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Prevalence and Severity of Astigmatism in Children After COVID-19

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IMPORTANCE Astigmatism can cause blurred vision at near and distance. It is common among schoolchildren and associated with ametropia. Although the COVID-19 pandemic generated a surge in myopia prevalence in children, the association with child astigmatism remains unknown.

OBJECTIVE To report the prevalence of refractive astigmatism and corneal astigmatism in schoolchildren from 2015 to 2023 and explore the associations between the pandemic and astigmatism.

DESIGN, SETTING, AND PARTICIPANTS This population-based cross-sectional study stratified all the primary schools registered with Education Bureau in Hong Kong into 7 clustered regions used by Hospital Authority Services in Hong Kong. Participants were schoolchildren aged 6 to 8 years who underwent comprehensive ocular examinations at 2 academic medical centers in Hong Kong from 2015 to 2023. Astigmatism was measured with optical biometry and auto-refractor after cycloplegia.

EXPOSURE COVID-19 pandemic.

MAIN OUTCOMES AND MEASURES The annual prevalence rates of refractive astigmatism and corneal astigmatism were the primary outcome measures. Logistic regression was used to evaluate the association of the pandemic with the risks of refractive astigmatism and corneal astigmatism. Linear regression was used to explore the association of the pandemic with the magnitudes of refractive astigmatism and corneal astigmatism.

RESULTS The cohort consisted of 21 655 children: 11 464 boys (52.9%) and 10 191 girls (47.1%); their mean (SD) age was 7.31 (0.90) years. The prevalence rate of refractive astigmatism of at least 1.0 diopter (D) was 21.4% and corneal astigmatism of at least 1.0 D 59.8% in 2015 and increased to 34.7% (difference, 13.3%; 95% CI, 9.3%-17.3%) and 64.7% (difference, 4.9%; 95% CI, 0.5%-9.2%), respectively, in 2022-2023. The pandemic was associated with a 20% increase in the risk of refractive astigmatism (odd ratio [OR], 1.20; 95% CI, 1.09-1.33; $P < .001$), 26% increase in the risk of corneal astigmatism (OR, 1.26; 95% CI, 1.15-1.38; $P < .001$), 0.04 D in the magnitude of refractive astigmatism (95% CI, 0.02-0.07; $P < .001$), and 0.05 D in the magnitude of corneal astigmatism (95% CI, 0.02-0.08; $P < .001$), compared with the prepandemic period of 2015-2019 and after adjusting for sociodemographic factors, parental astigmatism, and child myopia.

CONCLUSIONS AND RELEVANCE This study found an increase in both the prevalence and severity of refractive astigmatism and corneal astigmatism after the COVID-19 pandemic. Corneal changes especially along the steepest meridian may explain some of the progression of corneal astigmatism. The potential impact of higher degrees of astigmatism may warrant dedicated efforts to elucidate the relationship between environmental and/or lifestyle factors, as well as the pathophysiology of astigmatism.

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Astigmatism is the most common refractive error and a universal cause of visual impairment. It is caused by 1 or more spherocylindrical surfaces in our ocular system that converge distant lights differentially into more than 1 focal point on the retina, resulting in a blurred image. Refractive astigmatism (RA) refers to the total amount of astigmatism in the eye. It is a summation of 2 components, corneal astigmatism (CA) and internal astigmatism (IA).

In a global review on the prevalence of refractive errors from 1990 to 2016, 14.9% of children worldwide had astigmatism of more than 0.5 diopter (D).[1] While the prevalence varied among individuals of different ethnicities, as evidenced by a higher prevalence of astigmatism in China compared with the western Pacific region (16.5% vs 12.1%), the condition was also more common in the urbanized parts than the rural areas of the same country, suggesting an environmental factor in addition to inherent factors, such as genetics.[2] In Hong Kong, a metropolitan city in southeast China, we found that 63.6% of children had at least 0.5 D astigmatism and 21.9% had at least 1.0 D.[3] In the latest American Academy of Ophthalmology Preferred Practice Pattern on pediatric eye evaluation and amblyopia, an age-dependent amblyogenic threshold for children with astigmatism was defined. As children matured from younger than 1 year to age 3 to 4 years, the amblyogenic threshold of astigmatism reduced from 3.0 D or more to 1.5 D or more.[4] Unlike myopia or hyperopia, children affected by astigmatism could not see clearly at neither near nor distance, putting them at a greater risk of amblyopia if the condition is left untreated.[5,6]

The COVID-19 pandemic changed the ways people lived, including children. Schooling became virtual, which was associated with more frequent or prolonged use of electronic gadgets or reduced outdoor time as a result of social restrictions for many children. These changes were associated with a surge in myopia prevalence in children of Hong Kong as well as other parts of the world across the COVID-19 pandemic.[7,8] Given the known association between myopia and astigmatism, 2 local studies evaluated the prevalence of RA in Hong Kong during the enforcement of restrictions in 2020 and compared with historical data from earlier years.[9,10] The high co-occurrence of astigmatism with myopia suggested that the change in the prevalence of RA could be a byproduct of axial elongation. Nonetheless, there were no data on the changes of corneal component of astigmatism, which might also be related to an increase in RA. Furthermore, no study reported the prevalence of astigmatism after the lift of social and school restrictions.

Established in 2015, the Hong Kong Children Eye Study (HKCES) is a population-based cross-sectional study on childhood ocular conditions. In this study, we evaluated 9 years of consecutive data from 2015 to 2023 from the HKCES, which covered the prepandemic, pandemic, and postpandemic periods, on the prevalence changes in RA and CA, as well as related corneal parameters. We also explored the associations of astigmatism with myopia and other ocular factors.

Key Points

Question What is the association between the COVID-19 pandemic and child astigmatism?

Findings This cross-sectional study involving 21 655 children from 2015 to 2023 revealed substantial increases in the prevalence and severity of refractive and corneal astigmatism, independent of myopia. The pandemic was associated with increased risks and magnitudes of child astigmatism, regardless of sociodemographic background, parental astigmatism, or presence of myopia.

Meaning Lifestyle changes after the pandemic were associated with an increase in the prevalence and severity of child astigmatisms, likely associated with changes in the developing cornea.

Methods

Study Population

Schoolchildren aged 6 to 8 years were recruited from the HKCES. Our selection was based on a stratified and clustered randomized sampling frame, where we stratified all the primary schools registered with Education Bureau in Hong Kong into 7 clustered regions used by Hospital Authority Services in Hong Kong. All children underwent comprehensive ocular examinations, and their parents completed standardized questionnaires on lifestyle and environmental risk factors at the Chinese University of Hong Kong Eye Centre and the Chinese University Medical Centre from 2015 to 2023. None of these children was analyzed more than once during this multiyear recruitment. The study protocol was previously published.[11] Participants with congenital ocular diseases, ocular trauma, or prior ocular surgery and those with no data on either autorefraction or keratometry were excluded from the study. Ethics approval was obtained from the Chinese University of Hong Kong, and the study conformed to the tenets of the Declaration of Helsinki. Written informed consent was obtained from both the child and their parents ahead of their participation. None of study participants received any stipend or other incentive to participate in this study. We use the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) reporting guidelines for this cross-sectional study.[12]

Ocular Examinations

Cycloplegic autorefraction was performed on all children with an autorefractor (ARK-510A; NIDEK Co) after a cycloplegic regimen. At least 2 cycles of eye drops were administered. Two drops of cyclopentolate, 1% (Cyclogyl; Alcon-Convreur), and tropicamide, 1% (Santen), were administered to both eyes at 5 minutes apart in the first cycle. For the second cycle, the same cycloplegic drops were applied 10 minutes after the first cycle. An additional third cycle was given at 30 minutes after the second cycle if the pupil size was less than 6.0 mm or the pupillary light reflex was still present. Corneal parameters, including flattest keratometry (K1) and steepest keratometry (K2), were measured with a noncontact partial-coherence laser interferometry (IOL Master; Carl Zeiss Meditec).

Definition and Outcomes

Data of the right eye from each study participant were used because of the high correlation between the 2 eyes of the participants (Pearson r = 0.82, P < .001). Refractive astigmatism (RA) was defined as at least 1.0 cylindrical diopters, expressed in a positive notation. Corneal astigmatism (CA) was defined as an absolute difference of at least 1.0 D between the flattest and the steepest keratometry of the cornea, expressed in a positive notation. The primary outcome was the annual prevalence of RA and CA. Secondary outcomes included the mean cylindrical powers of RA and CA, K1 and K2, and the mean keratometry values (mean K). The period 2015-2019 was defined as the pre–COVID-19 period and the reference, whereas 2020 was considered the COVID-19 period when social and school restrictions were in place, and 2021-2023 the post–COVID-19 period when restrictions were gradually lifted. Since February 2022, Hong Kong experienced the fifth wave of COVID-19, primarily driven by the Omicron BA2 variant, resulting in an increase in infection rates and mortality. This situation adversely impacted our recruitment efforts, prompting us to combine study participants from 2022 and 2023 to achieve a subtotal comparable with that of the other years.[13]

Statistical Analysis

Descriptive statistics were used to investigate the demographic characteristics of study participants. Binary or categorical variables were reported using counts and percentages while their group differences were examined using the Pearson χ^2 test. Continuous variables were reported as mean (SD). The associations between COVID-19 pandemic, age, sex, family income, and self-reported parental astigmatism with child RA and CA were analyzed using logistic regression while those with cylindrical powers of RA and CA were estimated using linear regression. All statistical analyses were performed using R version 4.2.1 (R Core Team, 2022). All P values were 2-sided but not adjusted for multiple analyses. Sensitivity analysis was performed using data from the left eyes (eTable 1 in the Supplement).

Results

Study Population

Data for a total of 21 655 children, consisting of 11 464 boys (52.9%) and 10 191 girls (47.1%) with a mean (SD) age of 7.31 (0.90) years, were analyzed. The demographic characteristics are summarized in eTable 2 in the Supplement.

Increase in Prevalence and Severity of RA and CA After COVID-19

Before the pandemic, the prevalence of RA was 23.4% from 2015-2019 (**Table 1** and eTable 3 in the Supplement). During COVID-19, it increased slightly to 24.6% in 2020 (difference, 1.1%; 95% CI, −1.4% to 3.7%). After the lift of restrictions, the prevalence of RA continued to increase to 30.0% (difference, 6.5%; 95% CI, 4.7% to 8.3%) in 2021 and 34.7% (difference, 11.2%; 95% CI, 8.2% to 14.3%) in 2022-2023. Subgroup analyses revealed an increase in prevalence of RA in both sexes and across all ages from 2021 onwards when compared with the pre–COVID-19 period (eTable 3 in the Supplement).

The prevalence of CA in children was 59.7% between 2015 and 2019 (Table 1 and eTable 3 in the Supplement). It increased to 66.9% (difference, 7.2%; 95% CI, 5.3%-9.1%) in 2021 and maintained at 64.7% (difference, 5.0%; 95% CI, 1.8%-8.1%) in 2022-2023. Likewise, boys and girls across all ages had higher prevalence of CA in 2021 compared with the pre–COVID-19 period (from prevalence in pre–COVID-19 period to prevalence in 2021: boys, 57.4% to 64.1%; difference; 6.7% [95% CI, 4.0%-9.3%]; girls, 62.2% to 70.1%; difference; 7.8% [95% CI, 5.1%-10.5%]; aged 6 years, 61.6% to 67.9%; difference; 6.3% [95% CI, 2.8%-9.8%]; aged 7 years, 58.4% to 65.7%; difference; 7.3% [95% CI, 4.1%-10.5%]; aged 8 years, 58.4% to 67.3%; difference; 8.9% [95% CI, 5.6%-12.2%]). In 2022-2023, a similar significance was observed for both boys (57.4% in pre–COVID-19 period to 62.3% in 2022-2023; difference, 4.9%; 95% CI, 0.7%-9.2%) and girls (62.2% in pre–COVID-19 period to 67.6% in 2022-2023; difference, 5.4%; 95% CI, 0.8%-10.0%), and among the 6-year-olds (61.6% in pre–COVID-19 period to 68.3% in 2022-23; difference, 6.7%; 95% CI, 2.0%-11.5%) (eTable 3 in the Supplement).

The magnitude of mean cylindrical power of RA gradually increased from 0.70 D from 2015-2019 (Table 1 and eTable 3 in the Supplement) to 0.71 D in 2020 (difference, 0.01 D; 95% CI, −0.03-0.05 D), 0.81 D in 2021 (difference, 0.11 D; 95% CI, 0.08-0.14 D; P < .001), and 0.87 D in 2022-2023 (difference, 0.17; 95% CI, 0.12-0.22 D; P < .001). A similar trend was observed for CA, where the mean cylindrical power of CA increased from 1.24 D during 2015-2020 (difference, 0 D; 95% CI, −0.04-0.4 D) to 1.34 D in 2021 (difference, 0.1 D; 95% CI, 0.07-0.13 D; P < .001) and 1.35 D in 2022-2023 (difference, 0.11 D; 95% CI, 0.06-0.16 D; P < .001). The same phenomenon was observed in all subgroups by sex and age when comparing the data of 2021-2023 to the pre–COVID-19 period (eTable 3 in the Supplement). The prevalence and mean (SD) of RA in negative notation are summarized and reported in eTable 5 in the Supplement. The majority of children continued to have with-the-rule astigmatism during these 9 years (eTable 6 in the Supplement).

Changes in Corneal Curvatures After COVID-19

The K1 value decreased from 42.91 D in 2015-2019 to 42.85 D in 2022-2023 (difference, −0.06 D; 95% CI, −0.15-0.03 D), while the K2 value increased from 44.15 D in 2015-2019 to 44.20 D in 2021-2023. However, the only potential difference was observed when comparing the K2 value (44.2 D) in 2021 to the baseline K2 value of 44.15 D during 2015-2019 (difference, 0.05 D; 95% CI, −0.01-0.11 D; P after adjusting for age, sex, and spherical values from the child = .03). The widening difference between K2 and K1 was supported by no differences identified in the mean keratometry, which was the average of K1 and K2 values. The mean keratometry value was not shown to be different across all ages and both sexes from 2015 to 2023 (**Table 2** and eTable 4 in the Supplement).

Table 1. Annual Prevalence and Mean (SD) of Refractive and Corneal Astigmatisms by Age and Sex, 2015-2023

Characteristic	No.	2015	2016	2017	2018	2019	*P* value	Period in relation to COVID-19 pandemic and restrictions				*P* value[a]		
								(1) Before, 2015-2019	(2) During, 2020	(3) After restriction 1, 2021	(4) After restriction 2, 2022 + 2023	(2) vs (1)	(3) vs (1)	(4) vs (1)
Total No. by year		1021	1525	1368	5479	7100		16 493	1201	2831	1007			
Refractive astigmatism prevalence, No. (%)[b]														
Total	21 532	218 (21.35)	343 (22.49)	287 (20.98)	1317 (24.04)	1698 (23.92)	.04	3863 (23.42)	295 (24.56)	848 (29.95)	349 (34.66)	.55	<.001	<.001
Age, y														
6	8418	62 (20.46)	131 (23.52)	92 (21.15)	609 (24.69)	776 (25.25)	.16	1670 (24.43)	94 (23.86)	255 (32.61)	144 (35.38)	.69	<.001	<.001
7	7406	98 (21.97)	123 (22.32)	103 (20.32)	367 (22.31)	525 (22.46)	.89	1216 (22.16)	136 (23.94)	292 (28.57)	113 (34.35)	.43	<.001	<.001
8	5708	58 (21.32)	89 (21.34)	92 (21.60)	341 (24.95)	397 (23.51)	.37	977 (23.42)	65 (27.02)	301 (29.31)	92 (33.95)	.24	.002	.01
Sex														
Male	11 403	107 (21.10)	194 (24.74)	168 (22.55)	731 (24.86)	944 (25.25)	.20	2144 (24.60)	164 (26.75)	460 (30.56)	209 (36.37)	.24	<.001	<.001
Female	10 129	111 (21.60)	149 (20.11)	119 (19.10)	586 (23.09)	754 (22.43)	.15	1719 (22.10)	131 (22.28)	388 (29.26)	140 (31.96)	.76	<.001	<.001
Total No. by year		1027	1514	1342	5258	6858		15 999	1187	2803	962			
Corneal astigmatism prevalence, No. (%)[c]														
Total	20 951	614 (59.79)	885 (58.45)	751 (55.96)	3129 (59.51)	4172 (60.83)	.01	9551 (59.70)	696 (58.64)	1874 (66.86)	622 (64.66)	.61	<.001	<.001
Age, y														
6	8092	175 (57.76)	333 (59.89)	248 (58.35)	1430 (61.64)	1845 (62.69)	.20	4031 (61.57)	219 (56.44)	524 (67.88)	263 (68.31)	.09	<.001	.002
7	7238	273 (60.94)	322 (59.30)	273 (55.49)	902 (56.45)	1353 (59.76)	.12	3123 (58.43)	336 (59.79)	668 (65.68)	195 (62.10)	.49	<.001	.08
8	5621	166 (60.14)	230 (55.42)	230 (54.12)	797 (59.48)	974 (58.99)	.20	2397 (58.36)	141 (59.49)	682 (67.26)	164 (62.36)	.68	<.001	.18
Sex														
Male	11 030	276 (54.33)	424 (54.71)	401 (54.86)	1620 (57.84)	2099 (58.60)	.08	4820 (57.40)	349 (57.59)	955 (64.05)	334 (62.31)	.91	<.001	.02
Female	9921	338 (65.13)	461 (62.38)	350 (57.28)	1509 (61.42)	2073 (63.28)	.03	4731 (62.23)	347 (59.72)	919 (70.05)	288 (67.61)	.40	<.001	.01
Total No. by year		1021	1525	1368	5479	7100		16 493	1201	2831	1007			
Cylinder, mean (SD), D														
Total	21 532	0.70 (0.65)	0.68 (0.67)	0.66 (0.66)	0.72 (0.68)	0.70 (0.67)	.09	0.70 (0.67)	0.71 (0.66)	0.81 (0.72)	0.87 (0.79)	.76	<.001	<.001
Age, y														
6	8418	0.70 (0.7)	0.69 (0.66)	0.66 (0.63)	0.72 (0.66)	0.71 (0.66)	.41	0.71 (0.66)	0.70 (0.68)	0.84 (0.74)	0.85 (0.74)	.60	<.001	<.001
7	7406	0.70 (0.65)	0.68 (0.65)	0.66 (0.67)	0.71 (0.70)	0.70 (0.68)	.78	0.69 (0.68)	0.71 (0.66)	0.78 (0.67)	0.88 (0.80)	.98	<.001	<.001
8	5708	0.69 (0.60)	0.68 (0.69)	0.67 (0.68)	0.72 (0.68)	0.70 (0.67)	.61	0.70 (0.67)	0.72 (0.60)	0.81 (0.73)	0.90 (0.84)	.90	<.001	<.001
Sex														
Male	11 403	0.68 (0.63)	0.70 (0.68)	0.69 (0.70)	0.73 (0.68)	0.73 (0.70)	.29	0.72 (0.69)	0.74 (0.67)	0.81 (0.72)	0.90 (0.81)	.47	<.001	<.001
Female	10 129	0.71 (0.67)	0.67 (0.65)	0.64 (0.61)	0.70 (0.67)	0.68 (0.64)	.13	0.69 (0.65)	0.67 (0.64)	0.80 (0.71)	0.84 (0.75)	.23	<.001	<.001
Total No. by year		1027	1514	1342	5258	6858		15 999	1187	2803	962			
K1-K2, mean (SD), D														
Total	20 951	1.25 (0.75)	1.25 (0.70)	1.20 (0.68)	1.24 (0.69)	1.24 (0.66)	.29	1.24 (0.68)	1.24 (0.66)	1.34 (0.70)	1.35 (0.75)	.87	<.001	<.001
Age, y														
6	8092	1.30 (0.95)	1.28 (0.67)	1.22 (0.69)	1.26 (0.69)	1.26 (0.67)	.59	1.26 (0.70)	1.21 (0.68)	1.36 (0.71)	1.36 (0.69)	.42	<.001	.001
7	7238	1.25 (0.68)	1.24 (0.65)	1.20 (0.70)	1.23 (0.70)	1.23 (0.65)	.75	1.23 (0.67)	1.25 (0.68)	1.32 (0.68)	1.37 (0.79)	.31	<.001	<.001
8	5621	1.19 (0.57)	1.21 (0.80)	1.19 (0.66)	1.23 (0.67)	1.24 (0.66)	.57	1.23 (0.68)	1.23 (0.61)	1.33 (0.70)	1.32 (0.80)	.76	<.001	.02

(continued)

Table 1. Annual Prevalence and Mean (SD) of Refractive and Corneal Astigmatisms by Age and Sex, 2015-2023 (continued)

Characteristic	No.	2015	2016	2017	2018	2019	*P* value	Period in relation to COVID-19 pandemic and restrictions: (1) Before, 2015-2019	(2) During, 2020	(3) After restriction 1, 2021	(4) After restriction 2, 2022 + 2023	*P* value[a]: (2) vs (1)	(3) vs (1)	(4) vs (1)
Sex														
Male	11 030	1.17 (0.63)	1.22 (0.65)	1.21 (0.71)	1.22 (0.68)	1.23 (0.69)	.50	1.22 (0.68)	1.22 (0.67)	1.30 (0.69)	1.33 (0.78)	.75	<.001	<.001
Female	9921	1.33 (0.84)	1.28 (0.75)	1.20 (0.65)	1.27 (0.70)	1.26 (0.64)	.03	1.27 (0.69)	1.25 (0.65)	1.37 (0.70)	1.38 (0.72)	.97	<.001	<.001

Abbreviations: D, diopter; K1, flattest keratometry; K2, steepest keratometry.

[a] *P* values are adjusted for age, sex, and sphere.

[b] Refractive astigmatism was defined as cylinder refraction ≥1 D in the right eye.

[c] Corneal astigmatism was defined as the absolute difference between K1 and K2 more than or equal to ≥1 D in the right eye.

Associations of COVID-19 Pandemic With RA and CA

The COVID-19 pandemic was associated with a higher prevalence of RA (odds ratio [OR], 1.20; 95% CI, 1.09-1.33; *P* < .001; prevalence in 2015-2019, 23.4%; prevalence in 2020-2023, 29.6%; prevalence difference, 6.2% [95% CI, 4.8%-7.6%]) and CA (OR, 1.26; 95% CI, 1.15-1.38, *P* < .001; prevalence in 2015-2019, 59.7%; prevalence in 2020-2023, 64.5%; prevalence difference, 4.8% [95% CI, 3.3%-6.3%]) in both univariate and multiple logistic regressions (**Table 3**). Likewise, the magnitudes of RA and CA were both associated with the COVID-19 pandemic (RA: β, 0.04 D; 95% CI, 0.02-0.07; *P* < .001; mean [SD] in 2015-2019, 0.70 [0.67] D; mean [SD] in 2020-2023, 0.80 [0.72] D; mean difference, 0.1 D [95% CI, 0.08-0.12 D]; and CA: β, 0.05 D; 95% CI, 0.02-0.08; *P* < .001; mean [SD] in 2015-2019, 1.24 [0.68] D; mean [SD] in 2020-2023, 1.32 [0.70] D; mean difference, 0.08 D [95% CI, 0.06-0.1 D]), adjusted for the age, sex of child, spherical value, familial income, and presence of parental astigmatism (**Table 4**). Logistic and linear regressions done with RA in negative notation are summarized in eTables 7 and 8 in the Supplement. When compared with the prepandemic period 2015-2019, we observed a decrease in the amount of outdoor time (from 1.43 to 1.16 hours per day; difference, −0.27 hours; 95% CI, −0.29 to −0.25 hours; *P* < .001) and an increase in the amount of near work (from 3.33 to 4.91 hours per day; difference, 1.58 hours; 95% CI, 1.52-1.64 hours; *P* < .001) during 2020-2023 (eTable 11 in the Supplement).

Increase in Astigmatism Independent of Myopia

Our data demonstrated a delayed in increased prevalence of both RA and CA from 2020 to 2023, following the increase in myopia in 2019 during the pandemic (**Figure**). The absolute magnitude of RA and CA also increased from 2021 to 2023 (eFigure 1 in the Supplement).

Discussion

In this 9-year population-based study (from 2015 to 2023) conducted in Hong Kong and using standard measurements among children from the same region, we observed a sustained increase in the prevalence and severity of both refractive and corneal astigmatism in Chinese schoolchildren of Hong Kong. While myopia increased during the onset of the pandemic and related restrictions, astigmatism started to increase only in 2021 after the restrictions were gradually lifted. The increase in prevalence continued into 2023. By considering the spherical values for the children, we showed that the increase in astigmatism prevalence was independent from the surge in myopia. The pandemic itself imposed additional odds of RA and CA by 20%, or by a magnitude of 0.04 D.

Astigmatism remained highly prevalent after pandemic-related restrictions were lifted. The COVID-19 pandemic brought about lifestyle changes, particularly in the mode of learning and the school curriculum of schoolchildren. Switching from in-person classes to virtual, children were required to spend longer hours viewing electronic devices, which was intensive near work, compared with the prepandemic period.[7,14] In our current study, the prevalence of RA before 2019 was 23.4%, which was already higher than the 20.2% reported previously in Hong Kong during 2015-2016[9] and the 18.1% by our own institution during 1998-2000.[15] Compared with earlier reports, we observed an increase in the prevalence of RA and CA only in 2021. Wong et al[9] reported a prevalence of 28.9% in 418 schoolchildren during October to December 2020 using a 1 D or more threshold and an open-field autorefractor without cycloplegia and cited up to a 1.49-fold increase in the prevalence of RA when compared with historical data from another local study using a similar study design in 2015-2016, as well as a Singaporean Chinese study in 1999. Liang et al[10] also reported a similar 1.5-fold increase of astigmatism prevalence from 33.9% in 2018 to 49.1% in 2020 using a 0.75 D or more threshold among 285 students in Hong Kong. Both studies suggested school closure, increased use of digital device, and reduced outdoor time as well as axial myopia as possible associated factors. Like these published studies, our data suggested a similar extent in the increase of astigmatism prevalence; however, the timing of increase was later than that of myopia (Figure).

Our study showed an increase in the steepest corneal curvature and the prevalence and magnitude of CA in children after the COVID-19 pandemic, which might contribute to the increase in RA. We speculate that the increase in CA was due to an increasing trend of K2, which showed increases in 2021 at a value of 44.2 D. An increase was not demonstrated in 2022-

Table 2. Annual Mean (SD) of K1, K2, and Mean K by Age and Sex, 2015-2023

								Period in relation to COVID-19 pandemic and restrictions				P value[a]		
Characteristic	No.	2015	2016	2017	2018	2019	P value	(1) Before, 2015-2019	(2) During, 2020	(3) After restriction 1, 2021	(4) After restriction 2, 2022 + 2023	(2) vs (1)	(3) vs (1)	(4) vs (1)
Total No. by year		1027	1514	1342	5258	6858		15 999	1187	2803	962			
K1, mean (SD), D														
Total	20 951	42.93 (1.80)	42.93 (1.38)	42.95 (1.36)	42.87 (1.41)	42.93 (1.41)	.12	42.91 (1.43)	42.94 (1.37)	42.87 (1.43)	42.85 (1.44)	.75	.10	.22
Age, y														
6	8092	42.89 (1.36)	42.83 (1.44)	42.94 (1.36)	42.94 (1.43)	43.00 (1.41)	.32	42.94 (1.41)	43.05 (1.41)	42.95 (1.46)	42.88 (1.37)	.31	.78	.22
7	7238	42.96 (2.21)	42.98 (1.33)	43.03 (1.41)	42.81 (1.39)	42.92 (1.41)	.012	42.91 (1.48)	42.90 (1.37)	42.87 (1.40)	42.82 (1.48)	.80	.26	.63
8	5621	42.90 (1.44)	43.01 (1.37)	42.88 (1.31)	42.84 (1.39)	42.90 (1.41)	.29	42.89 (1.39)	42.88 (1.30)	42.82 (1.42)	42.84 (1.48)	.79	.14	.75
Sex														
Male	11 030	42.56 (2.08)	42.59 (1.30)	42.66 (1.34)	42.53 (1.35)	42.57 (1.34)	.27	42.57 (1.39)	42.54 (1.27)	42.54 (1.36)	42.57 (1.34)	.65	.25	.73
Female	9921	43.28 (1.37)	43.30 (1.38)	43.30 (1.30)	43.26 (1.37)	43.33 (1.38)	.42	43.30 (1.37)	43.36 (1.41)	43.25 (1.41)	43.21 (1.47)	.35	.23	.14
Total No. by year		1027	1514	1342	5258	6858		15 999	1187	2803	962			
K2, mean (SD), D														
Total	20 951	44.17 (1.98)	44.17 (1.57)	44.14 (1.53)	44.11 (1.55)	44.18 (1.57)	.26	44.15 (1.59)	44.17 (1.52)	44.20 (1.58)	44.20 (1.55)	.70	.03	.13
Age, y														
6	8092	44.19 (1.64)	44.10 (1.60)	44.15 (1.53)	44.19 (1.54)	44.22 (1.57)	.49	44.19 (1.56)	44.26 (1.59)	44.30 (1.61)	44.24 (1.48)	.53	.05	.65
7	7238	44.22 (2.36)	44.21 (1.53)	44.21 (1.58)	44.03 (1.57)	44.14 (1.56)	.052	44.13 (1.64)	44.15 (1.50)	44.19 (1.57)	44.19 (1.61)	.79	.27	.17
8	5621	44.09 (1.61)	44.20 (1.56)	44.06 (1.48)	44.07 (1.55)	44.14 (1.58)	.49	44.11 (1.56)	44.10 (1.45)	44.15 (1.56)	44.17 (1.59)	.82	.42	.38
Sex														
Male	11 030	43.73 (2.20)	43.80 (1.44)	43.85 (1.53)	43.75 (1.52)	43.80 (1.50)	.48	43.78(1.6)	43.76 (1.42)	43.84 (1.51)	43.90 (1.43)	.73	.16	.12
Female	9921	44.61 (1.62)	44.56 (1.60)	44.49 (1.47)	44.52 (1.49)	44.59 (1.54)	.31	44.56 (1.53)	44.61 (1.50)	44.62 (1.55)	44.59 (1.61)	.34	.09	.59
Total No. by year		1027	1514	1342	5258	6858		15 999	1187	2803	962			
Mean K, mean (SD), D														
Total	20 951	43.55 (1.85)	43.55 (1.43)	43.54 (1.41)	43.49 (1.44)	43.55 (1.45)	.19	43.53 (1.47)	43.56 (1.41)	43.54 (1.46)	43.53 (1.45)	.70	.69	.81
Age, y														
6	8092	43.54 (1.43)	43.47 (1.48)	43.54 (1.41)	43.56 (1.44)	43.59 (1.45)	0.4	43.57 (1.45)	43.65 (1.46)	43.62 (1.50)	43.56 (1.38)	.40	.35	.73
7	7238	43.59 (2.26)	43.60 (1.40)	43.61 (1.45)	43.42 (1.44)	43.53 (1.45)	0.024	43.52 (1.53)	43.52 (1.40)	43.53 (1.45)	43.51 (1.49)	.96	.95	.60
8	5621	43.49 (1.50)	43.60 (1.41)	43.47 (1.36)	43.45 (1.43)	43.52 (1.46)	0.4	43.50 (1.44)	43.49 (1.33)	43.48 (1.45)	43.51 (1.48)	.80	.77	.73
Sex														
Male	11 030	43.14 (2.12)	43.19 (1.33)	43.26 (1.39)	43.14 (1.40)	43.18 (1.38)	0.48	43.18 (1.44)	43.15 (1.30)	43.19 (1.40)	43.23 (1.33)	.70	.84	.49
Female	9921	43.95 (1.44)	43.93 (1.44)	43.89 (1.35)	43.89 (1.38)	43.96 (1.43)	0.31	43.93 (1.41)	43.98 (1.39)	43.93 (1.44)	43.90 (1.50)	.33	.74	.68

Abbreviations: D, diopter; K, keratometry; K1, flattest keratometry; K2, steepest keratometry.

[a] *P* values are adjusted for age, sex, and sphere.

2023 as the K2 value appeared to remain the same to that in 2021, which might be attributed to a lower number of children recruited in 2022-2023.

As most children had with-the-rule astigmatism (eTable 6 in the Supplement),[3] the steeper corneal curvature was almost exclusively located in the vertical meridian. We hypothesize that the habit of using digital devices during COVID-19 had an impact on the corneal curvatures. This had previously been reported at the superior region of the cornea in relation to the position of the upper eyelid during reading or using electronic devices.[16] Although these changes were thought to be transient and reversible after shifting from downward to pri-

Table 3. Logistic Regression on the Associations Between COVID-19 Pandemic and Astigmatism

Characteristic	Model 1[a] OR (95% CI)	Model 1[a] P value	Model 2[b] OR (95% CI)	Model 2[b] P value
Refractive astigmatism (≥1.0 D)				
COVID-19 pandemic (2015-2019 as reference)[c]	1.26 (1.15-1.39)	<.001	1.20 (1.09-1.33)	<.001
Age, y	NA	NA	0.81 (0.77-0.85)	<.001
Sex (male as reference)	NA	NA	0.90 (0.83-0.98)	.02
Parental astigmatism (no as reference)	NA	NA	1.20 (1.06-1.35)	<.001
Sphere, diopters	NA	NA	0.69 (0.67-0.70)	<.001
Family income (>HK$25 000 as reference[d])	NA	NA	0.92 (0.85-1.00)	.03
Corneal astigmatism (≥1.0 D)				
COVID-19 pandemic (2015-2019 as reference)[c]	1.26 (1.15-1.37)	<.001	1.26 (1.15-1.38)	<.001
Age, y	NA	NA	0.91 (0.88-0.95)	<.001
Sex (male as reference)	NA	NA	1.28 (1.19-1.37)	<.001
Parental astigmatism (no as reference)	NA	NA	1.21 (1.08-1.36)	<.001
Sphere, D	NA	NA	0.88 (0.86-0.91)	<.001
Family income (>HK$25 000 as reference[d])	NA	NA	0.97 (0.90-1.05)	.44

Abbreviations: D, diopter; OR, odds ratio; NA, not applicable.

[a] Model 1: not adjusted for covariates.

[b] Model 2: adjusted for age, sex, parental astigmatism, sphere, and family income.

[c] COVID-19 pandemic refers to the period 2020-2023.

[d] US $3215.79.

Table 4. Linear Regression of Effects of COVID-19 Pandemic on RA and CA

Characteristic	Model 1[a] β (95% CI)	Model 1[a] P value	Model 2[b] β (95% CI)	Model 2[b] P value
Refractive astigmatism (cylinder)				
COVID-19 pandemic (2015-2019 as reference)[c]	0.07 (0.04 to 0.10)	<.001	0.04 (0.02 to 0.07)	.001
Age, y	NA	NA	−0.07 (−0.08 to −0.06)	<.001
Sex (male as reference)	NA	NA	−0.02 (0.04 to 0)	.09
Parental astigmatism (no as reference)	NA	NA	0.05 (0.02 to 0.08)	.004
Sphere, D	NA	NA	−0.15 (−0.16 to −0.15)	<.001
Family income (>HKD$25 000 as reference[d])	NA	NA	−0.02 (−0.04 to 0)	.08
Corneal astigmatism (K1-K2)				
COVID-19 pandemic (2015-2019 as reference)[c]	0.07 (0.04 to 0.09)	<.001	0.05 (0.02 to 0.08)	<.001
Age, y	NA	NA	−0.05 (−0.07 to −0.04)	<.001
Sex (male as reference)	NA	NA	0.06 (0.04 to 0.08)	<.001
Parental astigmatism (no as reference)	NA	NA	0.07 (0.03 to 0.10)	<.001
Sphere, D	NA	NA	−0.09 (−0.10 to −0.08)	<.001
Family income (>HK$25 000 as reference[d])	NA	NA	−0.005 (−0.03 to 0.02)	.70

Abbreviations: D, diopter; K1, flattest keratometry; K2, steepest keratometry; NA, not applicable.

[a] Model 1: not adjusted for covariates.

[b] Model 2: adjusted for age, sex, parental astigmatism, sphere, and family income.

[c] COVID-19 pandemic refers to the period 2020-2023.

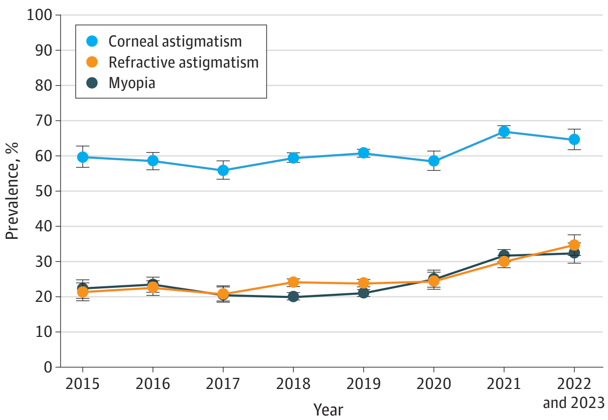
[d] US $3215.79.

mary gaze,[17] we speculate a cumulative effect on CA after habitual and prolonged periods of such gaze, leading to an increase in K2 value with time.

Compared with the change in myopia prevalence in Hong Kong over the pandemic, the increase in RA and CA exhibited a delayed onset. While the increase in myopia prevalence started from 2019-2020 during the COVID-19 restrictions, astigmatism only began to increase in 2021 and started to ease off in 2023.[7] Based on the previous reports that astigmatism and myopia are highly correlated and that astigmatism may be a byproduct of myopia,[3,15,18,19] the findings in our present study provided additional data on the corneal component, which is a major contributor to RA. We think that the change in corneal curvatures induced by near work takes time to develop. Moreover, the independent increase in astigmatism prevalence from myopia was supported by the regression models, which were adjusted for the spherical values from the children.

While parental astigmatism has been found to be an important risk factor for child astigmatism,[20-22] such information was often omitted in the published studies. Our regression models took into consideration the effects from parents, as well as the socioeconomic status of the family, which play a role in determining the mode of learning of the child.[23,24] After adjusting for the above factors, the association between the COVID-19 pandemic and the prevalence and severity of astigmatism remained.

Figure. Annual Prevalence of Refractive Astigmatism, Corneal Astigmatism, and Myopia From 2015 to 2023



Error bars indicate 95% CI.

Limitations

Our study has several limitations. The majority of the children were Han Chinese, and our results may not be generalizable to other ethnicities or geographical locations. In addition, in defining time periods in relation to COVID-19, each country or region may have their unique governmental policies on social restrictions. Local practices, including both the extent of the restrictions and population adherence, were variable, so our results may not be reproducible in countries with alternative quarantine measures during the pandemic. Apart from that, our sample size for the year 2022 and 2023 was smaller than those of the previous years. This may have affected the precision of data. Lastly, parental astigmatism, self-reported via questionnaire, was subject to recall bias. Although our previous trio study pinpointed parental astigmatism as a risk factor for child astigmatism, excluding this variable did not reveal any confounding effect on the associations between the COVID-19 pandemic and child astigmatism in our regression analyses.

Conclusions

This study identified an increase in both the prevalence and severity of refractive and corneal astigmatisms after the COVID-19 pandemic among schoolchildren in Hong Kong. Given the high prevalence of astigmatism, the potential impact of higher degrees of astigmatism may warrant dedicated efforts to elucidate the relationship between environmental and/or lifestyle factors, as well as the pathophysiology of astigmatism, in order to preserve children's eyesight and quality of life.

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Invited Commentary

Importance of Population-Based Studies in Childhood Eye Disease—Seeing the Bigger Picture

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There's good news and bad news about the most common causes of childhood vision loss. The good news is that some of the most common causes have easy, affordable treatments with the potential for great outcomes: think of the child with refractive error successfully treated with a pair of glasses who goes on to have normal vision. The bad news is that treatment initiation or access can be limited by our ability to understand the burden of childhood eye disease in certain populations. A well-designed population-based study has the potential to address this "bad news" and ultimately result in better visual outcomes for children.

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Leveraging data from the population-based Hong Kong Child Eye Study (HKCES), Kam et al[1] sought to determine the prevalence of one of the most common eye conditions in children, astigmatism. They evaluated the prevalence of astigmatism in over 21 000 children aged 6 to 8 years in Hong Kong from 2015 to 2023. Children underwent comprehensive eye examinations, and anatomic and visual outcomes were compared between children in the pre-COVID-19 group (2015-2019), COVID-19 group (2020), and post-COVID group (2021-2023). Evaluating the prevalence rate of refractive astigmatism of 1.0 diopter or more, the authors found an increase from approximately 23% before the COVID-19 pandemic to 35% after the COVID-19 pandemic, possibly mediated through increased corneal steepness.[1] This study's methodology highlights the importance of population-based studies in childhood eye disease as well as the challenges associated with this methodologic approach.

Population-based research aims to evaluate an entire population as defined by a shared geographic, environmental, or personal characteristic.[2] In HKCES, the target population was children attending school in Hong Kong. This type of research has obvious advantages, including the ability to determine population-level prevalences of specific conditions, representativeness, and the potential for longitudinal assessment of study populations less subject to referral bias. However, population-based studies are challenging to perform due to high costs and logistical complexities. Additionally, population-based studies that are performed over long periods of time are especially difficult given a host of unpredictable factors that can affect the underlying study population's willingness to participate.