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# Progression of myopia in teenagers and adults: a nationwide longitudinal study of a prevalent cohort

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## ABSTRACT

**Background** The prevalence of myopia is increasing worldwide. The purpose of this study was to evaluate the progression of myopia in teenagers and adults in France.

**Methods** This nationwide prospective study followed 630 487 myopic adults and teenagers (mean age 43.4 years±18.2, 59.8% of women) between January 2013 and January 2019. Myopia and high myopia were defined as a spherical equivalent less than or equal to −0.50 and −6.00 diopters (D), respectively. Demographic data were collected at first visit and refractive characteristics were collected at each visit. Analysis of short-term progression (first 12 to 26 months postbaseline) was modelled using analysis of variance (ANOVA). Progression of myopia was stratified according to age, gender and spherical equivalent at first visit.

**Results** Higher proportions of progressors were observed in the youngest age groups: 14–15 (18.2 %) and 16–17 years old (13.9 %). In multivariate analysis, after adjustment for over age, spherical equivalent and gender, the mean short-term progression decreased from −0.36 D in the 14–15 years age group to −0.13 D in the 28–29 years age group. Young age and higher myopia at baseline together were strongly associated with the risk of developing high myopia, the 5-year cumulative risk being 76% for youngest teenager with higher myopia status at baseline.

**Conclusion** In this large cohort of myopic teenagers and adults, myopia progression was reported in 18.2% and 13.9% of the 14–15 and 16–17 age groups, respectively. The risk to develop high myopia was higher for younger individuals with higher myopia at baseline examination.

## INTRODUCTION

Myopia, defined as refractive error equal or inferior to −0.50 diopters (D), is a major cause of vision impairment and blindness due to uncorrected refractive error or by complications related to myopia. Indeed, uncorrected refractive errors are the leading cause of moderate to severe visual impairment worldwide,[1] including high-income countries and some other European countries.[2]

Myopia is also a risk factor for various pathologies such as glaucoma,[3] cataract,[4] retinal detachment[5] and myopic maculopathy.[6] The latter has been reported to affect 0.5% of Germans aged 35–74 years[7] and 3.8% of older Singaporean adults (mean age 57.2 years).[8]

In East Asia, myopia affects 80% to 90% of young adults.[9] Western countries are not spared from the so-called ‘myopia boom’ and studies have estimated that myopia affects around half of young adults in the USA and Europe.[10] Concurrently, the prevalence of high myopia is increasing globally, reaching up to 20% among Taiwanese students.[11] In Europe, myopia prevalence has also increased in lesser proportion, and higher prevalence has been reported for younger adults,[12 13] with one population-based study conducted in the UK even showing almost a doubling of myopia prevalence in teenagers within a few decades, although the prevalence in final year high school students was less than 20%.[14]

The myopia epidemic has significant socioeconomic consequences, due not only to the cost of optical corrections[15] but also to the burden of myopia complications, which can occur at a relatively early age with possible consequential loss of productivity.[16] Indeed, myopic choroidal neovascularisation frequently occurs at middle age[17] while retinal detachment and glaucoma are more frequent among high myopic patients compared with non-myopes and frequently occur at a younger age.[18 19]

While myopia can also progress during early adulthood, which is a concern for myopic patients wishing to have refractive surgery, data on myopia progression in teenagers and young adults are scarce in Europe.[20 21] The purpose of this study was to evaluate the progression of myopia in European teenagers and in adulthood as a function of age, gender and degree of myopia at initial presentation.

## MATERIALS AND METHODS

### Study population

Data files were collected from 696 opticians located in different regions of France. The full data set included year of birth, gender, date of prescription performed by the ophthalmologist, sphere and cylinder measured by the ophtalmologist, type of prescription (spectacles or contact lenses) and type of correction (mainly near vision, distance vision or progressive glasses) over a period from January 2013 to January 2019.

Even in the case of correction renewal by the optician for various reasons, including broken glasses or desire to change glasses, the new correction was available in the data set used for the analyses.

The analysis used data from the right eyes of myopic individuals aged 14 years and over. Files with missing data for the right eye, gender or age were, therefore, excluded from the analyses. Patients who were likely to have undergone intraocular surgery or refractive surgery, based on the observation of major refractive changes observed

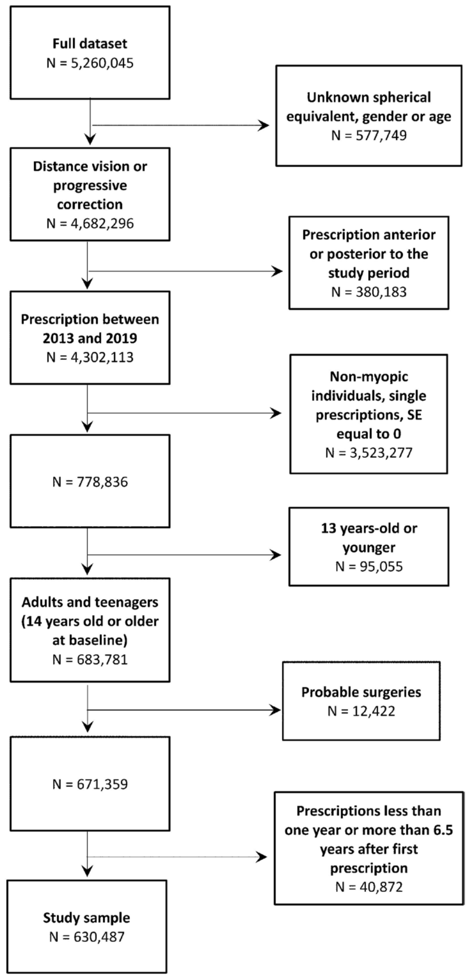


**Figure 1** Flowchart of study patients. SE, spherical equivalent.

between two visits, were also excluded. The study flowchart is presented in figure 1. Individuals with at least two optical corrections separated by at least 1 year were selected.

## Definitions

Myopia was defined as a spherical equivalent (SE) less than or equal to –0.50 D[22] and high myopia by a SE ≤ –6.00 D.

Progressors were defined as individuals with a mean rate of progression of myopia exceeding –0.50 D per year in the period between baseline and a second prescription within 12 and 26 months after baseline. Individuals without prescription in this period were excluded from the corresponding analyses but were included for longitudinal analysis. This duration represents the usual duration between prescriptions. We focus on this short period to define progressors and progression rates because computing an average progression over the full 7 years implies the assumption of a linear progression, which is not supported by the literature. However, the mean myopia progression was also evaluated during the follow-up of each individual, by the difference of refractive error between the baseline examination and the final examination.

## Statistical analysis

Age of myopia incidence was unknown in this cohort. The first prescription for myopia correction within the study window was considered as the baseline for study purposes and subsequent visits were used to quantify progression over time. Time intervals between visits were aggregated into 6-month intervals to evaluate the mean myopia progression during the follow-up. Progression rates were expressed in diopters per year (D/y). Analysis of progression values was stratified according to age at first visit, gender and SE at first visit.

The p values displayed when comparing proportions of progressors were computed using logistic regression to model 'progressor status' described above. Covariates were age group, SE at baseline and gender.

We modelled progression during the first 12–24 months with a univariate and multivariate analysis of variance (ANOVA). Covariates included age group, SE at first prescription and gender.

Average progression rates were computed using an ANCOVA with age as covariate and continuous time between two prescriptions as the main regressor. Progression rates were expressed in D/y.

We estimated the cumulative probability of developing high myopia using Kaplan-Meier estimators stratified over age and SE at baseline. We used a multivariate Cox model to compute the multivariate HRs of the age and SE classes and gender as well.

All analyses were performed with SAS/STAT software, V.9.4 of the SAS System for Windows. Copyright 2016 by SAS Institute.

# RESULTS

## Demographic and refractive data

The full data set included 630 487 myopes (59.8% of women) with mean age of 43.4 years±18.2 and mean SE of –2.8±2.3 D. Among them, 167 204 individuals belonged to the 14–29 year age group (61.5% of women) with mean age 21.4 years±4.7 and mean SE equal to –2.7±2.1 D.

Demographic and SE distributions of the cohort at baseline and progression status are detailed in table 1.

Median follow-up was 3.1 years. Follow-up duration was ≥2 years, ≥3 years, ≥4 years and ≥5 years for 505 501 (80.2%), 335 309 (53.2%), 197 029 (31.3%) and 86 074 (13.7%) participants, respectively. For the 14–29 year age group, median follow-up was 2.9 years. Follow-up duration was ≥2 years, ≥3 years, ≥4 years and ≥5 years for 123 768 (74.0%), 78 805 (47.1%), 44 857 (26.8%) and 19 602 (11.7%) participants, respectively.

## Progression of myopia as a function of age at baseline visit

The overall proportion of progressors was 7.8%. A higher proportion of progressors was observed in the younger (14–29 year) age groups, with proportion of progressors values ranging from 18.2% to 13.0% between the 14–15 and 18–19 year age groups. Other groups with a high proportion of progressors were the 65–69, 70–74, 75–79, 80–84 and 85–100 age groups, with proportions of progressors being 11.1%, 12.7%, 12.6%, 10.6% and 12.9%, respectively. The proportion of progressors also varied across SE groups ($p<0.0001$) and was highest among individuals with SE ≤ –6.00 D in both age subgroups (15.3% and 8.7% in the 14–29 and the 30–100 groups, respectively). Finally, although the proportion of progressors differed significantly between genders in both age subgroups, myopia progressed more among women in the 14–29 year age group. These data results are detailed in table 2.

The highest proportion of progressors was observed when combining younger age and higher myopia at baseline. Indeed, more than 20% of individuals aged 14–15 years with myopia ≤ –4.00 D at baseline were progressors. These data are detailed in table 3.

**Table 1** Demographic and refractive characteristics of the cohort

| Age | N | Age (mean±SD) | Gender (female, %) | Sphere (mean±SD) |
|---|---|---|---|---|
| All | 630 487 | 43.4±18.2 | 59.8 | −2.8±2.3 |
| 14–19 | 64 600 | 16.4±1.7 | 57.9 | −2.5±2.0 |
| 20–24 | 49 902 | 22.0±1.4 | 64.0 | −2.8±2.2 |
| 25–29 | 52 702 | 27.0±1.4 | 63.4 | −2.9±2.3 |
| 30–34 | 54 562 | 32.0±1.4 | 62.9 | −3.0±2.4 |
| 35–39 | 53 164 | 37.0±1.4 | 61.8 | −2.9±2.4 |
| 40–44 | 62 397 | 42.1±1.4 | 60.8 | −2.8±2.4 |
| 45–49 | 67 313 | 47.0±1.4 | 58.6 | −2.8±2.5 |
| 50–54 | 56 184 | 51.9±1.4 | 56.8 | −2.9±2.6 |
| 55–59 | 44 617 | 56.9±1.4 | 55.9 | −3.0±2.6 |
| 60–64 | 35 988 | 61.9±1.4 | 55.5 | −3.0±2.5 |
| 65–69 | 29 937 | 66.9±1.4 | 56.2 | −2.7±2.2 |
| 70–74 | 19 810 | 71.9±1.4 | 55.8 | −2.3±1.9 |
| 75–79 | 17 240 | 77.0±1.4 | 59.3 | −2.0±1.7 |
| 80–84 | 13 665 | 81.8±1.4 | 64.2 | −1.9±1.5 |
| 85–100 | 8406 | 87.6±2.5 | 69.3 | −2.0±1.5 |
| 30–100 | 463 283 | 51.4±14.3 | 59.2 | −2.8±2.4 |
| With progression status | 178 886 | 51.2±14.6 | 61.7 | −2.8±2.4 |
| 14–29 | 167 204 | 21.4±4.7 | 61.5 | −2.7±2.1 |
| With progression status | 87 631 | 20.6±4.7 | 63.0 | −2.7±2.2 |
| With mild or moderate myopia | 153 740 | 21.3±4.7 | 61.6 | −2.2±1.4 |

Progression status is defined for individuals with a prescription between 12 and 26 months after baseline. Mild or moderate myopia is defined as an SE > −6.00 D.
SE, spherical equivalent.

When focusing on the 14–29 year age group, mean myopia progression during 12 to 26 months postbaseline decreased progressively from −0.35 D in the 14–15 year age group to −0.13 D in the 28–29 year age group (table 4).

Decreasing rates of myopia progression with greater age were also observed over the full 6.5 years period (figure 2). In multivariate analysis, age appeared to be the major determinant of myopia progression. For the 14–15 year age group, mean myopia progression was −0.36 D. To a lesser degree, higher myopia at baseline and female gender were other determinants of myopia progression. Although the highest myopes had the greatest proportion of progressors, their mean progression rate was no higher than in other groups (table 4).

## Development of high myopia

When combining a younger age at baseline and higher myopic status, the 5-year cumulative risk of development of high myopia reached 76%. For the age group 19–23 with higher myopic status, the risk to develop high myopia was 58%. These data are detailed in figure 3.

## DISCUSSION

This cohort study focused on myopia progression in a large data set of myopic individuals (n=630 487) followed over a 7-year period.

We reported a higher proportion of progressors in the younger age groups with proportions ranging from 18.2% in the 14–15 age group to 6.4% in the 28–29 year age group (table 2). Furthermore, the current study showed that the most important risk factor for myopia progression is younger age rather than degree of myopia (table 4). A higher proportion of progressors was also observed after 65 years of age. This is likely to be explained by the occurrence of nuclear cataract, which tends to modify the refractive index of the lens towards myopia. The definition of

**Table 2** Proportion (%) of progressors by age and SE at baseline and gender

| | Total | Prescription between 12 and 26 months | | Progressors | | |
|---|---|---|---|---|---|---|
| | N | N | % | N | % | p |
| Age 14–29 | 167 204 | 87 631 | 52.4 | 10 190 | 11.6 | |
| Age | | | | | | <0.0001 |
| 14–15 | 23 463 | 16 124 | 68.7 | 2934 | 18.2 | |
| 16–17 | 21 093 | 13 880 | 65.8 | 1936 | 13.9 | |
| 18–19 | 20 044 | 11 299 | 56.4 | 1468 | 13.0 | |
| 20–21 | 19 994 | 9996 | 50.0 | 1020 | 10.2 | |
| 22–23 | 19 867 | 9325 | 46.9 | 898 | 9.6 | |
| 24–25 | 20 522 | 9094 | 44.3 | 726 | 8.0 | |
| 26–27 | 20 953 | 9052 | 43.2 | 643 | 7.1 | |
| 28–29 | 21 268 | 8861 | 41.7 | 565 | 6.4 | |
| SE | | | | | | <0.0001 |
| ]−1 ; −0.5] | 32 387 | 17 059 | 52.7 | 1704 | 10.0 | |
| ]−2 ; −1] | 47 008 | 24 339 | 51.8 | 2720 | 11.2 | |
| ]−3 ; −2] | 30 872 | 16 035 | 51.9 | 1794 | 11.2 | |
| ]−4 ; −3] | 20 758 | 11 015 | 53.1 | 1313 | 11.9 | |
| ]−5; −4] | 13 853 | 7327 | 52.9 | 943 | 12.9 | |
| ]−6; −5] | 8862 | 4808 | 54.3 | 637 | 13.2 | |
| ≤−6 | 13 464 | 7048 | 52.3 | 1079 | 15.3 | |
| Gender | | | | | | <0.0001 |
| F | 102 794 | 55 178 | 53.7 | 6461 | 11.7 | |
| M | 64 410 | 32 453 | 50.4 | 3729 | 11.5 | |
| Age 30–100 | 463 283 | 178 886 | 38.6 | 10 549 | 5.9 | |
| Age | | | | | | <0.0001 |
| 30–34 | 54 562 | 21 646 | 39.7 | 1045 | 4.8 | |
| 35–39 | 53 164 | 20 574 | 38.7 | 813 | 4.0 | |
| 40–44 | 62 397 | 25 222 | 40.4 | 1058 | 4.2 | |
| 45–49 | 67 313 | 28 127 | 41.8 | 1147 | 4.1 | |
| 50–54 | 56 184 | 20 671 | 36.8 | 765 | 3.7 | |
| 55–59 | 44 617 | 15 449 | 34.6 | 686 | 4.4 | |
| 60–64 | 35 988 | 12 069 | 33.5 | 859 | 7.1 | |
| 65–69 | 29 937 | 10 895 | 36.4 | 1214 | 11.1 | |
| 70–74 | 19 810 | 7863 | 39.7 | 998 | 12.7 | |
| 75–79 | 17 240 | 6926 | 40.2 | 876 | 12.6 | |
| 80–84 | 13 665 | 5616 | 41.1 | 596 | 10.6 | |
| 85–100 | 8406 | 3828 | 45.5 | 492 | 12.9 | |
| SE | | | | | | <0.0001 |
| ]−1; −0.5] | 91 612 | 36 303 | 39.6 | 1984 | 5.5 | |
| ]−2; −1] | 129 631 | 49 526 | 38.2 | 2837 | 5.7 | |
| ]−3; −2] | 80 547 | 30 744 | 38.2 | 1652 | 5.4 | |
| ]−4; −3] | 54 998 | 21 237 | 38.6 | 1172 | 5.5 | |
| ]−5; −4] | 36 563 | 13 729 | 37.5 | 778 | 5.7 | |
| ]−6; −5] | 25 029 | 9727 | 38.9 | 585 | 6.0 | |
| ≤−6 | 44 903 | 17 620 | 39.2 | 1541 | 8.7 | |
| Gender | | | | | | <0.0001 |
| F | 274 053 | 110 345 | 40.3 | 6260 | 5.7 | |
| M | 189 230 | 68 541 | 36.2 | 4289 | 6.3 | |

Progressors are individuals with a progression rate of more than −0.50 diopters per year in the first 12–26 months after baseline. Multivariate logistic regression type III p-values are displayed.
SE, spherical equivalent.

Table 3 Proportion (%) of progressors in younger age subgroup (14–29 N=87 631) by age and SE at baseline

| Age | 14–15 | 16–17 | 18–19 | 20–21 | 22–23 | 24–25 | 26–27 | 28–29 | Total |
|---|---|---|---|---|---|---|---|---|---|
| **SE** | | | | | | | | | |
| ]−1 ; −0.5] | 14.9 | 11.7 | 11.0 | 7.1 | 7.7 | 6.7 | 5.7 | 5.3 | 10.0 |
| ]−2 ; −1] | 17.0 | 13.7 | 13.7 | 9.4 | 8.6 | 7.6 | 6.2 | 5.3 | 11.2 |
| ]−3 ; −2] | 19.1 | 13.4 | 12.0 | 9.3 | 9.2 | 7.3 | 6.2 | 6.2 | 11.2 |
| ]−4 ; −3] | 19.1 | 15.0 | 12.6 | 12.0 | 9.8 | 8.0 | 7.4 | 6.2 | 11.9 |
| ]−5; −4] | 20.4 | 15.6 | 15.2 | 13.0 | 10.3 | 10.4 | 7.9 | 6.0 | 12.9 |
| ]−6; −5] | 22.9 | 16.0 | 14.1 | 14.1 | 13.4 | 7.8 | 7.9 | 8.4 | 13.3 |
| ≤ −6 | 27.4 | 18.9 | 16.0 | 13.6 | 13.8 | 10.5 | 11.7 | 10.1 | 15.3 |
| **Total** | 18.2 | 14.0 | 13.0 | 10.2 | 9.6 | 8.0 | 7.1 | 6.4 | 11.6 |

Progressors are individuals with a progression rate of more than −0.5 diopters per year in the first 12–26 months after baseline.
SE, spherical equivalent.

progressors adopted in the current study (mean rate of progression exceeding −0.50 D/y) was consistent with the definition provided in the report of the joint WHO—Brien Holden Vision Institute Global Scientific Meeting on myopia published in 2015.

This study completes data from a recent study focusing on the progression of myopia among myopic children.[23] Large data sets on progression of myopia in European teenagers and young adults are scarce, but there are a number of small university-based studies worthy of mention. The study design, sample size, mean follow-up and mean annual myopia progression of these studies are summarised in table 5.

Most of these studies were mainly conducted on university students, a selected group, while the profile of young individuals included in the current study was likely to be closer to that of the general population for the same age group. It is not surprising, therefore, that most reported an annual progression ranging from −0.18 to −0.71 D/y, which is higher than in the present study. On the contrary, the annual myopia progression observed in our study is very similar to that reported by Polling *et al*,[21] probably because of similar sample selection. In a less selective group, Pärssinen *et al* reported 20-year follow-up data from a longitudinal study that began in 240 myopic children aged 8–12 years.[20] Adult progression data were available from 147 subjects. Mean myopic progression over 8 years of persons with ages exceeding 20–24 years was −0.45±0.71 D with 45% of subjects progressing at least −0.50 D.

Few studies have followed progression in myopic children into their college years, the exception being the Correction of Myopia Evaluation Trial.[24] Data from 440 of the original 469 participants with at least 6 years of follow-up and at least seven refraction measurements after the age of 11 years were analysed. Among these, age and refractive error at myopia stabilisation could be established in 426 participants. The mean age at myopia stabilisation (defined as the age at which the estimated spherical refractive error was within 0.50 D of the asymptote) was 15.6±4.2 years, and the mean amount of myopia at

Table 4 Progression of myopia (in diopters) between 12 and 26 months according to age, spherical equivalent at baseline and gender: univariate and multivariate analysis in the 14–29 age subgroup (N=87 631)

| | Univariate | Multivariate | |
|---|---|---|---|
| | **Progression** | **Progression** | **p** |
| Age | | | <0.0001 |
| 14–15 | −0.35 (−0.36; −0.34) | −0.36 (−0.37; −0.36) | |
| 16–17 | −0.29 (−0.30; −0.29) | −0.31 (−0.31; −0.30) | |
| 18–19 | −0.27 (−0.28; −0.26) | −0.28 (−0.29; −0.27) | |
| 20–21 | −0.24 (−0.25; −0.23) | −0.24 (−0.25; −0.23) | |
| 22–23 | −0.22 (−0.23; −0.21) | −0.23 (−0.24; −0.22) | |
| 24–25 | −0.18 (−0.19; −0.17) | −0.19 (−0.20; −0.18) | |
| 26–27 | −0.16 (−0.17; −0.15) | −0.17 (−0.18; −0.16) | |
| 28–29 | −0.13 (−0.14; −0.12) | −0.13 (−0.14; −0.12) | |
| SE | | | <0.0001 |
| −1 to −0.5 | −0.21 (−0.22; −0.20) | −0.18 (−0.19; −0.17) | |
| −2 to −1 | −0.24 (−0.25; −0.24) | −0.22 (−0.23; −0.22) | |
| −3 to −2 | −0.25 (−0.25; −0.24) | −0.23 (−0.24; −0.22) | |
| −4 to −3 | −0.26 (−0.27; −0.25) | −0.24 (−0.25; −0.23) | |
| −5 to −4 | −0.27 (−0.28; −0.26) | −0.26 (−0.27; −0.25) | |
| −6 to −5 | −0.26 (−0.28; −0.25) | −0.26 (−0.27; −0.25) | |
| ≤ −6 | −0.28 (−0.29; −0.27) | −0.27 (−0.29; −0.26) | |
| Sex | | | <0.0001 |
| F | −0.25 (−0.25; −0.24) | −0.25 (−0.25; −0.24) | |
| M | −0.24 (−0.25; −0.24) | −0.23 (−0.24; −0.23) | |

Multivariate ANOVA type III p-values are displayed.
ANOVA, analysis of variance.

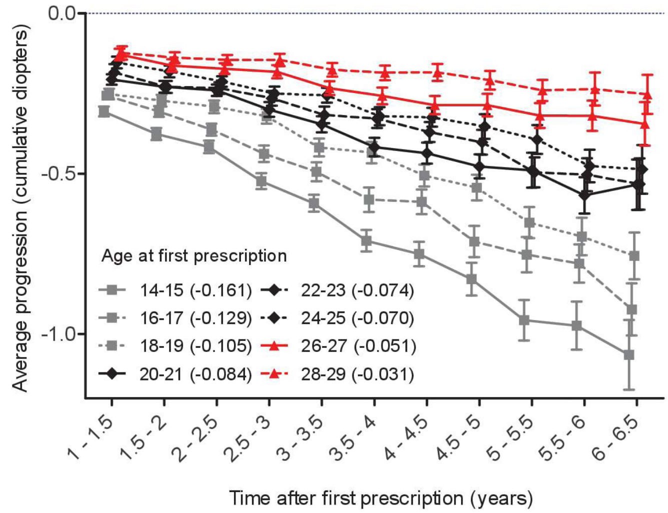


Figure 2 Average progression of myopia (in diopters) according to age in the younger subgroup (14–29, N=167 204). Values between parentheses indicate the average progression rate over the 6.5 years period in diopters per year.

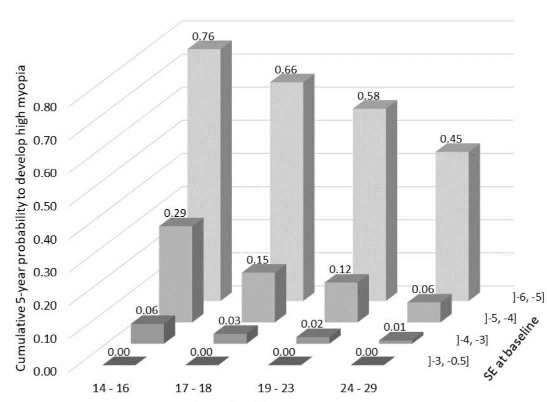


Figure 3 Kaplan-Meier estimations of the 5 year cumulative probability to develop high myopia stratified by age and SE at baseline in the younger subgroup (14–29, N=153 740). SE, spherical equivalent.

**Table 5** Studies on myopia progression in teenagers and young adults

| Authors | Population | Design | Sample size | Mean age (years) | Duration follow-up (years) | Mean annual myopia progression |
|---|---|---|---|---|---|---|
| O'Neal and Connon[33] | US Air Force cadets | Retrospective | 497 | 17–21 | 2.5 | −0.23 D/y |
| Kinge and Midelfart[34] | Engineering Norwegian students | Prospective | 224 | 20.6 | 3 | −0.22 D/y |
| Jacobsen, Jensen and Goldschmidt[35] | First year medical students (Danemark) | Prospective | 143 | 23.1 | † | −0.20 D/y |
| Lv and Zhang[36] 2013 | Medical students (China) | Prospective | 2053 | 18.3 | † | −0.18 D/y |
| Polling, Klaver and Tideman[21] | Children (prescription from opticians) (Netherlands) | Retrospective | 2555 | Children and young adults up to 21 | 1–22 years (mean 5.8) | ▲ −0.50 D/y (children≤10 y)<br>▲ −0.19 D/y (for 13–15 y)<br>▲ −0.09 D/y (for 16–18 y)<br>▲ −0.08 D/y (for 19–21 y) |
| French *et al*[37] | Population-based (Australia) | Prospective | 2760 | 12 and 17 years | 6 | −0.31 D/year* |
| Fan *et al*[38] | School-based (Hong Kong) | Prospective | 7560 | 5–16 (9.3) | * | −0.63 D/year |
| Zhou *et al*[39] | Population-based (China) | Prospective | 3070 | 6–15 | 5 years | −0.71 D/year† |
| Current study | Teenagers and adults (France) | Prospective | 167 204 (for 14–29 years) | Teenagers and young adults (21.4) | 7 years (mean 2.9) | ▲ −0.16 D/y (for 14–15 y)<br>▲ −0.13 D/y (for 16–17 y)<br>▲ −0.10 D/y (for 18–19 y)<br>▲ −0.08 D/y (for 20–21 y) |

*In the population of children aged 12 years at first examination.
†For myopic eyes at baseline.

stabilisation was −4.87±2.01 D. While progression rates were not specified, a companion paper presented a graph of mean refractive error as a function of age.[25] Digitisation of these data reveals a mean progression rate of −0.16, −0.08 and −0.03 D/y in 14–15, 16–17 and 18–19 year olds, respectively. While the progression rate at the youngest age was similar to that in the present study, the rates in the two older age groups were slower. Many studies have been conducted in Asian countries, usually in children, because myopia progresses more rapidly in paediatric populations and because the burden of myopia currently represents a major public health concern.[26–28] A number of reasons help to explain the apparent discrepancy of myopia progression between Asian and Caucasian populations. Indeed, major differences in terms of environmental pressure could explain some degrees of divergence. In other terms, a larger number of progressors in East Asian populations, for example, environmental exposure, could contextualise the so-called 'myopia boom' observed in that part of the world and the higher prevalence of myopia compared with that reported in European populations.

If environmental,[29] optical[30] and pharmacologic[31] approaches may help to reduce the progression of myopia in young people, particularly in the 7–12 year age group, which is more prone to progress, these strategies are minimally effective in adults and are likely to have little or no impact on the final degree of myopia.

## Strengths and limitations of this study

The strength of this study consists in large sample size and longitudinal design, providing original data on progression of myopia in teenagers and adults in different age groups, by level of myopia at baseline and by gender. We also observed that myopia progression towards high myopia represented 45% of the more myopic individuals aged 24–29 at baseline (figure 3), a result showing that if myopia progresses more among children, young adults are also, although in a lesser manner, affected by progression of myopia. To our knowledge, this is the largest longitudinal study on the progression of myopia in Europe. With its focus on teenagers and young adults, it provides new information that may contribute to better understanding and anticipation of the magnitude of this public health problem, because higher myopia prevalence means higher prevalence of myopia-related ocular complications.[32]

We acknowledge several limitations in this study. When speaking of progression of myopia, we only included individuals presenting for new prescriptions; persons with no correction and those who did not renew their correction during the study period were excluded from the analysis. Furthermore, people with stable corrections would be less likely to renew them, potentially leading to overestimation of progression rates. There were also missing data due to change of optician. In this context, a nation wide database would be very useful to avoid loss of data for that reason. In addition, the study design prevented us from estimating the frequency of adult-onset myopia. Indeed, a low myope presenting during the study period may have been either a new myope or an existing myope. While the means of determination of refractive status—with or without cycloplegia—was not provided in the data set, in accordance with national recommendations cycloplegia is usually used in children and not among adults. However, the assumption that refractive errors will be similar at all measures for a same individual is not likely to markedly affect estimates of progression. Finally, the computing of progression rates (and progressor status) over the first 12–26 months after baseline leads to overestimates as individuals with faster progression rates are more likely to frequently renew their equipment.

## CONCLUSION

This study provides longitudinal data on the progression of myopia in persons aged 14 years and over. Progression rates of myopia appear to be lower than those observed in East Asia, a region in which increased myopia was first documented. During an epoch marked by an increase in myopia prevalence and by a development of environmental, optical and pharmacological approaches, one of the major challenges will be to apply the most effective and well-tolerated preventive strategies to reduce myopia progression.

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## REFERENCES

1 Bourne RRA, Stevens GA, White RA, *et al*. Causes of vision loss worldwide, 1990-2010: a systematic analysis. *Lancet Glob Health* 2013;1:e339–49.
2 Bourne RRA, Jonas JB, Flaxman SR, *et al*. Prevalence and causes of vision loss in high-income countries and in eastern and central Europe: 1990-2010. *Br J Ophthalmol* 2014;98:629–38.
3 Marcus MW, de Vries MM, Junoy Montolio FG, *et al*. Myopia as a risk factor for open-angle glaucoma: a systematic review and meta-analysis. *Ophthalmology* 2011;118:1989–94.
4 Liu Y-C, Wilkins M, Kim T, *et al*. Cataracts. *The Lancet* 2017;390:600–12.
5 Risk factors for idiopathic rhegmatogenous retinal detachment. the eye disease case-control study Group. *Am J Epidemiol* 1993;137:749–57.
6 Morgan IG, Ohno-Matsui K, Saw S-M. Myopia. *Lancet* 2012;379:1739–48.
7 Hopf S, Korb C, Nickels S, *et al*. Prevalence of myopic maculopathy in the German population: results from the Gutenberg health study. *Br J Ophthalmol*:bjophthalmol-2019-315255 (Published Online First: 16 December 2019).
8 Wong Y-L, Sabanayagam C, Ding Y, *et al*. Prevalence, risk factors, and impact of myopic macular degeneration on visual impairment and functioning among adults in Singapore. *Invest Ophthalmol Vis Sci* 2018;59:4603–13.
9 Sun J, Zhou J, Zhao P, *et al*. High prevalence of myopia and high myopia in 5060 Chinese university students in Shanghai. *Invest Ophthalmol Vis Sci* 2012;53:7504–9.
10 Dolgin E. The myopia boom. *Nature* 2015;519:276–8.
11 Lin LLK, Shih YF, Hsiao CK, *et al*. Prevalence of myopia in Taiwanese schoolchildren: 1983 to 2000. *Ann Acad Med Singap* 2004;33:27–33.
12 Williams KM, Bertelsen G, Cumberland P, *et al*. Increasing prevalence of myopia in Europe and the impact of education. *Ophthalmology* 2015;122:1489–97.
13 Rudnicka AR, Kapetanakis VV, Wathern AK, *et al*. Global variations and time trends in the prevalence of childhood myopia, a systematic review and quantitative meta-analysis: implications for aetiology and early prevention. *Br J Ophthalmol* 2016;100:882–90.
14 McCullough SJ, O'Donoghue L, Saunders KJ. Six year refractive change among white children and young adults: evidence for significant increase in myopia among white UK children. *PLoS One* 2016;11:e0146332.
15 Zheng Y-F, Pan C-W, Chay J, *et al*. The economic cost of myopia in adults aged over 40 years in Singapore. *Invest Ophthalmol Vis Sci* 2013;54:7532–7.
16 Naidoo KS, Fricke TR, Frick KD, *et al*. Potential lost productivity resulting from the global burden of myopia: systematic review, meta-analysis, and modeling. *Ophthalmology* 2019;126:338–46.
17 Cheung CMG, Arnold JJ, Holz FG, *et al*. Myopic choroidal neovascularization: review, guidance, and consensus statement on management. *Ophthalmology* 2017;124:1690–711.
18 Chen S-N, Lian I-B, Wei Y-J. Epidemiology and clinical characteristics of rhegmatogenous retinal detachment in Taiwan. *Br J Ophthalmol* 2016;100:1216–20.
19 Xu L, Wang Y, Wang S, *et al*. High myopia and glaucoma susceptibility the Beijing eye study. *Ophthalmology* 2007;114:216–20.
20 Pärssinen O, Kauppinen M, Viljanen A. The progression of myopia from its onset at age 8-12 to adulthood and the influence of heredity and external factors on myopic progression. A 23-year follow-up study. *Acta Ophthalmol* 2014;92:730–9.
21 Polling JR, Klaver C, Tideman JW. Myopia progression from wearing first glasses to adult age: the DREAM study. *Br J Ophthalmol* 2021. doi:10.1136/bjophthalmol-2020-316234. [Epub ahead of print: 25 Jan 2021].
22 Flitcroft DI, He M, Jonas JB, *et al*. IMI - Defining and Classifying Myopia: A Proposed Set of Standards for Clinical and Epidemiologic Studies. *Invest Ophthalmol Vis Sci* 2019;60:M20–30.
23 Tricard D, Marillet S, Ingrand P, *et al*. Progression of myopia in children and teenagers: a nationwide longitudinal study. *Br J Ophthalmol* 2021. doi:10.1136/bjophthalmol-2020-318256. [Epub ahead of print: 12 Mar 2021].
24 COMET Group. Myopia stabilization and associated factors among participants in the correction of myopia evaluation trial (comet). *Invest Ophthalmol Vis Sci* 2013;54:7871–84.
25 Hou W, Norton TT, Hyman L, *et al*. Axial elongation in myopic children and its association with myopia progression in the correction of myopia evaluation trial. *Eye Contact Lens* 2018;44:248–59.
26 Fan DSP, Lam DSC, Lam RF, *et al*. Prevalence, incidence, and progression of myopia of school children in Hong Kong. *Invest Ophthalmol Vis Sci* 2004;45:1071–5.
27 Saw S-M, Tong L, Chua W-H, *et al*. Incidence and progression of myopia in Singaporean school children. *Invest Ophthalmol Vis Sci* 2005;46:51–7.
28 Zhou W-J, Zhang Y-Y, Li H, *et al*. Five-Year progression of refractive errors and incidence of myopia in school-aged children in Western China. *J Epidemiol* 2016;26:386–95.
29 Wu P-C, Tsai C-L, Wu H-L, *et al*. Outdoor activity during class recess reduces myopia onset and progression in school children. *Ophthalmology* 2013;120:1080–5.
30 González-Méijome JM, Peixoto-de-Matos SC, Faria-Ribeiro M, *et al*. Strategies to regulate myopia progression with contact lenses: a review. *Eye Contact Lens* 2016;42:24–34.
31 Chia A, Lu Q-S, Tan D. Five-year clinical trial on atropine for the treatment of Myopia 2: myopia control with atropine 0.01% eyedrops. *Ophthalmology* 2016;123:391–9.
32 Leveziel N, Marillet S, Dufour Q, *et al*. Prevalence of macular complications related to myopia - results of a multicenter evaluation of myopic patients in eye clinics in France. *Acta Ophthalmol* 2020;98:e245–51.
33 O'Neal MR, Connon TR. Refractive error change at the United States air force academy--class of 1985. *Am J Optom Physiol Opt* 1987;64:344–54.
34 Kinge B, Midelfart A. Refractive changes among Norwegian university students--a three-year longitudinal study. *Acta Ophthalmol Scand* 1999;77:302–5.
35 Jacobsen N, Jensen H, Goldschmidt E. Does the level of physical activity in university students influence development and progression of myopia?--a 2-year prospective cohort study. *Invest Ophthalmol Vis Sci* 2008;49:1322–7.
36 Lv L, Zhang Z. Pattern of myopia progression in Chinese medical students: a two-year follow-up study. *Graefes Arch Clin Exp Ophthalmol* 2013;251:163–8.
37 French AN, Morgan IG, Burlutsky G, *et al*. Prevalence and 5- to 6-year incidence and progression of myopia and hyperopia in Australian schoolchildren. *Ophthalmology* 2013;120:1482–91.
38 Fan DSP, Lam DSC, Lam RF, *et al*. Prevalence, incidence, and progression of myopia of school children in Hong Kong. *Invest Ophthalmol Vis Sci* 2004;45:1071–5.
39 Zhou W-J, Zhang Y-Y, Li H, *et al*. Five-Year progression of refractive errors and incidence of myopia in school-aged children in Western China. *Journal of Epidemiology* 2016;26:386–95.