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Global Prevalence of Presbyopia and Vision Impairment from Uncorrected Presbyopia

Systematic Review, Meta-analysis, and Modelling

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Topic: Presbyopia prevalence and spectacle-correction coverage were estimated by systematic review and meta-analysis of epidemiologic evidence, then modeled to expand to country, region, and global estimates.

Clinical Relevance: Understanding presbyopia epidemiologic factors and correction coverage is critical to overcoming the burden of vision impairment (VI) from uncorrected presbyopia.

Methods: We performed systematic reviews of presbyopia prevalence and spectacle-correction coverage. Accepted presbyopia prevalence data were gathered into 5-year age groups from 0 to 90 years or older and meta-analyzed within World Health Organization global burden of disease regions. We developed a model based on amplitude of accommodation adjusted for myopia rates to match the regionally meta-analyzed presbyopia prevalence. Presbyopia spectacle-correction coverage was analyzed against country-level variables from the year of data collection; variation in correction coverage was described best by a model based on the Human Development Index, Gini coefficient, and health expenditure, with adjustments for age and urbanization. We used the models to estimate presbyopia prevalence and spectacle-correction coverage in each age group in urban and rural areas of every country in the world, and combined with population data to estimate the number of people with near VI.

Results: We estimate there were 1.8 billion people (prevalence, 25%; 95% confidence interval [CI], 1.7−2.0 billion [23%−27%]) globally with presbyopia in 2015, 826 million (95% CI, 686−960 million) of whom had near VI because they had no, or inadequate, vision correction. Global unmet need for presbyopia correction in 2015 is estimated to be 45% (95% CI, 41%−49%). People with presbyopia are more likely to have adequate optical correction if they live in an urban area of a more developed country with higher health expenditure and lower inequality.

Conclusions: There is a significant burden of VI from uncorrected presbyopia, with the greatest burden in rural areas of low-resource countries. *Ophthalmology 2018;125:1492-1499 © 2018 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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Presbyopia was estimated to affect more than 1 billion people globally in 2005, with more than half unable to access the necessary refractive correction to overcome the associated vision impairment (VI).[1] When that estimate was made, high-quality prevalence data were available only for 4 countries—Tanzania,[2,3] Brazil,[4] India,[5] and Timor-Leste[6,7]—so the global presbyopia prevalence estimates involved extensive extrapolation and a high degree of uncertainty. Data for presbyopia correction rates similarly were limited, and correction estimates similarly uncertain. In addition to the paucity of evidence, the authors noted a need to increase consistency in presbyopia prevalence study methodology to enable comparability.[1]

Subsequently, the World Health Organization developed a standardized protocol for assessing prevalence of VI caused by uncorrected presbyopia.[8] Variations in font type, font size, and test distances previously had been a major cause of comparability issues and were addressed in the standardized protocol. The vast majority of near-vision research since then has used Times New Roman font, with ability to see either N6 or N8 (N = Times New Roman font and the number denotes the point size in print)[6] at either 40 cm or preferred distance as the threshold for impairment. N6 or N8 at 40 cm corresponds to 20/40 or 20/50, and there has been an assumption that the acuity variations caused by allowing preferred distance have been insignificant.

New prevalence and spectacle-correction data, together with improved modelling techniques based on newer demographic data, warrant updated global presbyopia estimates and projections. The objectives of this review were to update global and regional presbyopia prevalence and spectacle-correction coverage estimates based on new epidemiologic evidence and improved modelling.

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Methods

Presbyopia Epidemiology: Systematic Review, Meta-analysis, and Modelling

We performed a systematic search for prevalence of presbyopia evidence, summarized in Figure 1. Our inclusion criteria were (1) population-based studies quantifying presbyopia prevalence, (2) presbyopia defined as unaided near vision worse than N6 or N8 at 40 cm or customary working distance, (3) a mechanism to exclude people with eye disease causing reduced near vision, (4) sampling representative of entire communities, and (5) sample size of at least 400 participants, without date restrictions. We excluded articles that were not available in English, which did not specify the number of eligible participants or participation rate, that had unspecified or ambiguous definitions, that had a participation rate of less than 70%, or that were based on duplicate data used in other included studies. Seven additional articles were identified by key informants and reference lists of included studies.

From the 170 articles identified, we included 25 studies in our analysis of the prevalence of presbyopia, summarized in Table S1 (available at www.aaojournal.org).[2,5,9–27] Most article exclusions were the result of lack of presbyopia prevalence data, not being population based, not being representative of entire communities, or a combination thereof. Additionally, Duarte et al[4] was excluded because of data labelling ambiguities in the translated English version and use of an outlying definition (N4 at 37 cm), and Abdullah et al[28] was excluded for not specifying the presbyopia cutoff.

We gathered the prevalence data into 5-year age groups from 0 to 90 years or older. Published evidence covered all age groups 40 years or older in 11 of the 21 World Health Organization global burden of disease (GBD) regions, plus the 35- to 39-year-old age group in 6 of the same regions.[29] We meta-analyzed the prevalence of presbyopia within each age group within each of the 11 GBD regions using Comprehensive Meta-Analysis version 3 (Biostat, Englewood, NJ). A logit random effects model was used to combine studies within each age group and region. The logit prevalence was defined as $\log(p / (1 - p))$, where p is the prevalence within each age group. The study-to-study variance (τ^2) was not assumed to be the same for all age groups within the region, indicating that this value was computed within age groups and not pooled across age groups. Inverse of the variance was used to compute relative weights. The logit prevalence and its standard error were used to compute the 95% confidence interval (CI), which then were transformed to the estimated prevalence and its corresponding limits using the formula exp^(Logit prevalence) / (exp^(Logit prevalence) + 1).

Presbyopia was assumed to have 0 prevalence in people younger than 30 years of age. In the 6 regions with data from those 35 years of age or older and the 5 regions with data from those 40 years of age or older, we linearly decreased the prevalence from the last known evidence down through the relevant age groups to 0 at 30 years of age. In regions with data, but no data in 1 or more of the age groups 65 years of age or older, we extrapolated the prevalence as a constant from the last known evidence through to the 90 years or older age group.

We also estimated presbyopia prevalence in the same 11 GBD regions by developing a model based on published amplitude of accommodation versus age relationships,[30–33] modified by the age-specific prevalence of myopia (from section 5 of the online supplemental material for Holden et al[34]). Accommodation is the ability of the eye to change focus, and amplitude of accommodation is the maximum optical power an eye can achieve relative to rest. Evidence suggests that the average person can maintain two thirds of his or her amplitude of accommodation, meaning that an emmetropic person would need 3.75 diopters (D) or more of amplitude of accommodation to perform tasks at 40 cm for a prolonged period without optical assistance.[35] Because accommodative need is reduced in myopic people, estimates of the number of people in each country, in each 5-year age group from 0 to 90 years or older with myopia of −0.50 D or less, −0.75 D or less, −1.25 D or less, −1.75 D or less, or −2.25 D or less were made using the methods of Holden et al.[34] We found 4 articles describing the relationship between amplitude of accommodation and age of 30 years or older, 1 each from China, India, Nigeria, and the United States.[30–33] Age-specific mean and standard deviation amplitude of accommodation from these studies were translated via cumulative probability statistics to a percentage of people in each age group and level of ametropia who lack the appropriate accommodation for near tasks at 40 cm. We compared these presbyopia prevalence estimates with the epidemiologic evidence in the 11 regions with data, and then refined the model using a global constant. Level of agreement in regional presbyopia prevalence between estimates based on direct epidemiologic evidence and our model is shown in Figure S2 (available at www.aaojournal.org).

We extracted country-specific population data for 2015 and each decade from 2000 through 2050 in 5-year age groups from 0 to 90 years or older from the United Nations World Population Prospects.[36] Population data from the United States Census Bureau were used for a small number of low-population states aggregated within the available United Nations data.[37]

We estimated age-specific presbyopia prevalence in all countries using the adjusted amplitude of accommodation or myopia model. We applied amplitude of accommodation data from China to countries in Asia (Central), Asia (East), Asia (Southeast), and Asia Pacific High Income.[30] Amplitude of accommodation data from India were used in Asia (South),[31] whereas data from Nigeria were used in Caribbean, Sub-Saharan Africa (Central), Sub-Saharan Africa (East), Sub-Saharan Africa (Southern), and Sub-Saharan Africa (West),[32] and data from the United States were used in Australasia, Europe (Central), Europe (Eastern), Europe (Western), Latin America (Andean), Latin America (Central), Latin America (Southern), Latin America (Tropical), North Africa and Middle East, North America High Income, and Oceania.[33] The age- and country-specific average prevalence data, together with upper and lower 95% CI, were combined with the population data to estimate number of people with presbyopia in each country of the world in 2015 plus each decade from 2000 through 2050.

Presbyopia Spectacle-Correction Coverage: Systematic Review and Modelling

We performed a systematic search for presbyopia correction rates, coverage, or both, summarized in Figure 1. Our inclusion and exclusion criteria were the same as the review of presbyopia prevalence, except that in this search, studies needed to quantify presbyopia spectacle-correction rates, coverage, or both. In addition to 160 articles identified by systematic search, 12 published articles and 17 studies from the Rapid Assessment of Avoidable Blindness Repository were identified by key informants 23 and reference lists of identified studies.[38]

Data from the 43 accepted studies were translated into presbyopia spectacle-correction coverage, and then analyzed against health and development indicators from the country and year of data collection. We assessed gross domestic product per capita

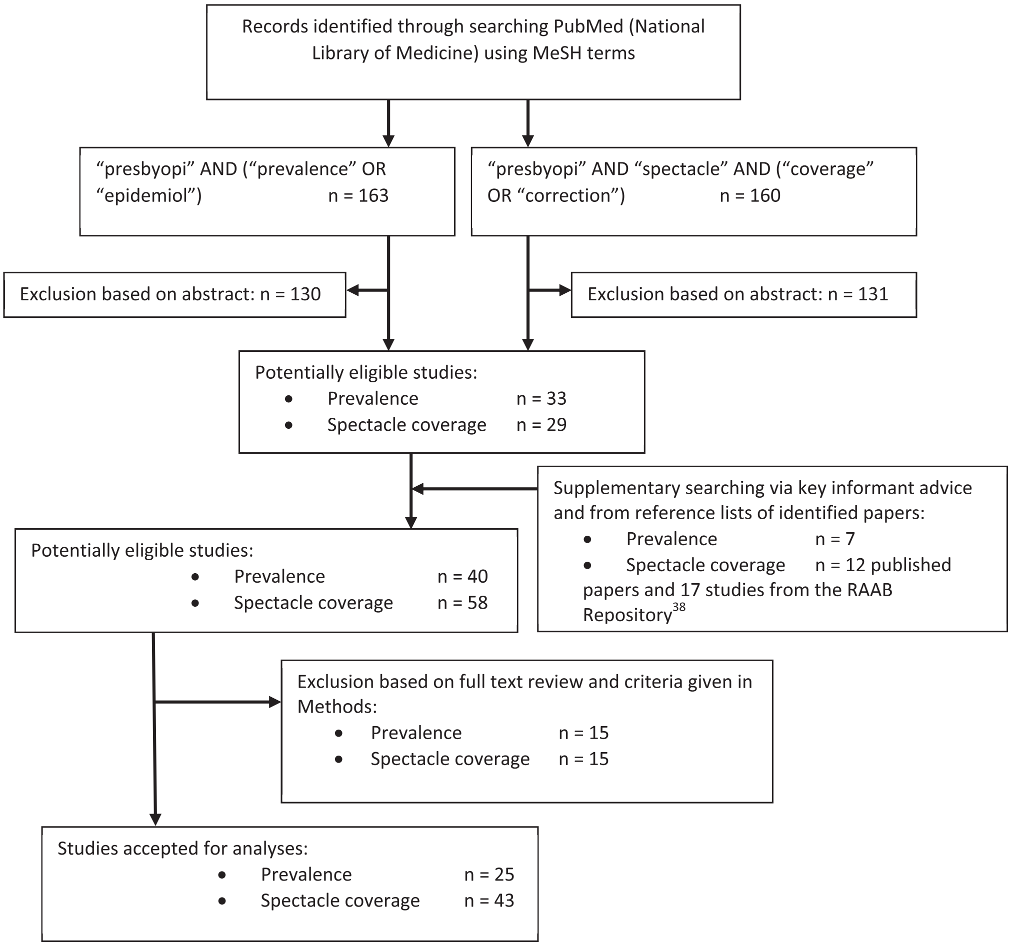

Figure 1. Flow diagram summarizing the systematic search and review process for identifying evidence regarding the prevalence of presbyopia and the presbyopia correction coverage rate. Inclusion and exclusion criteria are provided in the text. MeSH = medical subjects heading; RAAB = Rapid Assessment of Avoidable Blindness.

(in United States dollars [US$], and in international dollars adjusted for purchasing power parity),[39] gross national income per capita (in both US$ and international dollars),[39] Gini coefficient,[39] eye care practitioner need,[40] health expenditure per capita (in both US$ and international dollars),[39] ratio of public-to-total health expenditure,[39] average years of education,[39] adult literacy,[39] Human Development Index,[41] Socio-Demographic Index,[42] annual per capita electric power consumption,[39] and mobile cellular subscriptions (per 100 people).[39] The equation providing the best explanation of variance was used to calculate country-specific presbyopia spectacle-correction coverage. We also modelled the effects of urbanization and age on presbyopia spectacle-correction coverage. The country-, urbanization-, and age-specific presbyopia spectacle-correction coverage estimates determined by these models were bound to lower and upper limits of 1% and 99%.

Near Vision Impairment Estimate

The country-, urbanization-, and age-specific presbyopia spectacle-correction coverage estimates were converted to rates of presbyopia noncorrection, then matched and combined with the number of people with presbyopia in each country, urbanization level, and age group to estimate the number of people with VI from uncorrected presbyopia.

Confidence Intervals

Uncertainty in our presbyopia epidemiologic estimates derive from the 95% CI calculated in the meta-analysis of presbyopia prevalence evidence, the 95% CIs of the myopia estimates entered into our model,[34] and the high and low variants in future population projections from the United Nations.[36] Uncertainty in our estimates of presbyopia spectacle-correction coverage derive from the standard error in our modelling, where:

$$\text{Standard error} = 0.056 - 0.091 \times (\text{predicted coverage}) + 0.119 \times (\text{predicted coverage})^2$$

Results

A description and summary of findings from the included studies are provided in Table S1. Three studies that were excluded on the basis of a single criterion are included for perspective.

The following equation was found to explain best the variance of presbyopia spectacle-correction coverage (R^2, 79%):

$$\text{Presbyopia spectacle correction coverage} = 1.095 \times (\text{HDI})^2 - 0.00008 \times (\text{Gini})^2 + 0.0002 \times (\text{HE}) - 0.008,$$

where HDI is the Human Development Index and HE is the health expenditure per capita in US$. This formula then was used

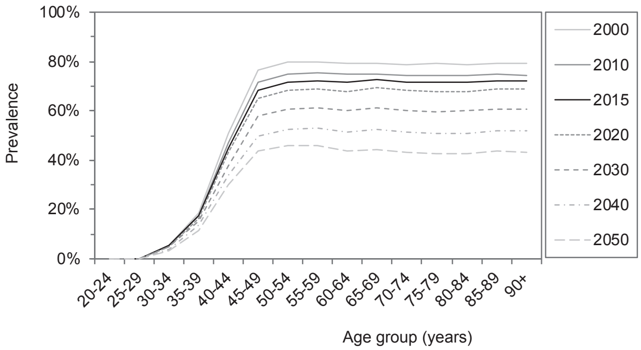

Figure 3. Presbyopia prevalence versus age in from 2000 through 2050.

for estimating presbyopia spectacle-correction coverage in each country of the world, with 2 country-specific adjustments. First, analysis of presbyopia spectacle-correction coverage in urban and rural areas of the same age groups of the same country suggested the following adjustments in countries with low and medium human development (HDI, $\leq$0.70): (1) ratio of rural-to-overall presbyopia spectacle-correction coverage, 0.86; and ratio of urban-to-overall presbyopia spectacle-correction coverage, 1.12. We could not identify any evidence for urbanization affecting presbyopia spectacle-correction coverage in more developed countries, so no adjustment was made to countries with HDI of more than 0.70. Second, analysis of presbyopia spectacle-correction coverage in different age groups of the same communities suggested the following adjustments: (1) in countries with HDI of 0.70 or less, presbyopia spectacle-correction coverage = 0.012 × (age) + 0.3641; and (2) in countries with HDI of more than 0.70, presbyopia spectacle-correction coverage = −0.0007 × (age) + 1.0413.

Figure 3 shows our estimated changes in global presbyopia prevalence against age from 2000 through 2050. At each time point, prevalence of presbyopia is predicted to increase from 0 at 30 years of age until stabilizing at approximately 50 years of age. However, the prevalence of presbyopia at each specific age point decreases gradually over time. The decrease in age-specific presbyopia prevalence is the result of increasing myopia prevalence, which decreases accommodative need in an individual without optical correction.

Figure 4 shows our global estimates of prevalence and people with presbyopia from 2000 through 2050. In 2000, presbyopia was estimated to affect 1.4 billion people, that is, 23% of the world population (95% CI, 1.3−1.5 billion [22%−24%]). In 2015, we estimate presbyopia affected 1.8 billion people, that is, 25% (95% CI, 1.7−2.0 billion [23%−27%]). The global crude, all-ages prevalence of presbyopia is predicted to peak soon after and then start to decrease. We predict that the number of people affected by presbyopia will continue to increase because of population growth until peaking at approximately 2.1 billion in 2030. By 2050, we predict a decrease to 1.9 billion, that is, 20% (95% CI, 1.6−2.3 billion [19%−21%]).

Figure 5 shows the regional differences in presbyopia prevalence, unmet need for presbyopia correction, number of people with presbyopia, and number of people with VI from uncorrected presbyopia predicted by our model. Additional details are provided in Table S2 (available at www.aaojournal.org). Prevalence of presbyopia is estimated to be higher in regions with longer life expectancies, whereas the greatest burden of VI resulting from uncorrected presbyopia occurs in low-resource countries. Globally, we estimated that there were 826 million people (95% CI, 686−960 million people) with VI resulting from uncorrected, or inadequately corrected, presbyopia in 2015. Figure 6 shows each country's prevalence of VI resulting from uncorrected presbyopia on a world map.

Discussion

Our systematic search and review of the literature, meta-analysis, and evidence-based modelling estimated that presbyopia currently affects approximately one quarter of the world's population. It is important to stress that this describes the number of people who would be vision impaired at near without adequate optical correction, not simply those who can not accommodate from distance to near. The latter essentially would be everyone from approximately 55 years of age onward.

We predict, assuming accuracy of the myopia prevalence projections, that increasing myopia will more than offset future population aging. This will lead to a decrease in presbyopia prevalence to approximately 20% by 2050. However, perhaps our most significant finding in terms of impact is that 826 million people (95% CI, 686−960 million people) with presbyopia had near VI because they had no, or inadequate, vision correction in 2015.

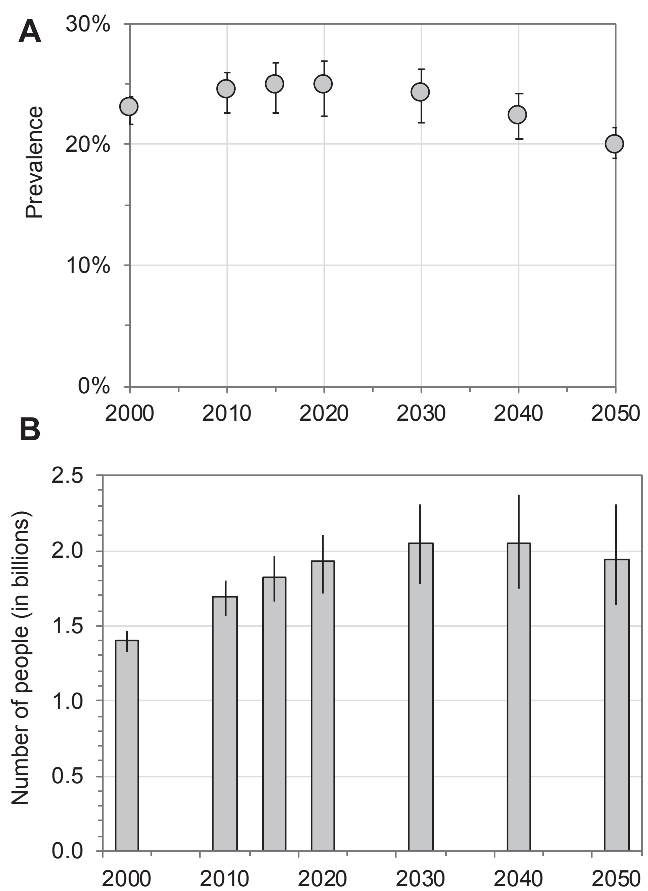

Figure 4. (**A**) Global presbyopia prevalence and (**B**) numbers from 2000 through 2050.

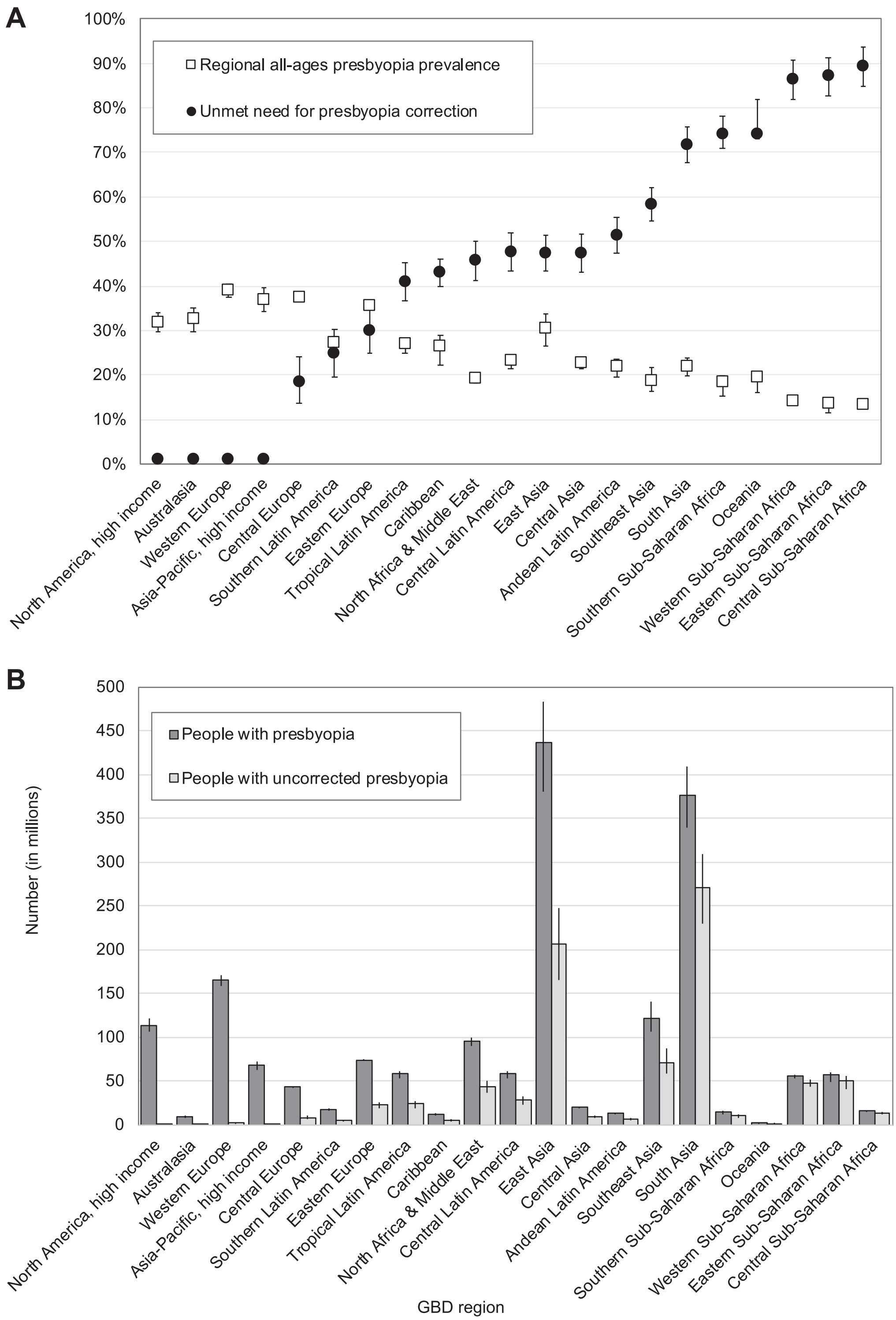

Figure 5. Regional comparison in 2015: (**A**) graph showing presbyopia prevalence and unmet need (%) and (**B**) bar graph showing number of people with presbyopia and vision impairment resulting from uncorrected presbyopia. GBD = global burden of disease.

Some of the strengths of this study compared with previous global presbyopia estimates are the increase in available data, increased homogeneity in data collection methods across the primary studies, and increased spread of data availability from different regions of the world. Data availability in regions with the largest populations, such as East and South Asia, means that 74% of the world's population was covered by primary data when analyzing at the GBD region level. However, considered another way, only 11 of the 21 GBD regions were covered—that is, only 52%

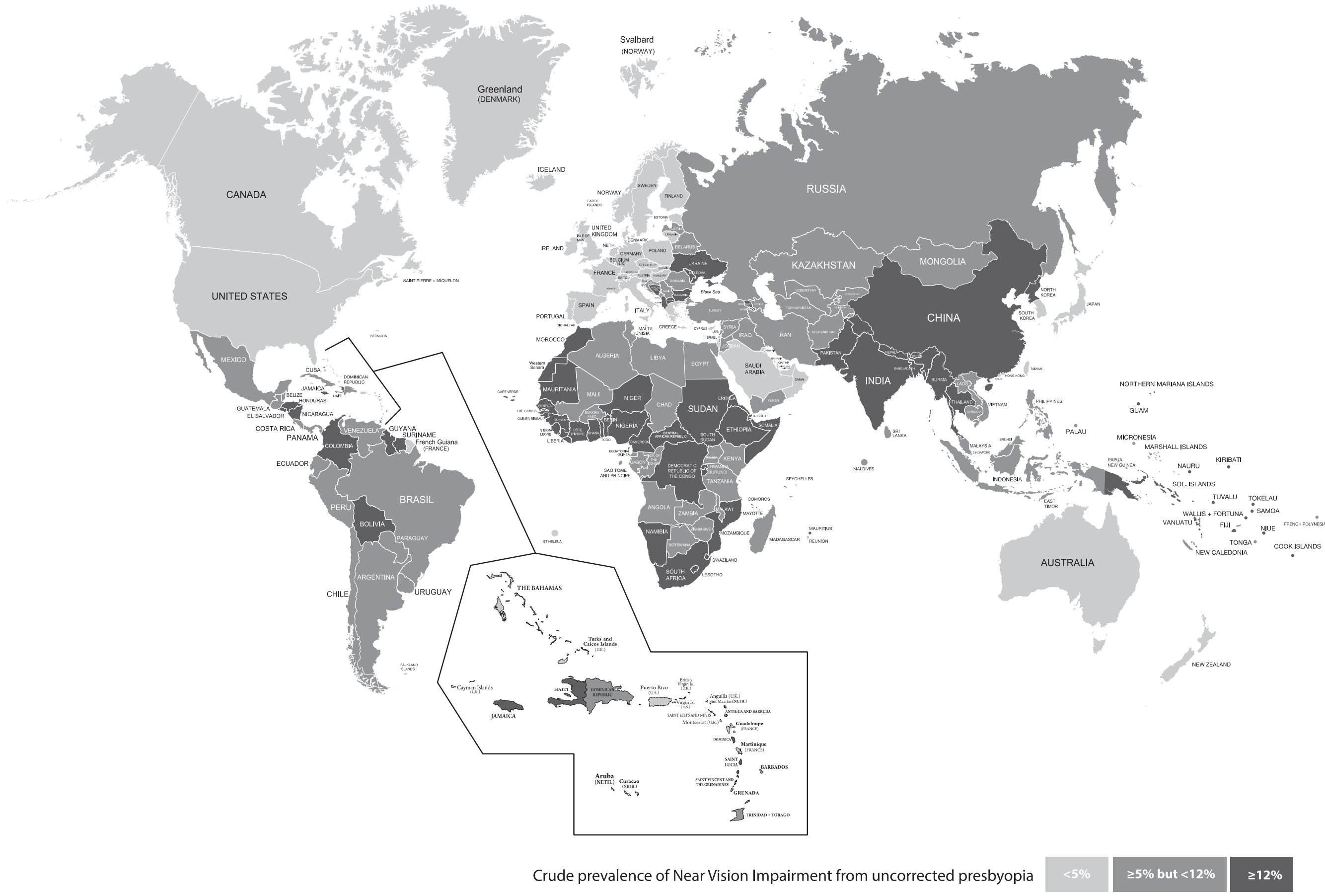

Figure 6. Map showing the prevalence of vision impairment resulting from uncorrected presbyopia. BOS & HER = Bosnia and Herzegovina; CRO = Croatia; LEB = Lebanon; LUX = Luxembourg; MONT = Montenegro; NETH = the Netherlands; SLO = Slovenia; SWITZ = Switzerland; U.S. = United States; U.K. = United Kingdom.

of regions by number. Consequently, rather than simply extrapolating presbyopia prevalence age profiles from the 11 meta-analyzed regions to the 10 regions without data, we modelled the published epidemiologic data using known accommodation characteristics,[35] amplitude of accommodation profiles,[30−33] and myopia prevalence.[34] Paucity of data and poor coverage are common problems, often making mathematical modelling necessary for global estimates and projections.[29] Our model closely approximates the epidemiologic evidence across the 11 meta-analyzed regions (Fig S2, available at www.aaojournal.org) and, in the absence of numerous additional epidemiologic studies, provides a reasonable way to project estimates across all countries and forward into the future.

The model we devised as the best description of published studies of presbyopia spectacle-correction coverage suggests that at the country level, development and health expenditure improve outcomes, whereas inequality worsens outcomes. Development was represented by HDI, an aggregated index of achievement in health (life expectancy at birth), education (expected years of schooling), and wealth (gross national income per capita). Inequality was represented by the Gini coefficient, a statistical measure of wealth distribution within countries. Specific programs targeting presbyopia spectacle correction are likely to have local and perhaps even national effects, but in our inter-country comparisons, these 3 factors best explained the variation.

Bourne et al[43] recently published an estimate that 1097.4 million people (80% uncertainty interval, 581.1−1686.5 million people) globally had VI as a result of uncorrected presbyopia. The major difference in methodology was that they directly analyzed near VI using a different statistical approach, compared with our approach of modelling presbyopia, then modelling correction rates, then combining these to estimate VI resulting from uncorrected presbyopia. Although our method has the potential to collect cumulative errors, the data on which it is based allow better capture of age-, ethnic-, and place-related differences. We also believe our modelling approach has advantages in preserving these differences in estimates in countries without primary data. Even with these significant methodologic differences, our 95% CI (686−960 million) sits entirely within their 80% uncertainty interval (581−1686 million).

Our study design has some potential limitations. The first is the spread of primary evidence around the world: there could be location and ethnicity effects that have not been detected in this analysis. We mitigated against this using the modelling techniques described. The second limitation is that we did not account for hyperopia in our modelling. We took account of the reduced accommodative needs of people with low to moderate myopia, but did not account for the increased accommodative needs of people with hyperopia. Our reasons were that the evidence describing the prevalence of hyperopia is far more limited than the myopia evidence, hyperopia evidence is more variable in terms of definition, and the evidence that does exist suggests hyperopia prevalence is less variable than myopia between countries and over time. The combination of these reasons meant that we dealt with the effect of hyperopia via adjusting our model with a constant rather than calculating the cumulative probability effects of hyperopia causing near VI in the absence of optical correction. The third limitation is that our estimates of refractive correction rates are reliant on the accuracy of country-level HDI, Gini coefficient, and health expenditure data. These data tend to be less reliable in low-income countries where sampling is sometimes incomplete. The fourth limitation is that the nature of our sequential methodology—modelling presbyopia based on myopia estimates and amplitude of accommodation evidence, then modelling correction rates, then combining these to estimate VI resulting from uncorrected presbyopia—means that errors can be cumulative.

Distance VI from uncorrected refractive error is a widespread and concerning problem, recently estimated to affect 123.7 million people globally.[44] However, we estimate that near VI resulting from people with presbyopia lacking adequate vision correction affects more than 6 times that number: 826 million people globally. Additionally, VI resulting from inadequate optical correction has been shown to have similar quality-of-life impacts regardless of whether it is at near only or distance only.[45] Although we predict that presbyopia prevalence will moderate in future because of increasing myopia prevalence, uncorrected presbyopia currently is the most prevalent cause of VI globally and will remain so over the forecast period. Vision impairment resulting from uncorrected presbyopia places significant productivity and quality-of-life burden on the poorest communities (rural people in the least developed and least equitable countries).[46] The relative ease and low cost of correcting presbyopia provides an argument for health policy focus on near-vision correction.

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Abbreviations and Acronyms:
CI = confidence interval; **D** = diopter; **GBD** = global burden of disease; **HDI** = Human Development Index; **HE** = health expenditure; **US$** = United States dollars; **VI** = vision impairment.

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