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Secondhand smoke (SHS) exposure is associated with an increased risk of developing myopia among nonmyopic children in China

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Abstract

Purpose To investigate the impact of secondhand smoke (SHS) exposure on myopia prevalence and risk among nonmyopic children in China.

Methods This was a retrospective cohort study. A total of 232 children aged 5–10 years were included, with 128 exposed to SHS and 104 who were not. Baseline characteristics such as age, sex, height, weight, spherical equivalent refraction (SER), axial length (AL), average corneal K-reading (Ave-K), intraocular pressure (IOP), pupil diameter (PD) and subfoveal choroidal thickness (SFCT) were measured. Follow-up assessments at 3-, 6-, 9-, and 12-month visits were focused on changes in SER and AL. Behavioural and parental factors, including parental myopia status, parental education level, daily time spent on near work and outdoor activities were collected via questionnaires from medical records. Linear regression was applied to identify the factors that have a significant impact on axial elongation over 1 year.

Results The mean spherical refraction myopic shift in the SHS group was -0.64 ± 0.41 D/year, which was significantly greater than that in the control group (-0.47 ± 0.52 D/year) ($P = 0.004$). Children in the SHS group had significantly greater axial elongation than did children in the control group (0.26 ± 0.14 mm vs. 0.20 ± 0.13 mm, $P = 0.002$). Multivariate linear regression analysis revealed that SHS exposure ($\beta = 0.053$, $P = 0.002$), baseline SER ($\beta = -0.054$, $P = 0.001$) and parental myopia ($\beta = 0.028$, $P = 0.036$) were significant predictors of 12-month axial elongation.

Conclusions This retrospective cohort study revealed that SHS exposure was associated with a greater likelihood of developing early-onset myopia. These findings indicate that eradicating SHS exposure is highly important for preventing myopia among children, especially in families with young children.

Keywords Myopia, Secondhand smoke exposure, Nonmyopic children, Axial length, Spherical equivalent

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Introduction

The incidence of myopia has increased over the past few decades, and it is estimated that 49.8% of the world's population will be affected by this condition by 2050 [1]. In addition to the increasing prevalence of myopia, the early onset of myopia among younger individuals also raises concerns regarding the heightened likelihood of developing high myopia [2, 3]. High myopia, defined by a spherical equivalent refraction exceeding −6.00 dioptres (D), is associated with several sight-threatening complications, such as cataracts, glaucoma, retinal detachment, and myopic maculopathy [4]. Although the mechanism of myopia is not fully understood, it is widely accepted that both genetic and environmental factors significantly influence the development of myopia [5]. Investigating the risk factors for myopia and enhancing modifiable environmental predictors are crucial for mitigating the myopia epidemic.

According to new WHO data, in some countries of the European Region, up to 60% of children are exposed to secondhand smoke (SHS) at home, making it a significant public health concern. Exposure to SHS increases the risk of children contracting respiratory tract infection [6], sudden infant death syndrome [7], asthma, wheezing [8], and meningitis [9]. Associations between SHS exposure and myopia have been reported in previous studies, but the conclusions remain controversial. For example, a prospective birth cohort study in Singapore indicated that 3-year-old children who were exposed to SHS from birth to six months had a 2.8-fold increased risk of developing myopia [10], which suggested that early-life exposure to SHS may increase the risk of myopia development. Conversely, several epidemiological studies have shown that SHS exposure during childhood leads to a lower myopia prevalence and an overall refractive shift towards hyperopia [11–13]. However, most previous studies are cross-sectional and cannot be used to determine a causal relationship, and the participants in the Singapore cohort study underwent only one cycloplegic autorefraction and axial length (AL) measurement at age 3, which is insufficient follow-up data. Therefore, further evidence is warranted to illustrate the impact of SHS exposure on ocular development. This research represents the first cohort study established in China that examines the relationship between SHS exposure and the onset of myopia, which offers a unique perspective and contributes significantly to filling the existing knowledge gap in this field.

In this study, we investigated the role of SHS exposure as a risk factor for myopia onset among nonmyopic children in China.

Methods

This was a retrospective clinical study targeting nonmyopic children who had never received any prevention or control measures for myopia. The study adhered to the tenets of the Declaration of Helsinki and was approved by the Ethics Committee of the Peking University People's Hospital.

Participants

The involved subjects were children who visited the Optometry Center & Ophthalmology Department of Peking University People's Hospital for the first time between June 1, 2023, and June 30, 2023, and were followed-up for more than 1 year. The inclusion criteria were as follows: (1) cycloplegia spherical equivalent ranging from +2.00 D to 0.00 D and astigmatism less than 1.50 D in each eye; (2) anisometropia less than 1.00 D; (3) no strabismus, diabetes, or any other ocular or systematic diseases that may affect refractive development; and (4) not using myopia prevention and control measures, such as low-concentration atropine eye drops or peripheral defocusing spectacle lenses. Children who were exposed to SHS were included in the SHS group, and those who were not were placed in the control group. Cycloplegic refraction and AL were measured at baseline, and the changes in refraction and AL among the SHS and control groups were compared over 1 year.

Measurements

A corneal topography system (Sirius, Italy) was used to obtain the photopic pupil diameter (PPD) and average corneal K-readings (Ave-K, Ave-K = (flat keratometry + steep keratometry)/2). AL, mesopic PD (MPD), central corneal thickness (CCT), anterior chamber depth (ACD), and crystalline lens thickness (CLT) were measured at baseline and every 3-month interval via noncontact partial-coherence laser interferometry (IOL Master; Carl Zeiss Meditec, Oberkochen, Germany). For accuracy, the measurements were taken by the same technical staff, and five consecutive measurements were taken and averaged for definitive statistical analysis.

After the biometry measurements, cycloplegia was induced by the instillation of 0.5% compound tropicamide eye drops (Santen Pharmaceutical Co. Ltd., Japan; 0.5% tropicamide combined with 0.5% phenylephrine) at 5-min intervals (4 times). At least 30 min after the last drop, five consecutive measurements of refractive error were obtained by using an autorefractor (KP8800; Topcon Corp., Tokyo, Japan). SER was calculated as the spherical power plus half of the cylinder power. Myopia is defined as SER $<$ -0.50 D. Height and weight were measured and recorded every time the children visited the hospital.

Behavioural and parental factors

A range of potential risk factors concerning myopia progression, including age, sex, parental myopic status (categorized as yes or no), parental educational level (categorized as college degree and below or bachelor's degree and above), time spent on outdoor activities and near work (continuous variables with the unit of h/d) were collected via questionnaires from medical records.

Statistical analysis

Statistical analyses were performed via SPSS statistical analysis software, version 26.0 (IBM Corp., Armonk, NY, USA). As there was a high correlation between both eyes, analyses were performed using data from the right eye only. The Shapiro−Wilk test was used to confirm the normality of the primary parameters prior to further analysis. Continuous variables are reported as the means ± standard deviations (SDs), and categorical variables are reported as frequencies and percentages. Differences between the SHS group and the control group were assessed via independent-samples t tests for continuous data and the chi-square test for categorical data.

Univariate linear regression was applied to explore the factors that might influence axial elongation at 12 months. All factors that exhibited a P value of less than 0.1 in the univariate analysis were subsequently included in the multiple linear regression analysis. Multivariate linear regression models were constructed to examine the association between SHS exposure and AL changes, adjusting for potential confounding variables. A two-tailed P value < 0.05 was considered to indicate statistical significance.

To explore potential population differences between SHS and myopia progression, subgroup analyses based on age, sex, and parental myopia status were conducted.

Results

A total of 232 children were included in this retrospective study, with 128 in the SHS group and 104 in the control group. The differences in baseline demographic and other characteristics between the SHS group and the control group are presented in Table 1.

The AL and SER changes between the two groups over 1 year are shown in Fig. 1; Table 2. An increase in AL was observed in both groups, and axial elongation was lower in the control group than in the SHS group (0.20 ± 0.13 vs. 0.26 ± 0.14 mm, $P = 0.002$). It significantly differed between the two groups at 9 and 12 months (all $P < 0.05$) but not at 3 and 6 months. The myopic shift was lower in the control group than in the SHS group (-0.47 ± 0.52 vs. -0.64 ± 0.41 D, $P = 0.004$).

The data in the Fig. 1 are represented as Mean and Standard Error of the Mean (SEM).

According to the univariate regression analysis, axial elongation at 12 months was significantly correlated with SHS exposure (β = 0.055, $P = 0.002$). As indicated in Table 3, factors such as baseline SER (β = -0.079, $P = 0.003$), subfoveal choroidal thickness (CT; β = 0.000, $P = 0.039$), parental myopia (β = 0.039, $P < 0.001$), and maternal education (β = 0.055, $P = 0.002$) were significantly associated with 12-month axial elongation in the univariate linear regression analysis. Upon further examination via multivariate linear regression analyses, these factors, namely, baseline SER (β = -0.054, $P = 0.001$), SHS exposure (β = 0.053, $P = 0.002$), and parental myopia (β = 0.028, $P = 0.036$), remained significantly associated with 12-month AL elongation.

As shown in Table 4, the subgroup analyses based on age, sex, and parental myopia status suggest that there is no significant difference between secondhand smoke exposure and the 12-month axial elongation.

Discussion

In this retrospective study, we found that, compared with children who were not exposed to SHS, children exposed to SHS had a greater myopic shift and earlier myopia onset after one year. SHS was an independent factor linked to alterations in the ocular axis after controlling for potential confounders such as age, sex, parental myopia, parental education level, time spent outside, and time spent on near work.

According to the results of previous studies, smoking is strongly associated with several common eye diseases, such as glaucoma [14, 15], cataracts [16], age-related macular degeneration (AMD) [4] and Grave's orbitopathy [17]. Since cigarette smoking highly irritates the conjunctival mucosa, it also affects the eyes of nonsmokers via SHS.

A similar association between SHS exposure and myopia was reported by Zhang, who found that among 12,630 children from Hong Kong aged 6 to 8 years, exposure to SHS was associated with greater myopic refraction, longer AL, earlier onset of myopia and greater likelihood of developing moderate or high myopia [18]. A cross-sectional study involving 1,400 children in Hong Kong conducted by Nan Yuan et al.. revealed that exposure to SHS in children led to a dose-dependent reduction in the thickness of the choroidal membrane [19]. Similarly, a comparison of macular choroidal thickness (CT) between smokers and nonsmokers aged over 65 years with early atrophic AMD by Sigler et al. revealed that CT was significantly thinner in smokers than in nonsmokers ($P = 0.003$) [20]. These discoveries support a possible hypothesis for the development of myopia due to SHS exposure by impairing choroidal circulation and decreasing perfusion. Up to 4,700 active compounds can be found in tobacco smoke, including various toxic

Table 1 Baseline demographic and other characteristics between SHS group and control group

Characteristic		Mean (SD)		
		SHS group (*n* = 128)	Control group (*n* = 104)	*P* value
Age, y		6.83 (1.32)	6.90 (1.42)	0.676
Sex, No. (%)				
	Male	64 (50.0)	50 (48.1)	0.771
	Female	64 (50.0)	54 (51.9)	
Height, cm		127.21 (9.78)	127.94 (10.98)	0.593
Weight, kg		27.50 (7.87)	28.18 (9.44)	0.546
Spherical equivalent, D[a]		0.72 (0.56)	0.78 (0.51)	0.389
Axial length, mm[b]		22.94 (0.75)	22.95 (0.72)	0.922
Average corneal K-reading, D[c]		43.52 (2.23)	43.72 (1.40)	0.427
Intraocular pressure, mmHg[d]		16.14 (2.21)	16.07 (2.61)	0.812
Central corneal thickness, um[e]		544.7 (32.99)	542.16 (28.32)	0.537
Anterior chamber depth, mm[f]		3.03 (0.22)	3.06 (0.23)	0.245
Crystalline lens thickness, mm[g]		3.65 (0.23)	3.68 (0.24)	0.390
Pupil size, mm				
	Photopic[h]	3.15 (0.59)	3.09 (0.58)	0.433
	Mesopic[i]	6.14 (0.91)	6.12 (0.77)	0.845
Subfoveal choroidal thickness, um[j]		260.79 (55.05)	267.00 (47.17)	0.364
Outdoor activity, h/d[k]		1.09 (0.88)	0.88 (0.55)	0.044
Near work after school, h/d[l]		1.91 (0.81)	1.86 (0.85)	0.626
Parents with myopia, No. (%)				
	0	36 (28.1)	32 (30.8)	0.317
	1	65 (50.8)	58 (55.8)	
	2	27 (21.1)	14 (13.5)	
Mother's education level, No. (%)				
	College degree and below	66 (51.6)	62 (59.6)	0.220
	Bachelor's degree and above	62 (48.4)	42 (40.4)	
Father's education level, No. (%)				
	College degree and below	90 (70.3)	54 (51.9)	0.004
	Bachelor's degree and above	38 (29.7)	50 (48.1)	

a. Spherical equivalent is calculated as spherical power plus half of the cylinder power

b. Axial length is the distance from the anterior surface of the cornea to the retinal pigment epithelium

c. Average corneal K-reading represents the average curvature of the cornea

d. Intraocular pressure refers to the fluid pressure inside the eye

e. Central corneal thickness is the thickness of the central cornea

f. Anterior chamber depth refers to the distance between the posterior surface of the cornea and the anterior surface of the iris

g. Crystalline lens thickness indicates the size and condition of the crystalline lens within the eye

h. Photopic pupil size is measured in a environment with an intensity of 500 lx

i. Mesopic pupil size is measured in a environment with an intensity of 4 lx

j. Subfoveal choroidal thickness is the thickness of the choroidal beneath the foveal

k. Outdoor activity includes outdoor exercise plus outdoor leisure activity

l. Near work after school includes doing homework, reading, playing cell phone, using computer, playing video game, watching television and so on

substances such as nicotine, which stimulates the release of catecholamines, resulting in increased vasoconstriction [21, 22], and carbon monoxide, which has been demonstrated to impair the vascular endothelium, augment vascular endothelial permeability, and facilitate atherosclerosis [23]. These harmful substances enter children's blood circulation through inhalation or mucosal contact and alter choroidal blood flow [24], resulting in remodelling of the scleral extracellular matrix, subsequently causing elongation of the AL and ultimately altering refraction [25]. In fact, the influence of SHS on children's visual development is evident not only postnatally but also from the onset of gestation. A study including 2,487 people aged 44 years who were selected randomly from the 1958 British birth cohort revealed that myopia was positively associated with maternal smoking in early pregnancy [26].

In contrast to our findings, a negative association between SHS exposure and myopia has also been reported. S-M Saw et al.. reported that children with

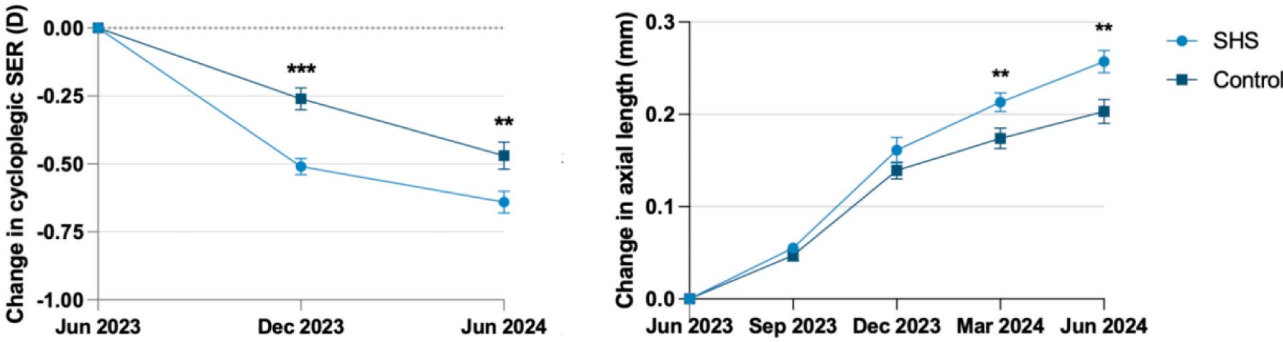

Fig. 1 Changes in SER and AL over 1 year between SHS group and Control group

Table 2 Changes in spherical equivalent and axial length over 1 year

Follow-up	Mean (SD)		
	SHS group	Control group	*P* value
Changes in spherical equivalent, D			
6 months	-0.51 (0.34)	-0.26 (0.33)	< 0.001
12 months	-0.64 (0.41)	-0.47 (0.52)	0.004
Changes in axial length, mm			
3 months	0.06 (0.05)	0.05 (0.06)	0.333
6 months	0.16 (0.14)	0.14 (0.08)	0.204
9 months	0.21 (0.10)	0.17 (0.10)	0.009
12 months	0.26 (0.14)	0.20 (0.13)	0.002

mothers who had ever smoked during their lifetime had more "positive" refractions [12], but this study was limited by the small number of smoking mothers in the sample [23 (1.7%)]. A cross-sectional study conducted by Stone et al.. revealed that children with one or both parents who smoked presented a lower prevalence of myopia (12.4% vs. 25.4%; $P = 0.004$) and more hyperopic mean refractions (1.83 ± 0.24 vs. 0.96 ± 0.27 D; $P = 0.02$) than those whose parents never smoked [13]. However, half (162/323) of the subjects in that study had strabismus, which may have influenced the outcomes. Another cross-sectional study including 300 children aged 5 to 12 years from Egypt indicated that passive smoking might be linked to a refractive error shift towards hypermetropia [11]. Given the cross-sectional nature of these studies, a causal relationship clearly cannot be proven.

In addition to environmental factors, our results also indicate that the offspring of myopic parents are predisposed to myopia. A comparable correlation has been reported previously. For example, a myopia study conducted in Sydney by Ip et al.. (2007) involving 2353 children revealed that the prevalence of myopia in children with myopic parents was 7.6% in children with no myopic

Table 3 Linear regression analyses of 1-year axial length elongation and ocular parameters

Parameters	Univariate regression		Multivariate regression[a]	
	Beta (95% CI)	*P* value	Beta (95% CI)	*P* value
Age, y	-0.003 (-0.016 to 0.010)	0.674	-	-
Sex, male	0.003 (-0.032 to 0.038)	0.863	-	-
Baseline height, cm	0.000 (-0.002 to 0.002)	0.821	-	-
Baseline weight, kg	0.000 (-0.002 to 0.002)	0.937	-	-
Height change, cm	0.005 (-0.003 to 0.014)	0.191	-	-
Weight change, kg	0.006 (-0.001 to 0.012)	0.072	0.002 (-0.004 to 0.008)	0.452
Baseline spherical equivalent, D	-0.079 (-0.131 to -0.028)	0.003	-0.054 (-0.086 to -0.021)	0.001
Average corneal K-reading, D	-0.001 (-0.011 to 0.008)	0.784	-	-
Intraocular pressure, mmHg	0.006 (-0.001 to 0.014)	0.091	0.005 (-0.002 to 0.012)	0.131
Photopic pupil size, mm	0.020 (-0.010 to 0.050)	0.197	-	-
Mesopic pupil size, mm	0.013 (-0.008 to 0.033)	0.234	-	-
Subfoveal choroidal thickness, um	0.000 (-0.001 to 0.000)	0.039	0.000 (-0.001 to 0.000)	0.237
SHS exposure, yes	0.055 (0.02 to 0.089)	0.002	0.053 (0.019 to 0.086)	0.002
Parental myopia	0.039 (0.016 to 0.062)	< 0.001	0.028 (0.002 to 0.055)	0.036
Paternal education	0.034 (-0.002 to 0.07)	0.065	0.009 (-0.032 to 0.051)	0.658
Maternal education	0.055 (0.020 to 0.089)	0.002	0.029 (-0.016 to 0.073)	0.203
Outdoor activities, h/d	-0.009 (-0.032 to 0.014)	0.433	-	-
Near work after school, h/d	0.010 (-0.011 to 0.031)	0.36	-	-

a. All factors that exhibited a P value of less than 0.1 in the univariate analysis were subsequently included in the multiple linear regression analysis

Table 4 Subgroup analyses based on age, sex, and parental myopia status

Variables	*n* (%)	Control group	SHS group	Beta (95%CI)	*P*	*P* for interaction
All patients	232 (100.00)	0.20 ± 0.13	0.26 ± 0.14	0.05 (0.02 ~ 0.09)	**0.002**	
Sex						0.934
Female	118 (50.86)	0.21 ± 0.14	0.26 ± 0.13	0.05 (0.01 ~ 0.10)	**0.034**	
Male	114 (49.14)	0.20 ± 0.12	0.26 ± 0.14	0.06 (0.01 ~ 0.11)	**0.028**	
Age, y						0.072
5–8	190 (81.90)	0.22 ± 0.13	0.26 ± 0.14	0.04 (-0.00 ~ 0.08)	0.067	
9–12	42 (18.10)	0.15 ± 0.11	0.27 ± 0.12	0.12 (0.05 ~ 0.19)	**0.001**	
Paternal myopia						0.396
Non-myopic	134 (57.76)	0.17 ± 0.09	0.24 ± 0.11	0.07 (0.04 ~ 0.11)	**< 0.001**	
Myopic	98 (42.24)	0.24 ± 0.15	0.28 ± 0.16	0.04 (-0.02 ~ 0.11)	0.176	
Maternal myopia						0.672
Non-myopic	103 (44.40)	0.18 ± 0.12	0.24 ± 0.12	0.06 (0.02 ~ 0.11)	**0.010**	
Myopic	129 (55.60)	0.22 ± 0.14	0.27 ± 0.14	0.05 (-0.00 ~ 0.10)	0.056	

parents, 14.9% in children with one myopic parent, and 43.6% in children with two myopic parents [27]. In addition, children whose parents were myopic had longer mean ALs.

Our study also revealed that the degree of parental myopia was not associated with smoking status ($P = 0.058$), possibly because myopia usually occurs before adulthood, whereas smoking tends to occur after adulthood, when refractive development has stabilized. However, the degree of parental myopia was significantly related to education status ($P = 0.005$). These results were verified via Mendelian randomization [28, 29].

Strengths

This is the first cohort study conducted among nonmyopic Chinese children regarding the relationship between SHS and myopia, providing a substantial contribution to improving eye health, promoting public awareness, and guiding future research and policy decisions in myopia prevention and control. Moreover, in the regression analysis used in this study, we incorporated a wide range of confounding factors, including weight, height, SER, IOP, subfoveal choroidal thickness, parental education level, time spent on outdoor activities, and time spent on near work, which enhances the reliability and validity of the research findings.

Limitations

Limitations of the present study include the use of questionnaires to assess time spent on outdoor activities and near work, which methodology inevitably introduces a degree of imprecision and potential inaccuracy into our data. We ardently anticipate the advent of more precise behavioural measurement techniques. Such advancements would equip us with the tools necessary to execute more meticulous and in-depth investigations, thereby enhancing the rigour and reliability of future research endeavours. In addition, this was a retrospective study, and there may have been unmeasured confounding factors that affected the results; however, through multivariate regression analysis, we tried to avoid the influence of interfering factors. In addition, owing to the small proportion of mothers who smoked, we did not test the association between this factor and the risk of developing myopia. Thus, studies with larger sample sizes are warranted to draw more valid conclusions.

Conclusions

The results of this retrospective cohort study suggest that SHS exposure is associated with an increased risk of developing early-onset myopia among nonmyopic children, which indicates that the public should give greater attention to the issue of SHS. For parents with children, quitting smoking is not only beneficial for their own health but also crucial for the well-being of their children. It is hoped that more people will take steps to protect children from the harmful effects of SHS and create a healthier environment for children.

Abbreviations

SHS	Secondhand smoke
SER	Spherical equivalent refraction
AL	Axial length
IOP	Intraocular pressure
Ave-K	Average corneal K-reading
PD	Pupil diameter
CCT	Central corneal thickness
ACD	Anterior chamber depth
CLT	Crystalline lens thickness
SDs	Standard deviations
SFCT	Subfoveal choroidal thickness

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Author contributions

Yuchang Lu was responsible for the investigation and data analysis, with a leading role in data curation and writing the original draft, as well as reviewing and editing the manuscript. Xuewei Li and Yuanqi Deng contributed equally to the project administration, and participated equally in reviewing and editing the manuscript. Yan Li and Mingwei Zhao gave statistical advice and made significant contributions to the data analysis plan and statistical analyses. Kai Wang led the funding acquisition, and contributed to the project administration and the review and editing of the manuscript. All authors read the final manuscript.

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Data availability
The data have not been placed in any online data storage. The datasets generated and analyzed during the study are available upon request from the corresponding author.

Declarations

Ethics approval and consent to participate
The study was approved by the Ethics Committee of the Peking University People's Hospital(2022PHB120), and informed consent obtained from all subjects who provided written informed consent prior to the beginning of the study. All methods were carried out in accordance with relevant guidelines and regulations.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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