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Evolution of the Prevalence of Myopia among Taiwanese Schoolchildren

A Review of Survey Data from 1983 through 2017

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Purpose: The aim of this study was to evaluate the changes in the prevalence of myopia in Taiwanese schoolchildren over the past few decades and to analyze the risk factors for myopia.

Design: Analysis of 8 consecutive population-based myopia surveys conducted from 1983 through 2017.

Participants: An average of 8917 (5019−11 656) schoolchildren 3 to 18 years of age were selected using stratified systematic cluster sampling or by probability proportional to size sampling.

Methods: All participants underwent complete ophthalmic evaluations. Three drops of 0.5% tropicamide were used to obtain the cycloplegic refractive status of each participant. Questionnaires were used to acquire participant data from the 1995, 2005, 2010, and 2016 surveys.

Main Outcome Measures: Prevalence of myopia (spherical equivalence of ≤ -0.25 diopter [D]) and high myopia (≤ -6.0 D) was assessed. Multivariate analyses of risk factors were conducted.

Results: The prevalence of myopia among all age groups increased steadily. From 1983 through 2017, the weighted prevalence increased from 5.37% (95% confidence interval [CI], 3.50%−7.23%) to 25.41% (95% CI, 21.27%−29.55%) for 7-year-olds ($P = 0.001$ for trend) and from 30.66% (95% CI, 26.89%−34.43%) to 76.67% (95% CI, 72.94%−80.40%) for 12-year-olds ($P = 0.001$ for trend). The prevalence of high myopia also increased from 1.39% (95% CI, 0.43%−2.35%) to 4.26% (95% CI, 3.35%−5.17%) for 12-year-olds ($P = 0.008$ for trend) and from 4.37% (95% CI, 2.91%−5.82%) to 15.36% (95% CI, 13.78%−16.94%) for 15-year-olds ($P = 0.039$ for trend). In both the 2005 and 2016 survey samples, children who spent less than 180 minutes daily on near-work activities showed significantly lower risks for myopia developing (<60 minutes: odds ratio [OR], 0.48 and 0.56; 60−180 minutes: OR, 0.69 and 0.67). In the 2016 survey, spending more than 60 minutes daily on electronic devices was associated significantly with both myopia and high myopia (OR, 2.43 and 2.31).

Conclusions: The prevalence of myopia among schoolchildren increased rapidly from 1983 through 2017 in Taiwan. The major risk factors are older age and time spent on near-work activities. Use of electronic devices increased the amount of time spent on near-work and may increase the risk of developing myopia. *Ophthalmology 2021;128:290-301 © 2020 by the American Academy of Ophthalmology. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).*

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The prevalence of myopia is increasing globally, and in East Asia, its prevalence is sufficiently high to warrant the use of the term *epidemic*.[1−3] High myopia originating from early myopia may cause visually debilitating complications, such as retinal detachment, glaucoma, cataract, and macular disorders.[1,3,4] Therefore, it is important to understand the epidemiologic features and risk factors of myopia development to develop preventive strategies. However, studies examining the temporal changes in age-specific myopia prevalence over different birth cohorts are limited because usually it was measured in single cross-sectional studies or in specific participant cohorts.[5−16]

Taiwan is an island located in East Asia with a population of more than 23 million people, 97% of whom are Han Chinese.[17] One of the earliest large-scale myopia surveys since the 1980s was conducted in Taiwan.[18] Afterward, 7 surveys involving schoolchildren were conducted from 1983 through 2010.[18−25] These consecutive field surveys on myopia conducted over 3 decades were based on stratified systemic cluster sampling or probability proportional to size sampling with replacement.[2] Morgan et al[1] stated that the series of surveys conducted in Taiwan were the only repeated series of surveys at that time, and the use of cycloplegia was an additional advantage of them; cycloplegic refraction was performed for every patient in each survey, which facilitated the acquisition of precise and accurate data. The trends from these data and the differences between

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each survey provide important information about the epidemiologic features of myopia.

Because drastic lifestyle changes have occurred over the past decade and the use of portable electronic devices has grown exponentially, the prevalence of myopia in schoolchildren is expected to increase. To understand the current prevalence of myopia among Taiwanese schoolchildren, we conducted the eighth national survey from 2016 through 2017, focusing specifically on the association between the use of portable electronics and myopia. This study explored the risk factors for myopia in schoolchildren and compared the results with those of the 7 previous national surveys.

Methods

Participants

Eight face-to-face myopia surveys were conducted in Taiwan between 1983 and 2017 on a target population comprising schoolchildren between 3 and 18 years of age.[18−25] The children were sampled from elementary schools (age range, 7−12 years), junior high schools (age range, 13−15 years), and high schools or vocational schools (age range, 16−18 years). Students from military schools, extracurricular schooling facilities, schools for special education, and reform schools were excluded (less than 1% of 16- to 18-year-old students). Students using orthokeratology were excluded because their refraction error data could not be obtained. Preschool children (age range, 3−6 years) were enrolled in the surveys conducted in 1983, 2010, and 2017 (Table S1, available at www.aaojournal.org).[19,22,25,26] All surveys followed the tenets of the Declaration of Helsinki. The study protocol, recruitment method, and consent procedure in the latest survey were approved by the research ethics committees of the National Taiwan University Hospital (ClinicalTrials.gov identifier, NCT03750630). Written informed consent was obtained prospectively from the participants and the parent/guardian.

Sampling Designs

The surveys conducted in 1983, 1986, and 1990 used systematic stratified cluster sampling, and those conducted in 1995, 2000, 2005, 2010, and 2016 through 2017 (2016 hereafter) used probability proportional to size sampling with replacement. The stratification of urbanization was based on the socioeconomic and sociogeographic categories of each survey[18−25,27] (Table S1 and Supplementary Methods, available at www.aaojournal.org). Students from these schools were selected randomly with respect to academic year and gender. In the latest survey conducted in 2016, 23 primary schools, 20 junior high schools, 23 senior high schools, and 35 kindergartens were selected. A total of 10 000 students 3 to 18 years of age were selected; among them, 7348 (73.48%) students (3931 boys and 3417 girls) participated in the study (Table S2, available at www.aaojournal.org).

Examination

Different aspects of ocular health, including visual acuity, intraocular pressure, eye position and motility, stereopsis, cycloplegic refractive status, and funduscopic manifestations of the participants were evaluated in the surveys. Cycloplegic refraction was performed by instilling 3 successive drops of 0.5% tropicamide at 5-minute intervals, carrying out refraction using autorefractometers, and performing retinoscopy 30 minutes after the final instillation. The devices used to measure cycloplegic refraction and eyeball axial length in each survey are listed in Table S3 (available at www.aaojournal.org).

Definition of Myopia

Emmetropia was defined as a mean spherical equivalent ranging from −0.25 to +0.25 diopter (D). Myopia was defined as a spherical equivalent of −0.25 D or less, and high myopia was defined as a spherical equivalent of −6.0 D or less.

Questionnaires

Questionnaires were used in the 1995, 2005, 2010, and 2016 surveys. We compared the results of the questionnaires from the 2005 and 2016 surveys to identify changes that occurred over the 10-year period. The following information was obtained from the 2016 questionnaires (2016 Questionnaire, available at www.aaojournal.org). First, demographic information was included that comprised age, gender, birth history, parents' refractive status, socioeconomic status (based on parents' education, employment status, and house ownership), living conditions, and access to medical facilities. Second, personal activity patterns were included that comprised sleep time and duration of outdoor, indoor, and near-work activities on weekdays, at the weekend, and during recess and summer and winter vacations. Children's outdoor activities included outdoor sports, playing, or walking outside, and other outdoor recreational activities such as outings or picnics. Indoor activities included indoor sports and recreational activities, such as watching television or playing board games. Near-work activities included reading for learning or pleasure and doing homework. Information about computer, smartphone, and tablet use was solicited using the 2016 questionnaire. Third, parents' actions to prevent and treat myopia and their assessment of the child's visual behaviors were included. The 2005 questionnaire version was comparatively simplified. For example, the information about outdoor activities in the 2005 questionnaire was acquired using a true or false question, whereas in the 2016 survey, estimated time in minutes was recorded. Further, general average time spent engaged in outdoor activities was obtained in the 2005 questionnaire, instead of assessing time spent engaged in activities on weekdays, at the weekend, and during recess and summer and winter vacations, as discussed in the 2016 questionnaire. Questions regarding smartphone and tablet use were not applicable when the 2005 questionnaire survey was conducted. Estimated times spent on indoor and near-work activities were obtained from both the 2005 and 2016 questionnaires.

Data Analysis

We adjusted all age-specific prevalence values of myopia and high myopia in each survey by urbanization level in each stratum based on the population data for the corresponding year. The *P* values for trends in age-specific weighted prevalence from the consecutive surveys were calculated. To analyze the association between behavior and myopia in the 2005 and 2016 surveys, the self-reported duration of each child's activity was divided into 2 or 3 categories as follows: sleep duration was divided into less than 9 and more than 9 hours; time spent on daily outdoor activities was noted as either a yes or no response for the 2005 survey and as less than 60 minutes or more than 60 minutes for the 2016 survey; and time spent on daily near-work activities was divided into less than 60 minutes, 60 to 180 minutes, and more than 180 minutes. In the 2016 questionnaire, the overall time spent on electronic devices (computer, smartphone, and tablet) was divided into less than 60 minutes and more than 60 minutes. We used the chi-square test to compare all categorical variables between schoolchildren with and without myopia. Univariate and multivariate logistic regression analyses were used to calculate the crude and adjusted odds ratios (OR) for myopia according to sleep, outdoor activities, and near-work activities. In age- and gender-adjusted multivariate analyses, we included these 3 activities as covariates.

Statistical significance was evaluated using 2-tailed tests at the $P = 0.05$ level. Data analysis was performed using SAS statistical software (SAS Institute, Inc, Cary, NC) and SPSS statistical software (IBM Corp, Armonk, NY). The correlation between the refractive error of one eye and that of the other for the participants was very high; therefore, the spherical equivalence of only the right eye was used to evaluate the distribution of refractive error and to estimate the prevalence of myopia.

Results

Prevalence and Trends of Myopia

The prevalence of myopia (≤ -0.25 D) among children in each school grade recorded in the 8 surveys is shown in Table 1 and illustrated in Figure 1A. The prevalence of myopia in first-grade schoolchildren (7 years of age) increased from 5.37% (95% confidence interval [CI], 3.50%–7.23%) in 1983 to 25.41% (95% CI, 21.27%–29.55%) in 2016 ($P = 0.001$ for trend). Similarly, a 2- to 3-fold increase in the prevalence of myopia in 12-year-old schoolchildren was noted (30.66% in 1983 to 76.67% in 2016; $P = 0.001$ for trend). Similarly, steady increases in the prevalence of myopia were noted among junior and senior high schoolchildren (Fig 1A).

Prevalence and Trends of High Myopia

The prevalence of high myopia (≤ -6 D) among the children in each school grade as recorded in the 8 surveys is shown in Table 2 and Figure 1B. The prevalence of high myopia almost tripled over the 30-year period. In 12-year-old schoolchildren, the rate of myopia development increased from 1.39% (95% CI, 0.43%–2.35%) in 1983 to 4.26% (95% CI, 3.35%–5.17%) in 2016 ($P = 0.008$ for trend). The prevalence of high myopia in 15-year-old schoolchildren increased from 4.37% (95% CI, 2.91%–5.82%) in 1983 to 15.36% (95% CI, 13.78%–16.94%) in 2016 ($P = 0.039$; Fig 1B).

Analysis of the Risk Factors for Myopia and the Behavior of Schoolchildren Using Data from the 2005 and 2016 Surveys

A total of 4005 schoolchildren (34.4%; age range, 12–18 years) completed the questionnaires in the 2005 survey and 3190 schoolchildren (43.4%; age range, 4–18 years) completed the questionnaires in the 2016 survey. The demographic data and distributions of behavior are shown in Table S4 (available at www.aaojournal.org). In 2005, most schoolchildren with myopia were older, female, had less sleep time, spent more time on daily near-work activities, and engaged in less daily outdoor exercise. Similarly, children with myopia in the 2016 survey were older, had less sleep time, and spent more time on daily near-work activities. It is important to note that the time spent on near-work activities was considerably higher in 2016 than in 2005. In 2005, 8.9% of the junior and senior high schoolchildren spent more than 180 minutes on daily near-work activities; by 2016, this percentage increased to 37.7% of children from all grades, including kindergarten.

The results of the univariate and multivariate risk factor analyses for 2005 and 2016 are shown in Table 3. Age was associated significantly with myopia in 2005 (OR per 1-year increase, 1.18; 95% CI, 1.12–1.24). This association was stronger in 2016 (OR, 1.45; 95% CI, 1.40–1.50). Children who slept for more than 9 hours per day demonstrated a significantly lower risk of myopia (OR, 0.72; 95% CI, 0.56–0.92) in 2005, but this association was not significant in 2016. In 2005, children who spent less than 180 minutes per day on near-work activities showed a significantly lower risk for myopia than those who spent more than 180 minutes per day (<60 minutes: OR, 0.48 [95% CI, 0.34–0.68]; 60–180 minutes: OR, 0.69 [95% CI, 0.48–0.97]). A similar association was observed in 2016 (<60 minutes: OR, 0.56 [95% CI, 0.43–0.73]; 60–180 minutes: OR, 0.67 [95% CI, 0.53–0.84]). Children who performed daily outdoor exercise showed a significantly lower risk for myopia in 2005 (OR, 0.76; 95% CI, 0.64–0.90). In contrast, results of the 2016 survey showed that more than 60 minutes of outdoor activity per day was not associated with lowering the risk of myopia development. Many of these variables were correlated with each other. For that reason, some were significant in the univariate analysis, but not in the multiple regression model. In the 2016 survey, the Pearson correlation between age and time spent on near-work activities was 0.47 ($P < 0.001$). Children sleep less as they age (Pearson correlation, −0.77; $P < 0.001$). No substantial relationship was found between age and time spent on outdoor activities (Pearson correlation, 0.04), although it was statistically significant ($P = 0.02$).

Use of Electronic Devices as a Risk Factor for Myopia in the 2016 Survey

Information about the rate and daily duration of electronic device use is shown in Figure 2A, B. Rate of use referred to the percentage of children using specific kinds of electronic devices (smartphone, tablet, desktop) at each school level. Increase in the rates of smartphone use ranged from 44.9% among kindergarteners to 60.9% among senior high schoolchildren. Figure 2C displays the association between the time spent on electronic devices and the risk of myopia. The OR for myopia and electronic device use was 2.21 ($P < 0.001$) for those who used smartphones for more than 30 minutes daily and 2.81 ($P < 0.001$) for desktop users. The OR for high myopia was 2.16 ($P < 0.001$) for smartphone users and 2.20 ($P < 0.001$) for desktop users. For those who used electronic devices for more than 60 minutes per day, the OR was 2.43 ($P < 0.001$) for myopia and 2.31 ($P < 0.001$) for high myopia.

The time spent on electronic devices was not included in the multivariate regression model in 2016 because it also contributed to the amount of time spent on near-work activities. Spending more than 60 minutes per day on a device was strongly associated with age (t statistic, 19.54; $P < 0.001$), sex (OR, 1.21; $P < 0.01$), sleeping time (<9 h; OR, 0.28; $P < 0.001$), and outdoor activity (>60 min; OR, 2.03; $P < 0.001$). The prevalence of myopia among all participants was 53.0%, which was lower than that among those who spent more than 60 minutes per day on electronic devices (65.6%). The prevalence of myopia was 65.3% in children who spent more than 60 minutes each on the use of electronic devices and engaged in outdoor activities per day. Age was associated with both the myopia prevalence and the time spent using electronic devices.

Discussion

According to the results of the series of surveys reviewed in this study, the prevalence of myopia in Taiwanese schoolchildren increased between 1983 and 2017. In the latest survey, the myopia rate plateaued at 92.90% and 90.34% of students in junior and senior high school, respectively. Based on the results of the multivariate analysis, the major

Table 1. Prevalence of Myopia (≤−0.25 Diopter) among Schoolchildren in Taiwan from 8 Consecutive Surveys, 1983−2017

School Level and Grade	Year: 1983	1986	1990	1995	2000	2005	2010	2016	P Value for Trend*
Sample Size (Response Rate)	*n* = 5019 (50.7%)	*n* = 10 500 (95.5%)	*n* = 8667 (91.2%)	*n* = 11 178 (94.0%)	*n* = 10 889 (91.7%)	*n* = 11 656 (64.6%)	*n* = 6075 (88.0%)	*n* = 7348 (73.48%)	
	Prevalence, % (95% Confidence Interval)								
Kindergarten									
Junior	3.26 (1.89−4.63)							11.06 (8.20−13.92)	
Middle								9.73 (7.35−12.11)	
Senior	3.73 (2.04−5.42)							12.11 (9.80−14.42)	
Elementary school									
1	5.37 (3.50−7.23)	2.99 (2.12−3.86)	6.78 (5.53−8.03)	12.05 (10.03−14.07)	20.35 (17.76−22.94)	19.60 (17.14−22.06)	20.38 (17.74−23.02)	25.41 (21.27−29.55)	0.001
2	8.91 (6.67−11.16)	6.52 (5.29−7.75)	13.83 (12.13−15.53)	22.28 (19.59−24.97)	30.05 (27.08−33.02)	32.40 (29.44−35.36)	32.75 (29.84−35.66)	45.31 (40.58−50.04)	< 0.001
3	14.75 (11.88−17.61)	9.51 (8.03−10.99)	20.13 (18.05−22.21)	33.41 (30.35−36.47)	41.12 (37.89−44.35)	42.34 (39.33−45.35)	42.67 (39.68−45.66)	50.00 (45.28−54.72)	0.002
4	18.57 (15.49−21.64)	15.38 (13.57−17.19)	23.25 (21.17−25.33)	37.93 (34.96−40.90)	49.10 (45.91−52.29)	49.16 (45.98−52.34)	54.63 (51.73−57.53)	57.14 (52.56−61.72)	0.001
5	26.09 (22.56−29.63)	21.70 (19.62−23.78)	29.67 (27.38−31.96)	45.33 (42.27−48.39)	56.04 (52.88−59.20)	55.35 (52.21−58.49)	60.23 (57.17−63.29)	70.00 (65.81−74.19)	0.001
6	30.66 (26.89−34.43)	27.47 (25.21−29.73)	36.46 (33.76−39.16)	55.45 (52.49−58.41)	60.54 (57.39−63.69)	61.82 (58.74−64.90)	64.05 (61.10−67.00)	76.67 (72.94−80.40)	0.001
Junior high school									
7	30.59 (27.35−33.83)	42.44 (40.04−44.84)	49.04 (46.32−51.76)	63.88 (60.93−66.83)	71.72 (68.89−74.55)	65.08 (62.55−67.61)		85.36 (82.07−88.65)	0.005
8	39.30 (35.87−42.74)	56.73 (54.28−59.18)	65.36 (62.83−67.89)	67.00 (64.09−69.91)	77.40 (74.77−80.03)	70.54 (68.05−73.03)		89.07 (86.34−91.80)	0.007
9	44.31 (40.77−47.85)	61.61 (59.19−64.03)	73.90 (71.51−76.29)	75.92 (73.27−78.57)	80.68 (78.17−83.19)	77.15 (74.84−79.46)		92.90 (90.69−95.11)	0.009
Senior high school									
10	72.23 (69.67−74.79)	73.54 (71.83−75.25)	67.43 (65.09−69.77)	84.31 (81.81−86.81)	83.67 (81.24−86.10)	73.78 (70.56−77.00)		88.12 (85.12−91.12)	0.168
11	72.30 (69.77−74.83)	73.43 (71.70−75.16)	72.08 (69.85−74.31)	84.30 (81.69−86.91)	83.42 (80.83−86.01)	76.13 (72.72−79.54)		91.78 (89.24−94.32)	0.071
12	74.48 (71.97−76.99)	76.21 (74.39−78.03)	75.39 (73.08−77.70)	83.67 (80.83−86.51)	84.18 (81.60−86.76)	85.13 (82.18−88.08)		90.34 (87.69−92.99)	0.005

All prevalence data is the adjusted value calculated by giving weighting in each stratum of urbanization level based on entire population data.
*Calculated using logistic regression models with the year of each survey modeled as a continuous variable.

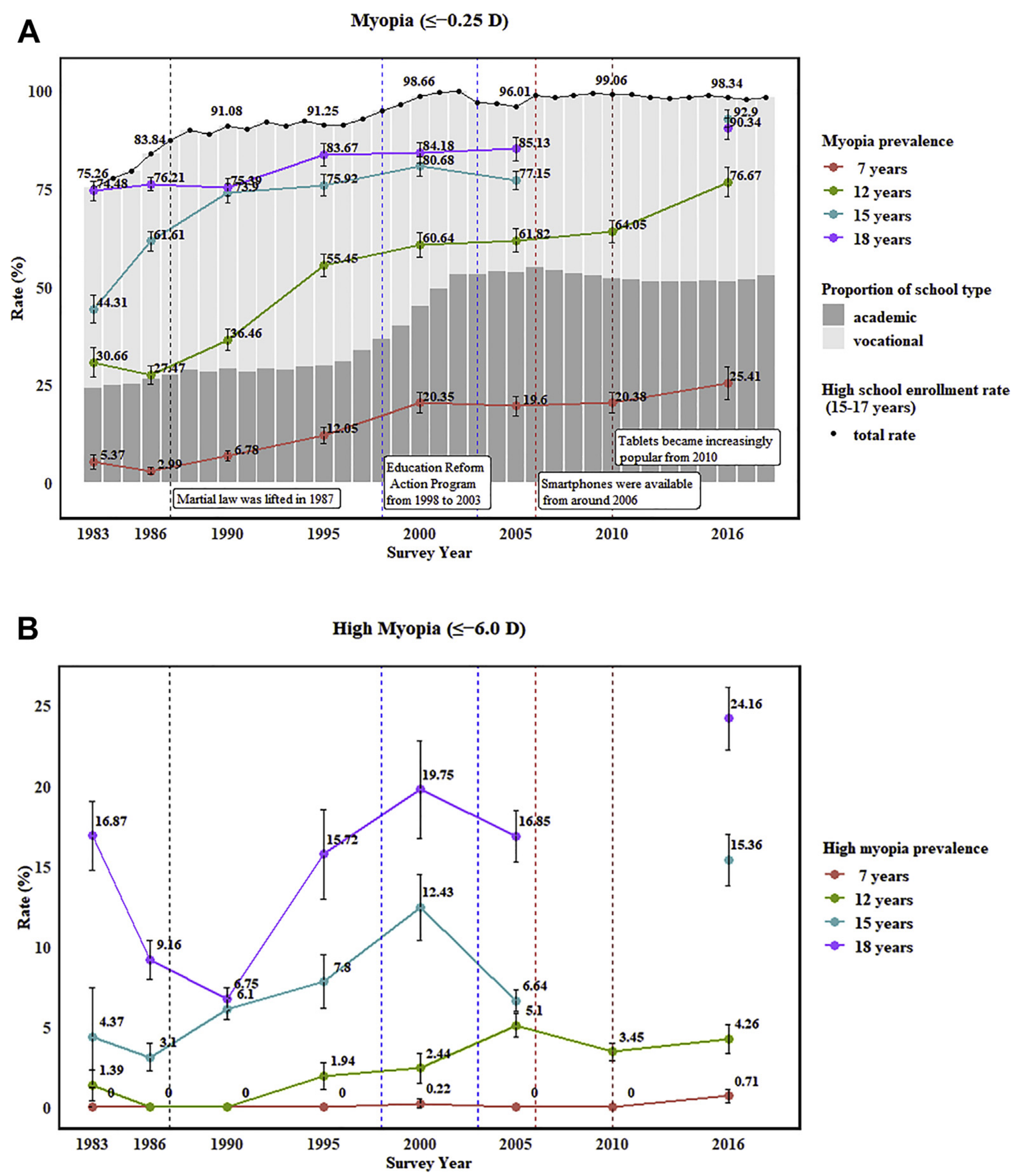

Figure 1. Graphs showing (**A**) trends in myopia prevalence (≤−0.25 diopter [D]) and (**B**) prevalence of high myopia (≤−6.0 D) in schoolchildren in Taiwan from 8 consecutive surveys from 1983 through 2017. Information regarding high school enrollment rate, proportion of school type, and events that may be associated with myopia prevalence also is incorporated as a timeline graph.

risk factors for myopia were older age and spending more than 3 hours per day on near-work activities.

Myopia was defined as a spherical equivalent of −0.25 D or less in our study, a definition that has been used since the first survey was conducted in 1983.[18–25] It is a relatively strict definition and is not consistent with the definition used in other epidemiologic myopia studies (spherical equivalent, ≤−0.50 D).[5,14–16,28] We re-analyzed the data obtained through 2016 questionnaires using the latter definition and the results were very similar, as shown in the demographic information in Table S5 (available at www.aaojournal.org) and the regression analysis in Table S6 (available at www.aaojournal.org). However, the definitions of myopia and high myopia did have significant impact on the estimated prevalence of myopia (Table S7, available at www.aaojournal.org). Another method used in our survey that differed from other research was the administration of a cycloplegic agent: 3 successive drops of 0.5% tropicamide were used instead of cyclopentolate. Tropicamide generally is considered as a less potent parasympatholytic agent compared with cyclopentolate; however, studies found that the difference in the cycloplegic effect between these 2 agents was clinically negligible.[29–31] The characteristics of rapid onset, fast recovery, and a relatively lower incidence of systemic toxicity[32] of tropicamide make it a more acceptable cycloplegic agent for use in children when performing large-scale field surveys outside of the hospital setting. To record the trend of myopia prevalence better, we obtained data from each survey with consistent methods.

Table 2. Prevalence of High Myopia (≤−6.0 Diopters) among Schoolchildren in Taiwan from 8 Consecutive Surveys, 1983−2017.

School Level and Grade	1983	1986	1990	1995	2000	2005	2010	2016	P Value for Trend*
	Sample Size (Response Rate [%])								
	n = 5019 (50.7%)	*n* = 10 500 (95.5%)	*n* = 8667 (91.2%)	*n* = 11 178 (94.0%)	*n* = 10 889 (91.7%)	*n* = 11 656 (64.6%)	*n* = 6075 (88.0%)	*n* = 7348 (73.48%)	
	Prevalence, % (95% Confidence Interval)								
Kindergarten									
Junior	0.31 (0−0.74)							0.43 (0.13−0.73)	
Middle								0.00 (0−0)	
Senior	0 (0−0)							0.52 (0.26−0.78)	
Elementary school									
1	0.00 (0−0)	0.00 (0−0)	0.00 (0−0)	0.00 (0−0)	0.22 (0−0.51)	0.00 (0−0)	0.00 (0−0)	0.71 (0.30−1.12)	0.122
2	0.00 (0−0)	0.00 (0−0)	0.00 (0−0)	0.1 (0−0.3)	0.38 (0−0.78)	0.31 (0.13−0.49)	0.26 (0.11−0.41)	0.94 (0.47−1.41)	0.014
3	0.34 (0−0.81)	0.00 (0−0)	0.00 (0−0)	0.22 (0−0.52)	0.45 (0.02−0.88)	0.48 (0.27−0.70)	0.42 (0.23−0.61)	0.23 (0−0.46)	0.109
4	0.49 (0−1.04)	0.00 (0−0)	0.00 (0−0)	0.39 (0.59−0.77)	0.48 (0.06−0.90)	0.94 (0.63−1.25)	0.96 (0.68−1.24)	1.56 (0.97−2.15)	< 0.0001
5	1.01 (0.21−1.81)	0.00 (0−0)	0.00 (0−0)	1.28 (0.59−1.97)	1.85 (1.02−2.68)	1.04 (0.71−1.37)	2.05 (1.63−2.47)	2.61 (1.87−3.35)	0.006
6	1.39 (0.43−2.35)	0.00 (0−0)	0.00 (0−0)	1.94 (1.12−2.76)	2.44 (1.52−3.36)	5.1 (4.39−5.81)	3.45 (2.91−3.99)	4.26 (3.35−5.17)	0.008
Junior high school									
7	0.77 (0.16−1.39)	0.86 (0.41−1.31)	1.39 (1.07−1.72)	2.46 (1.51−3.41)	5.26 (3.89−6.63)	3.51 (3.01−4.01)		9.23 (7.86−10.60)	0.006
8	2.06 (1.06−3.06)	2.73 (1.93−3.53)	3.32 (2.83−3.81)	4.50 (3.22−5.78)	7.08 (5.49−8.67)	6.08 (5.41−6.75)		11.53 (10.10−12.96)	0.002
9	4.37 (2.91−5.82)	3.10 (2.24−3.96)	6.10 (5.44−6.77)	7.80 (6.14−9.46)	12.43 (10.39−14.47)	6.64 (5.94−7.34)		15.36 (13.78−16.94)	0.039
Senior high school									
10	11.07 (9.28−12.87)	4.98 (4.14−5.82)	5.92 (5.32−6.52)	11.27 (9.10−13.44)	15.54 (13.05−18.03)	7.95 (6.94−8.96)		16.82 (15.05−18.59)	0.077
11	12.06 (10.22−13.90)	8.25 (7.17−9.33)	7.45 (6.78−8.12)	12.89 (10.48−15.30)	17.82 (15.07−20.57)	12.86 (11.49−14.23)		20.00 (18.11−21.89)	0.026
12	16.87 (14.71−19.03)	9.16 (7.93−10.39)	6.75 (6.06−7.44)	15.72 (12.92−18.52)	19.75 (16.69−22.81)	16.85 (15.27−18.44)		24.16 (22.20−26.12)	0.013

All prevalence data are the adjusted value calculated by giving weighting in each stratum of urbanization level based on entire population data.
*Calculated using logistic regression models with the midpoint of each survey modeled as a continuous variable.

Table 3. Univariate and Multivariate Risk Factor Analysis of Schoolchildren's Behavior for Myopia (≤−0.25 Diopter) from 2005 and 2016 Survey Samples with Valid Questionnaire Responses (2005, n = 4005; 2016, n = 3190)

	Univariate Analysis, Crude Odds Ratio (95% Confidence Interval)		Multivariate Analysis, Adjusted Odds Ratio (95% Confidence Interval)	
	2005	2016	2005	2016
Age (per 1-yr increase)	1.18 (1.12−1.24)*	1.49 (1.45−1.53)*	1.18 (1.12−1.24)*	1.45 (1.40−1.50)*
Female gender	1.22 (1.04−1.43)†	0.99 (0.87−1.15)	1.04 (0.87−1.22)	1.01 (0.84−1.22)
Sleeping time (hrs/day)				
<9	Reference	Reference	Reference	Reference
≥9	0.62 (0.49−0.78)*	0.12 (0.10−0.14)*	0.72 (0.56−0.92)‡	0.99 (0.78−1.26)
Time spent on near work activities (min/day)				
≥180	Reference	Reference	Reference	Reference
60−180	0.69 (0.49−0.95)‡	0.20 (0.17−0.24)*	0.69 (0.50−0.97)†	0.67 (0.53−0.84)‡
<60	0.54 (0.38−0.75)*	0.14 (0.12−0.17)*	0.48 (0.34−0.68)*	0.56 (0.43−0.73)*
Daily outdoor exercise§				
No	Reference		Reference	
Yes	0.70 (0.59−0.82)*		0.76 (0.64−0.90)‡	
Time spent on outdoor activities (min/day)§				
≥60		Reference		Reference
<60		1.04 (0.88−1.23)		0.85 (0.68−1.08)

The information of time spent on electronic devices use was only acquired in 2016 questionnaire, not in 2005 questionnaire.
*$P < 0.001$.
†$P < 0.05$.
‡$P < 0.01$.
§For outdoor activity, a dichotomous question was used in the 2005 questionnaire, whereas the estimated time was asked in the 2016 questionnaire.

However, it is noteworthy that the results of the prevalence in different studies are not directly comparable because of the differences in methodology. The definition of myopia (≤−0.25 D) and the cycloplegic agent we adopted might have contributed to the higher prevalences of myopia that were reported from Taiwan, especially in the evaluation of refractive errors in preschool children (Table S7). The prevalence of myopia in 3- to 6-year-old children in Taiwan (6%−9%) is similar to that in Hong Kong and Singapore.[2] However, a study conducted in preschools in Guangzhou, China, found a low myopia prevalence of 1%, despite a similar myopia prevalence in 15-year-olds.[33,34] It was suggested that using up to 4 drops of 1% cyclopentolate may be necessary to measure refractive error accurately in young children with dark irises.[33] The methodologic issues concerning cycloplegia and factors contributing to the discrepancy of myopia prevalence in preschool children require further clarification with carefully designed multicenter studies.

The prevalence of myopia in first-grade students exhibited a 5-fold increase from 1983 to 2017. In sixth graders, the prevalence more than doubled from 30.66% to 76.67%. Notably, as the prevalence of myopia increased significantly, the age of myopia onset decreased among schoolchildren in Taiwan.[2,18−21] In the 1986 survey, the age-specific mean refractive status transformed from hyperopic to myopic in the 11-year-old group, whereas in 2000, this transformation was observed to occur in the 8-year-old group, indicative of the early occurrence of myopia during childhood.[2,18−21] Moreover, the prevalence of high myopia also increased.

Near-work activities were proposed as a key component of the cause of myopia over 400 years ago.[35] Subsequently, theories favoring genetic origins had overtaken it. Later, the emergence of new evidence led to the return of environmental factors to prominence.[36] More than 3 hours of near-work per day was the main risk factor for myopia in our multivariate analysis. In the latest survey, the percentage of children with myopia who performed near-work activities for more than 3 hours per day was 56%, whereas the corresponding percentage among children without myopia was only 17.3%. Preschool children in Singapore who spend an additional 3 hours on near-work activity outside schoolwork or who read more books have been found to show an increased risk of myopia.[37−39] Morgan and Rose[40] suggested that, in areas such as Taiwan, the combination of high expectations for educational outcomes and an extensive use of tutorials is associated with the high prevalence of myopia. A recent study discovered an independent association between educational systems and corresponding near-work activities and myopia. The ultraorthodox educational system involves intensive reading starting in early childhood and is similar to the educational system in Taiwan, is associated with the prevalence and severity of myopia.[41] Overall, emerging evidence suggests that near-work plays a major role in myopia development.

Some historical background information may be helpful to investigate the relationship between the education system and the evolution of myopia prevalence. First, in addition to the rapid economic growth at the end of the 1980s, martial law was lifted in 1987 in Taiwan. The entire society marched toward a diverse and open, but more competitive, educational environment. This may be associated with the steadily increasing myopia prevalence in Taiwan's youth since the late 1980s. Second, the 9-year compulsory education from elementary

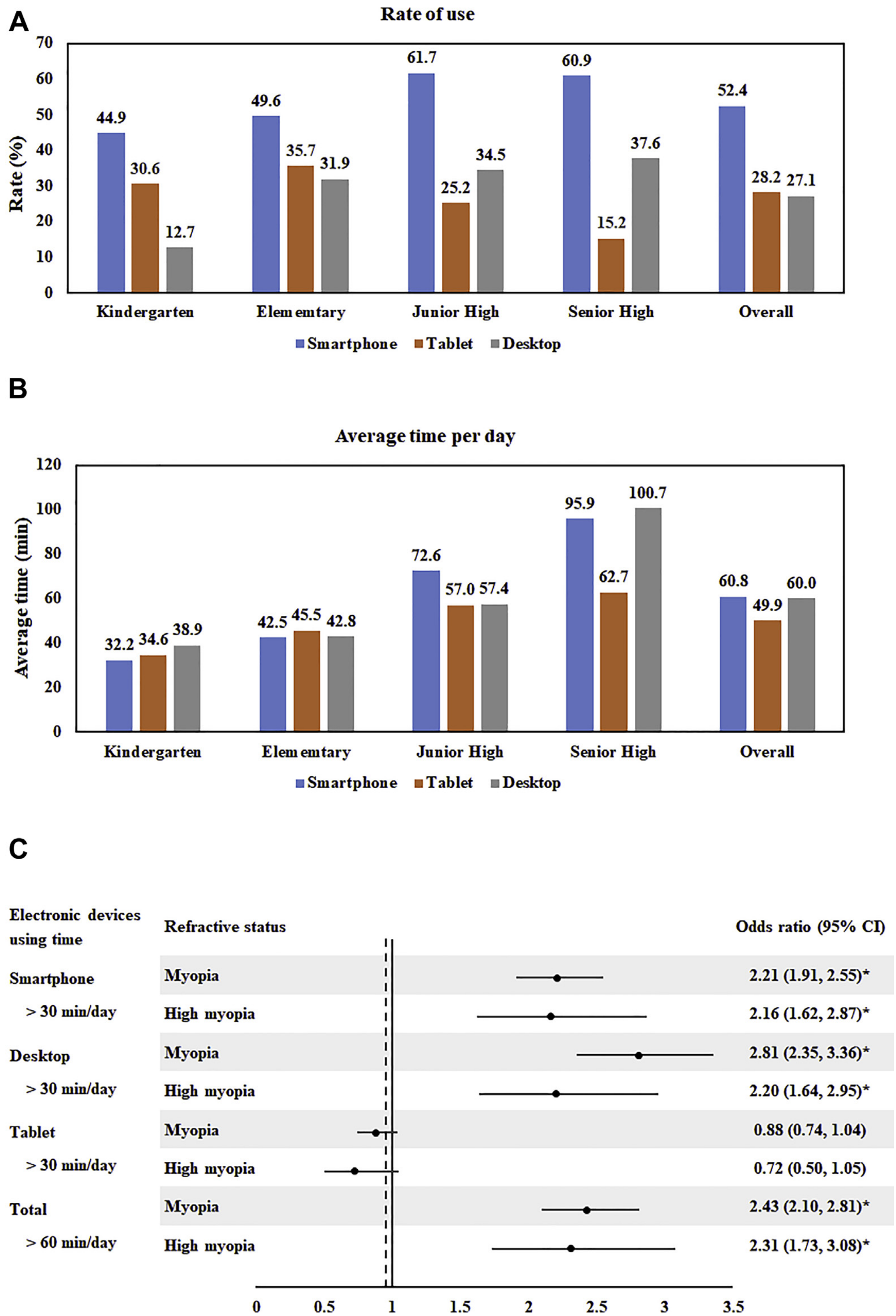

Figure 2. Graphs showing electronic device use and its association with myopia. **A**, Percentage of children using specific electronic devices (smartphone, tablet, desktop) at each school level. **B**, Average duration of use per day for each kind of electronic device among different age groups of schoolchildren. Schoolchildren who do not use an electronic device were not included in this calculation. **C**, Odds ratios of myopia and high myopia associated with the use of individual electronic devices for more than 30 minutes or overall device use for more than 60 minutes (*$P < 0.001$). CI = confidence interval.

school was initiated in 1968. However, the enrollment rate for high school was 75% in 1983 (Fig 1),[42] and of this group, three quarters of 16- to 18-year-old students went into vocational schools. Most parents in Taiwan at that time believed receiving higher education at a good academic school was the ticket to a bright future. Academic competition was extremely high among children younger than 15 years preparing for high school entrance examinations. The Ministry of Education carried out the Education Reform Action Program from 1998 through 2003 to establish more senior high schools and universities with the aim of relaxing the limitations in the educational system and facilitating paths to school entrance. The high school enrollment rate increased to 99% and the ratio of students enrolled in vocational schools versus high schools was reduced to 1.3 in 2003 and has remained consistent since. The prevalence of myopia started to stabilize from 2000 through 2010. Notably, the results of high myopia prevalence in 18-year-olds in the earlier surveys may have been affected by the enrollment rate and the academic tendency of the high schools selected. For example, high myopia prevalence dropped to 6.75% in the 1990s survey, with 11 vocational schools and 6 high schools selected that year.

In addition to the well-known correlation between the modern East Asian education system and the high prevalence of myopia,[1] the increase in myopia corresponds with the increase in the popularity of portable electronic devices. Previous studies in East Asia have found a so-called saturated level of myopia prevalence, indicating that the environmental myopigenic influences may have maximized their effects, thus causing the prevalence of myopia to plateau.[43,44] However, because of advances in technology, electronic devices have been integrated into the everyday life of schoolchildren; 72% and 89% of children and adolescents, respectively, have at least 1 device in their bedrooms.[45,46] Many educational systems also incorporate portable electronic devices into the curriculum. According to a survey by the Child Welfare League Foundation, access to cellular phones among schoolchildren rose by 22% from 2005 to 2011 and is growing steadily.[47,48] The myopia prevalence in 18-year-olds plateaued at approximately 83% to 85% for 10 years (1995−2005); however, in 2016, the prevalence increased to 90.34% (Fig 1). Smartphones were available on the market from approximately 2006, and tablets became increasingly popular from 2010. The 7-year-old population in 2005, with a myopia prevalence of 19.6%, grew up with the additional influence of electronic devices and subsequently reached an unprecedented myopia rate 11 years later in 2016 (90.34% in the 18-year-olds). A similar trajectory also can be plotted for the prevalence of high myopia in these study participants (24.16% in 2016). Likewise, the 7-year-old population in 2016, born in the era of electronic devices, showed an early high prevalence of myopia (25.41%).

From the analysis of the surveys, we noted that schoolchildren spent much more time on near-work in 2016 than in 2005. The overall mean time schoolchildren spent on electronic devices daily in 2016 was 67 minutes. The rate and duration of smartphone use was dramatically higher at 60.9% and 95.9 minutes in senior high school, compared with 49.6% and 42.5 minutes in elementary school. The time spent on a desktop computer was an average of 101 minutes among senior high school students. The OR of myopia in those who spent more than 60 minutes engaged with electronic devices (particularly smartphones or desktops) was 2.43 (Fig 2C). The relationship between the surge in the incidence of myopia and the advent of electronic devices requires investigation and should be interpreted with caution.[49] For example, age is associated with both myopia prevalence and the time spent engaged with electronic devices. The OR of myopia prevalence with substantial use of electronic devices may vary with age stratification. We also found that the use of electronic devices was associated strongly with other factors; these other associations may provide an explanation for why the correlation of electronic device use with myopia was not recognized in previous studies, and this is the reason why electronic device use could not be included independently in our multivariate regression model.[50,51] Because the time spent engaged with electronic devices contributes to the time spent doing near-work activities, we suggest that a longer duration of near-work with electronic devices might be a contributory factor to the further increase in the prevalence of myopia in Taiwan during the past 10 years. In contrast, a recent study from Hong Kong found that the prevalence of myopia in 6- to 8-year-olds was high (25%), but slightly lower than that of 15 years ago.[28] This improvement might be the result of policy reformation in the education system in Hong Kong.

Outdoor activity has been suggested to play a protective role against myopia[52]; however, the results of the present study did not show a consistent relationship between outdoor activity and myopia. Multivariate analysis of the 2005 survey data showed a protective effect of daily outdoor exercise (OR, 0.76). Conversely, more than 60 minutes of outdoor activities in the 2016 survey study was not associated with such an effect. One reason for this difference may be the different references used for this variable or the inappropriate determination of the parameter used in the 2 regression models. Interestingly, the protective effect of outdoor activity was not observed among children who both used electronic devices and performed outdoor activities for more than 60 minutes per day. The prevalence of myopia was similar in children who spent more than 60 minutes engaged with electronic devices (65.6%) and those who additionally spent 60 minutes engaged in outdoor activities (65.3%) other than the 60 minutes spent on electronic devices use. One possible explanation for this is that 60 minutes of outdoor activities is insufficient to prevent myopia. In a recent meta-analysis, an inverse nonlinear dose-response relationship was found between time spent outdoors and risk of myopia.[53]

The present study had some limitations. First, the different stratification and sampling methods used in the surveys may have led to heterogeneity; however, these stratifications were modified to fit the degree of urbanization at the time of each survey. The 2 probability sampling methods were used to provide a sample that could represent the population, if the population size was large, the school enrollment rate was high, and the response rate was high. In Taiwan, a 9-year compulsory education program from elementary school exists with resultant high enrollment rates, and the school enrollment rates for students 15 to 17 years of age were high as well (75.26% in 1983, more than 90% from 1990, and 97.9% in 2017), as shown in Figure 1. The varied response rates may result in estimates that are biased by selective nonresponse; nevertheless, all prevalence data were calculated with weights and were derived based on entire population data in each stratum of urbanization level. Thus, results should be comparable. Second, the response rate and imprecise nature of the questionnaire surveys should be considered. Accordingly, we categorized the time spent on activities into discrete groups instead of obtaining continuous time data to analyze its association with the risk of myopia. The study targets and the designs of the questionnaires differed between the 2005 and 2016 surveys, rendering direct comparison difficult. However, despite the varied designs of the questionnaires, the findings of the two surveys, a decade apart, were similar, and their conclusions were consistent with each other.

In conclusion, these series of surveys conducted over the last 3 decades revealed a rising trend in myopia prevalence in Taiwan. The most consistent major risk factors were older age and time spent on near-work activities. Eye care professionals and policy makers need to be aware that the growing popularity of electronic devices over the past 10 years has increased the amount of time schoolchildren spend on near-work activities, which may be associated with an increase in the prevalence of myopia. Additional randomized, interventional, prospective studies are needed to validate the effect of these risk factors on myopia development in future.

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Footnotes and Disclosures

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HUMAN SUBJECTS: Human subjects were included in this study. All surveys followed the tenets of the Declaration of Helsinki. The study protocol, recruitment method, and consent procedure in the latest survey were approved by the research ethics committees of the National Taiwan University Hospital (ClinicalTrials.gov identifier, NCT03750630). Written informed consent was obtained prospectively from the participants and their parent/guardian.

No animal subjects were included in this study.

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Analysis and interpretation: Tsai, Liu, L.L.-K.Lin, Hsiao, Wang

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Obtained funding: L.L.-K. Lin, Wang

Overall responsibility: Tsai, Liu, Ma, Hsiao, Wang

Abbreviations and Acronyms:

CI = confidence interval; **D** = diopter; **OR** = odds ratio.

Key Words:

epidemiology of myopia, population-based survey, risk factor, prevalence.

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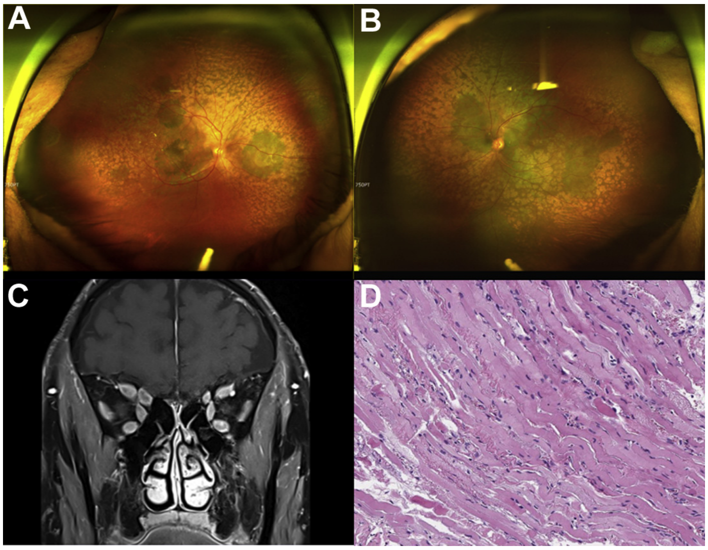
Pictures & Perspectives



Extraocular Muscle Enlargement in Bilateral Diffuse Uveal Melanocytic Proliferation Associated with Hepatocellular Carcinoma

A 64-year-old man with bilateral diffuse uveal melanocytic proliferation (BDUMP) (Figs **A** and **B**) associated with hepatocellular carcinoma presented with painless ocular movement limitations. Visual acuity was count fingers and 20/100, respectively. The eyelids and orbital changes were not observed. Extraocular muscle restriction was not presented on the forced duction test in both eyes. Orbit magnetic resonance imaging demonstrated tendon sparing extraocular muscle enlargement on the rectus and oblique muscles (Fig **C**), and the test for thyroid function and antibodies were within normal ranges. Tumor metastasis was not observed; however, vasculitis with perivascular lymphocytic infiltrations was presented on extraocular muscle biopsy (Fig **D**). (Magnified version of Fig **A**-**D** is available online at www.aaojournal.org).

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