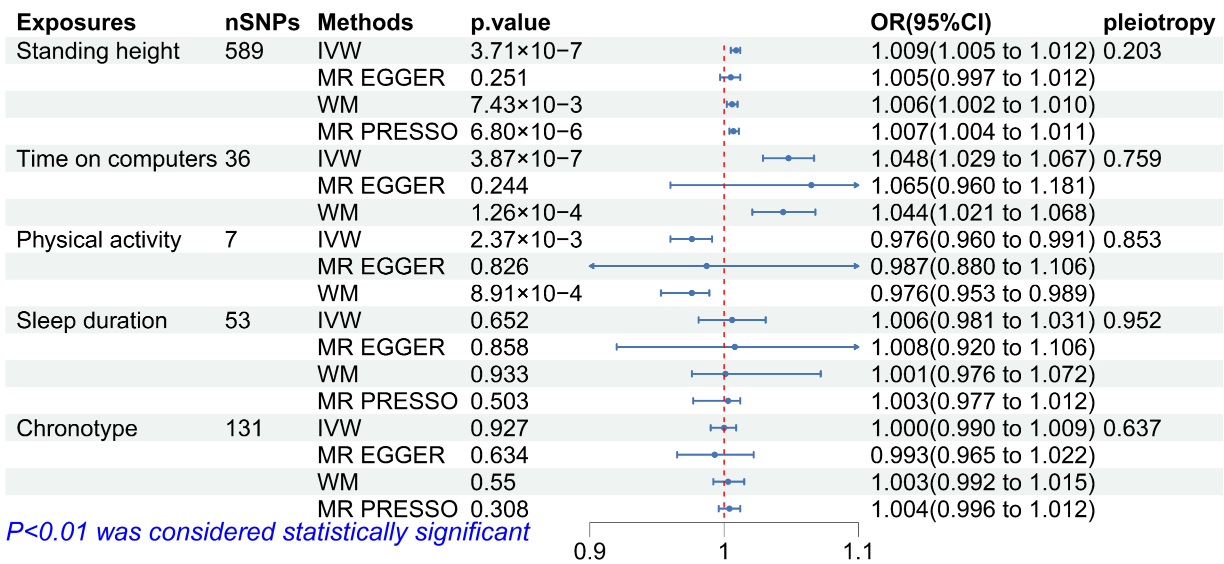

FIGURE 2
Mendelian randomization estimated effects of exposures on myopia.

TABLE 1 The results of MVMR analysis and the proportion of mediation effects.

Exposure	Multivariate model	OR (95%CI)	*p* value	Mediation effect (%)
Height	MVMR adjusted for education	1.006 (1.003–1.01)	7.64×10^{-8}*	31.4%
	MVMR adjusted for time outdoors	1.007 (1.004–1.011)	5.14×10^{-5}*	18.8%
Time on computers	MVMR adjusted for education	1.005 (0.983–1.028)	0.648	64.5%
	MVMR adjusted for time outdoors	1.031 (1.012–1.05)	1.44×10^{-3}*	46.5%
Physical activity	MVMR adjusted for education	0.993 (0.983–1.003)	0.185	15.8%
	MVMR adjusted for time outdoors	0.989 (0.974–1.004)	0.145	39.8%

*$p < 0.01$ is considered to be statistically significant.

and time outdoors by mediation analysis. The results shown in Table 1 indicate that the effects of these exposures on myopia were all mediated to varying degrees by education and time spent outdoors.

Discussion

Numerous observational studies have reported that height, screen time, physical activity and sleep may be risk factors for myopia, but these causal relationships have been inconsistent. Because it is difficult in observational studies to rule out the effects of known mediators and to avoid reverse causation. MR is a method of exploring the causal relationship between phenotypes and diseases at the genetic level using publicly available summary-level data, which overcomes the above shortcomings while simulating RCT. To our knowledge, we are the first to use MR to provide stronger evidence for the genetic association of these exposures with myopia. According to this MR study, taller height, longer time on computer and less moderate physical activity had a total effect on the increased risk of developing myopia. After adjusting for education, only taller height remains an independent risk factor for myopia. After adjusting for education, the causal relationship between height, screen and myopia still had statistical significance.

Many observational studies have reported a positive correlation between children's height and axial length (AL) (7–10). In a cross-sectional observational study in Malaysia, Mohd-Ali et al. reported that for every centimeter increase in height, the longitudinal axial length of the eye increased by 0.056 mm (7). Tao et al. gave similar conclusions that there is a significant correlation between eye axis growth and height growth during the growth of preschool children in a 5-year cohort study (8). A recent longitudinal changes and cross-sectional analysis study came to the same conclusion in the post-COVID-19 era (34). Although it is well known that AL plays a crucial role in myopia, it does not mean that the lengthening of AL will necessarily increase the risk of the onset of myopia. In addition, Stickler syndrome is an autosomal recessive disease characterized by cleft palate, high myopia and increased height due to heterozygous pathogenic variants in the collagen genes COL2A1 and COL11A1, which to some extent suggests that there may be a potential genetic relationship between height and myopia (35). In contrary, some studies have suggested that adult height is independently related to ocular dimensions, but does not appear to have an effect on refraction (36). During the period of coordinated eye growth in children, the crystalline lens thins, which may also compensate for some myopia related to AL growth (37). In our MR study, similar to the results of most previous studies, we found that height had a genetic causal association with myopia (OR = 1.009, 95%CI = 1.005–1.012, $p = 3.71 \times 10^{-7}$). The results as shown in Figure 2 gave us sufficient confidence that height may increase the risk for short-sightedness. The statistical results are significant, although the OR value is not high. Some scholars believe that greater height and myopia are independent consequences of better socioeconomic status; therefore, there may be no causal relationship between height and myopia (38). At the same time, education, as an established risk factor for myopia (6), has an undeniable causal relationship with socioeconomic status. We therefore performed MVMR and mediation analysis to explore the direct causal relationship between height and myopia after adjusting for education. The results showed that the causal relationship between height and myopia remained after adjusting for education (OR = 1.006, 95%CI = 1.003–1.01, $p = 7.64 \times 10^{-8}$, 31.4%). Therefore, we can draw a conclusion that height has both total and direct genetic effect on myopia, with part of the effect mediated by education. The underlying biological mechanism for this causal relationship is unknown and some studies have reported that some systemic hormones may be regulators of longitudinal bone growth factors in childhood, which are also involved in the development of myopia (39).

Over the past decade, electronic devices such as computers and smartphones have taken up an increasing amount of children's leisure and entertainment time with the rapid development of electronic information technology. It is reported that children are getting younger and younger to use smartphones (22% of children start at or under 3 years old), and 1/3 of children (1–6 years old) use smartphones for between 1 and 2 h a day (40, 41). Compared to traditional reading materials, smart devices can be watched for longer and closer distances, placing greater demand on accommodation and vergence (42). Therefore, whether screen use time, as a potential changeable risk factor, will increase the prevalence of myopia has become an urgent problem for parents and ophthalmologists. A recent systematic review and meta-analysis suggested that exposure to smart devices may be associated with an increase in the risk of myopia (11). Another systematic review involving 15 studies found insufficient evidence to show that there is a significant association between screen time and myopia prevalence, incidence or progression (12). Apparently, conclusions are inconsistent regarding the causal relationship between screen time and myopia. Long before the popularity of smart devices, myopia was widespread in East Asia. In recent years, as smartphones have become more integrated into every aspect of life, some recent observational studies have tended to confirm this link (12). However, it is difficult for observational studies to strictly control the mediating role of confounding factors such as education and outdoor activities in investigating the causal relationship between screen use time and myopia. According to the results of MR, we have reason to believe that the incidence of myopia will increase with the increase of time spent on computers (OR = 1.048, 95%CI = 1.029–1.047, $p = 3.87 \times 10^{-7}$). MVMR analysis results showed that after adjusting the outdoor time, the causality between them was still statistically significant (OR = 1.031, 95%CI = 1.012–1.05, $p = 1.44 \times 10^{-3}$, 46.5%). However, this causal relationship disappeared after adjusting for education (OR = 1.005, 95%CI = 0.983–1.028, $p = 0.648$), and 64.5% of the effect of computer use time on myopia was mediated by education. This result shown in Table 1 suggests that screen time has an overall effect on myopia, but it is largely mediated by education and has no direct effect. However, as screen time has continued to increase in recent years, this cannot be considered a final result. Recently, a large-scale intervention study from China showed that students' online time was significantly positively associated with increased myopia incidence (43). Thus, the impact of screen time on myopia needs to be further evaluated.

Physical activity (PA) has a beneficial effect on the physical and cognitive health of school children, but the evidence is inconclusive as to whether it delays the onset and progression of myopia (44). Many well-designed observational studies have investigated the causal relationship between PA and myopia, but have not reached consistent conclusions (13–16). Liu et al. used a Bayesian model average to investigate the risk factors for myopia in adolescents, and the results showed that frequent participation in moderate sports activities was a powerful factor influencing the eyesight of middle school students (14). In contrast, seven-year longitudinal objective data on PA showed no significant association between PA and myopia during childhood (16). This discrepancy in results is not surprising since most studies do not exclude the regulation of outdoor time. However, what we want to investigate is whether indoor physical activity can be used as an intervention to prevent myopia, but this is difficult to design for observational studies. A previous detailed investigation concluded that among 12-year-old students, higher levels of outdoor activity were associated with lower prevalence of myopia while time spent in indoor sports had no effect (45). This conclusion is highly consistent with the results of our MR analysis. The MR analysis showed that the risk of myopia decreased with more frequent moderate physical activity of more than 10 min (OR = 0.976, 95%CI = 0.96–0.991, $p = 2.37 \times 10^{-3}$). However, this association became insignificant after adjusting for outdoor time (OR = 0.989, 95%CI = 0.974–1.004, $p = 0.145$) with a mediation effect of 39.8%. This means that even though physical activity has a total effect on the development of myopia, it is largely mediated by time outdoors and has no direct effect. A recent report provided a new perspective that physical activity may affect the onset and progression of myopia by improving children's balance control (15). This means that increasing time outdoors may not be the only way for physical activity to reduce the risk of myopia, and further studies should be conducted to fully assess the complex relationship between them.

In recent years, many studies have been devoted to investigating the causal relationship between sleep and myopia, however the evidence provided is equivocal (17–21). Whether sleep duration and chronotype are modifiable risk factors for the development of myopia has also aroused the interest of many researchers. A recently published systematic review including a total of 31 studies with 205,907 participants showed that sufficient sleep duration was associated with a lower risk of myopia (46) (OR = 0.63, 95%CI = 0.51–0.78). In addition, a population-based cross-sectional study in Shanghai reported that not only was shorter sleep duration associated with myopia, but evening and intermediate chronotypes were positively correlated (47). The underlying mechanism for this causation may be related to the inactivity of the ciliary muscle, the self-regulation of the eye during sleep and the interaction of dopaminergic function with melatonin (48, 49). Evidence from animal studies also supports the notion that there are circadian or diurnal rhythms in parameters, such as axial length and choroidal thickness (48). Instead, the results of a cohort study design over a 4-year follow-up period showed that there was no significant association between sleep duration and myopia progression and axial elongation in primary school children (20). Consistently, according to our MR results, there is no sufficient evidence to suggest that there is a causal relationship between sleep duration, chronotype and myopia. The speculation about the difference in these consequences is that high educational intensity may make children spend more time on nearwork indoors, sacrificing the time spent exercising outdoor and sleeping, and mental activities before going to bed may also affect sleep duration and quality to some extent.

However, there are also several limitations in our MR research. First, the samples involved in our study are limited to the European population and may not apply to the Asian population with a higher incidence. Therefore, large-scale genetic data from more races are needed to help provide fully applicable conclusions on the causality. Second, as the outcome of this study, myopia is a binary variable and we can only explore whether there is a causal relationship between exposures and the onset of myopia but not the progression of myopia. Finally, we selected the GWAS data for exposures and outcome from publicly available summary data, however, it is impossible to determine whether overlapping subjects were included in our MR analysis.

In summary, this MR study revealed that genetically predicted taller height, longer time on computer and less moderate physical activity increased the risk of myopia. There is insufficient evidence for a genetic association between chronotype, sleep duration, and myopia. After full adjustment for known risk factors for myopia (education and time outdoors), only height remained independently associated with myopia. However, 64.5% of the effect of screen time on increased myopia risk was mediated by education. Physical activity does not appear to have a direct effect on the onset of myopia. As a complement to observational studies, the results of our analysis provide strong evidence for the improvement of myopia risk factors and provide a theoretical basis for future feasible measures to prevent and control myopia in adolescents.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

XL: Data curation, Formal analysis, Investigation, Software, Visualization, Writing – original draft. FZ: Conceptualization, Funding acquisition, Methodology, Writing – original draft. WY: Conceptualization, Software, Writing – original draft. JX: Supervision, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2024.1383449/full#supplementary-material

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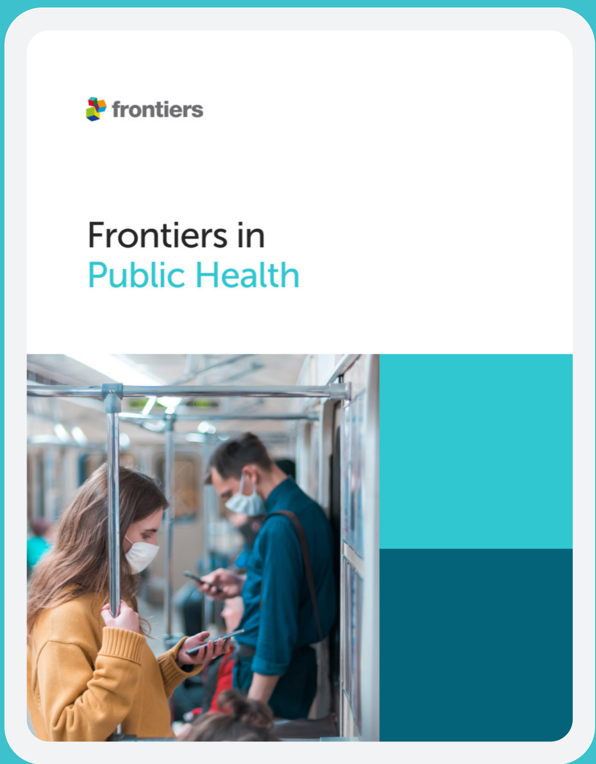

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