Myopia is a major public health concern in Asia, especially in urban areas, such as Japan, Taiwan, Hong Kong, and Singapore.1–4 The prevalence of myopia in middle-aged to elderly adults is as high as 19% in Taiwan,1 23% in China,2 39% in Singapore,3 and 42% in Japan.4 Myopia is a huge public health problem and the economic burden of myopia is tremendous.5–7 The global productivity lost due to uncorrected visual impairment is estimated to be $121.4 billion international dollars (equivalent to USD$91.3 billion),8 and the global costs of facilities and personnel for establishing refractive care services are USD$20 billion.9 However, these estimates do not reflect the burden at the regional level, especially in Asian urban areas where myopia has reached an epidemic proportion.1–3 Furthermore, although refractive correction is normally an elective procedure, few studies have addressed its economic importance to refractive services. A better understanding of the costs of refractive examination and treatments, which represent a burden for patients and their families, is important for developing public policies and interventions to prevent patients from developing high myopia and associated visual impairment.

Our study aimed to evaluate the economic cost of myopia in a consecutive sample of adult Singaporeans aged 40 years or older in a population-based study and to estimate the annual costs for the country using age-specific prevalence data.

Materials and Methods

Study Population

Data from this ancillary study were collected from the Singapore Chinese Eye Study (SCES), a cross-sectional population-based study of Chinese Singaporeans older than 40 years, and the study procedures have been described elsewhere.11–13 In this ancillary study, 125 participants who had myopia (defined below) were consecutively recruited to participate in...
Data were collected between June 2011 and October 2011, and we asked about estimates of costs of eye care directly relevant to myopia in the preceding 12 months. The study was conducted in accordance with the Declaration of Helsinki. Ethics approval was obtained from the Singapore Eye Research Institute Institutional Review Board.

Clinical Measurements

Refration was measured using an autorefractor (Canon RK-5 Auto Ref-Keratometer; Canon, Inc., Ltd., Tokyo, Japan). Final refraction was determined using subjective refraction by trained and certified study optometrists. A trial frame was placed and adjusted on the subject’s face. Autorefraction readings were used as the starting point, and refinement of sphere, cylinder, and axis was performed until best-corrected visual acuity was obtained. The refractive error was estimated using standardized subjective refraction techniques. We used the worse myopic eye data for our primary analysis. Spherical equivalent (SE) was defined as sphere plus half cylinder. Low myopia was defined as SE $\leq 1.0$ diopter (D), mild/moderate myopia as SE $2.0 \leq 5.9$ D, and high myopia SE $\geq 6.0$ D. Participants who had a best-corrected visual acuity of two lines or more (or less) than presenting visual acuity were considered to have undercorrected or uncorrected myopia.

Health Expenditure on Myopia Questionnaire

The HEM questionnaire was designed to assess the health expenditure on myopia. First, the interview, which averaged 5 minutes in length, began with questions on the cost of the last pair of glasses purchased and monthly cost of contact lenses and solutions for seeing distance (see Supplementary Material). We also assessed the frequency and age of onset of wearing glasses or contact lenses. Second, we assessed the costs of optical or optometry services during the past 12 months. We asked the participants how many times during the past 1 year they had received care from an optometrist or optician for myopia, and the costs and mode of transportation (e.g., taxi, bus, underground train system, or private car) for each visit. Third, the participants were then asked whether they had undergone laser refractive surgery and, if so, the costs (including payments made by other parties and insurance on the participant’s behalf) and the mode of transportation for each visit. Fourth, the participants were asked whether they had visited outpatient clinic for complications related to contact lenses or laser refractive surgery and, if so, the costs (including payments made by other parties and insurance on the participant’s behalf) and the mode of transportation for each visit. Finally, the participants were asked whether they had received eye care by an eye specialist for complications related to pathologic myopia (e.g., choroidal neovascularization) and, if so, the costs (including payments made by other parties and insurance on the participant’s behalf) and the mode of transportation for each visit.

Statistical Analyses

Calculating Costs. The overall direct health care costs for each participant were calculated. These included (1) costs of spectacles, (2) annual costs of contact lenses and solutions, (3) annual costs of optician or optometry visits, (4) costs of laser refractive surgery, (5) costs due to complications of laser refractive surgery, (6) costs due to pathologic changes in high myopia, and (7) total annual transport costs (twice the cost of the single journey based on the mode of transportation). Estimate of transport costs was made as follows: public bus or
Cost of Myopia in Singapore

**Table 2. Cost of Myopia Correction in Singapore**

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>No. of Singapore Residents in 2011</th>
<th>Prevalence of Myopia, %</th>
<th>Source of Data for the Prevalence of Myopia</th>
<th>No. of Myopes</th>
<th>Annual Cost per Myope</th>
<th>Total Annual Cost, in SGD</th>
<th>Total Annual Cost, in USD, 1USD = 1.27SGD</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–4</td>
<td>1,272,140</td>
<td>10</td>
<td>STARS*</td>
<td>18,830</td>
<td>100</td>
<td>1,883,000</td>
<td>1,482,677</td>
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<tr>
<td>5–9</td>
<td>2,080,100</td>
<td>30</td>
<td>Tan et al.†</td>
<td>62,430</td>
<td>222</td>
<td>13,859,460</td>
<td>10,912,961</td>
</tr>
<tr>
<td>10–14</td>
<td>2,405,500</td>
<td>60</td>
<td>SCORM follow-up (unpublished)</td>
<td>144,300</td>
<td>222</td>
<td>32,034,600</td>
<td>25,224,094</td>
</tr>
<tr>
<td>15–19</td>
<td>2,608,800</td>
<td>80</td>
<td>Quek et al.†</td>
<td>208,640</td>
<td>222</td>
<td>46,318,080</td>
<td>36,470,929</td>
</tr>
<tr>
<td>20–24</td>
<td>2,555,000</td>
<td>80</td>
<td>Saw et al. IOVS 2012; J3: ARVO E-Abstract 2301</td>
<td>204,000</td>
<td>222</td>
<td>45,288,000</td>
<td>35,659,843</td>
</tr>
<tr>
<td>25–29</td>
<td>2,626,600</td>
<td>90</td>
<td>SP2 (unpublished)</td>
<td>236,340</td>
<td>222</td>
<td>52,467,480</td>
<td>41,312,976</td>
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<tr>
<td>30–34</td>
<td>2,975,000</td>
<td>90</td>
<td>SP2 (unpublished)</td>
<td>267,750</td>
<td>222</td>
<td>59,440,500</td>
<td>46,803,543</td>
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<tr>
<td>35–39</td>
<td>3,162,200</td>
<td>90</td>
<td>SP2 (unpublished)</td>
<td>284,580</td>
<td>222</td>
<td>63,176,760</td>
<td>49,745,480</td>
</tr>
<tr>
<td>40–44</td>
<td>3,066,000</td>
<td>45</td>
<td>SEED†</td>
<td>137,970</td>
<td>952</td>
<td>131,347,440</td>
<td>103,423,181</td>
</tr>
<tr>
<td>45–49</td>
<td>3,240,000</td>
<td>45</td>
<td>SEED†</td>
<td>145,800</td>
<td>952</td>
<td>138,801,600</td>
<td>109,292,598</td>
</tr>
<tr>
<td>50–54</td>
<td>3,081,100</td>
<td>35</td>
<td>SEED†</td>
<td>107,855</td>
<td>125</td>
<td>133,284,060</td>
<td>104,948,079</td>
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<td>55–59</td>
<td>2,670,100</td>
<td>35</td>
<td>SEED†</td>
<td>91,245</td>
<td>125</td>
<td>112,778,820</td>
<td>88,802,220</td>
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<tr>
<td>60–64</td>
<td>2,082,100</td>
<td>30</td>
<td>SEED†</td>
<td>62,460</td>
<td>765</td>
<td>47,656,980</td>
<td>37,525,181</td>
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<td>65–69</td>
<td>1,112,400</td>
<td>30</td>
<td>SEED†</td>
<td>55,720</td>
<td>765</td>
<td>25,728,360</td>
<td>20,258,551</td>
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<tr>
<td>70–74</td>
<td>100,000</td>
<td>30</td>
<td>SEED†</td>
<td>30,000</td>
<td>765</td>
<td>22,890,000</td>
<td>18,023,622</td>
</tr>
<tr>
<td>75–79</td>
<td>66,900</td>
<td>30</td>
<td>SEED†</td>
<td>20,070</td>
<td>765</td>
<td>15,313,410</td>
<td>12,057,803</td>
</tr>
<tr>
<td>80+</td>
<td>75,300</td>
<td>30</td>
<td>SEED†</td>
<td>21,990</td>
<td>763</td>
<td>16,778,370</td>
<td>13,211,315</td>
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<tr>
<td>Total</td>
<td>3,789,200</td>
<td></td>
<td></td>
<td>2,077,950</td>
<td></td>
<td>959,046,920</td>
<td>755,155,055</td>
</tr>
</tbody>
</table>

* Population-based prevalence data from STARS (Strabismus, Amblyopia, and Refractive Error study of preschool Singapore children), SCORM, SP2 (Singapore Prospective Study Program), and SEED (Singapore Epidemiology of Eye Disease Study).
† Annual costs per myope in teenagers and young adults (aged <40 years) from SCORM were derived from Lim et al. Annual costs for adults aged 40 years and older were derived from the current study.

underground train, Singapore dollar (SGD) $1.00; taxi or car, SGD$10.00.

**Costs Per Year for the Whole Population.** To calculate the total direct health care costs for Singapore, we carried out a burden-of-disease evaluation. We extrapolated the sample costs to population size by multiplying the per-patient costs by national prevalence weights from 0 to 80 years. The annual population cost of myopia was estimated as the costs per myopic individual multiplied by prevalence weights, by population size. To estimate the costs for the whole population, we used the cost data for adults from this study as well as the cost data for older children and young adults in the Singapore Cohort of the Risk factors for Myopia (SCORM) teenager study. Statistical analyses were performed using standard statistical software (Statistical Package for Social Sciences, SPSS V16; SPSS, Inc., Chicago, IL). All costs were converted to US dollars using the 2011 exchange rate of USD$1 = SGD$1.27.

**Lifetime Per Capita Costs.** According to the multivariate regression model (see results below), the total cost of myopia was associated only with age at initial diagnosis: the longer the duration, the higher the costs of myopia. Therefore, weighted average per capita costs were computed based on the assumed linear relationship between costs and duration of having myopia (the intercept of the regression line was SGD$294.9, and the beta coefficient was 15.8). Costs were tabulated from 0 to 80 years’ duration. Costs were inversely discounted to baseline year (0 year’s duration) to reflect the fact that a dollar today is worth less than a dollar in the past. A discount rate of 3% was used as recommended by the Panel on Cost-effectiveness in Health and Medicine.

**RESULTS**

A total of 125 subjects were consecutively approached and 113 (response rate: 90.4%) provided valid cost data from the questionnaires. There were no significant differences in age and sex between the responders and nonresponders. Of the 113 responders, the mean age was 52.6 ± 7.8 years and 37 (32.7%) were males. The subjects could be divided into 3 age groups: 40 to 49 (32.7%) did not visit an optometrist in the past year. The subjects could be divided into 3 age groups: 40 to 49 (32.7%) did not visit an optometrist in the past year.

Thirty-two (29.2%) wore monthly disposables, eight (33.3%) wore weekly disposables, eight (33.3%) wore daily disposables, one (4.2%) wore weekly disposables, eight (33.3%) wore monthly disposables, and seven (29.2%) wore permanent contact lenses.

Thirteen (11.5%) wore contact lenses on a daily basis, 3 (2.7%) on an occasional basis, and 89 (78.8%) never wore contact lenses. Among those who used contact lenses, regularly, 8 (7.1%) on an occasional basis, and 89 (78.8%) never wore contact lenses. Among those who used contact lenses, 8 (7.1%) on an occasional basis, and 89 (78.8%) never wore contact lenses.

A total of 103 subjects (90.3%) reported costs associated with the use of spectacles, and among these, 84 subjects reported constant use (on a daily basis) of spectacles, 8 subjects on regular use (several times per week) and 10 subjects on occasional use (several times per month). The mean age at onset of wearing spectacles was 17. 6 ± 9.5 years and the mean cost per pair of spectacles was SGD$393.3 ± 292.6 or USD$267.2 ± 230.2 (Table 1). A total of 102 subjects provided data on the time of last spectacle change, which occurred less than 6 months earlier in 19 subjects (8.8%), 6 to 12 months earlier in 18 subjects (17.7%), 12 to 24 months earlier in 18 subjects (17.7%), and more than 24 months earlier in 57 subjects (55.9%). There was no significant association between length of time since the last change of spectacles and educational level (chi-square test, P = 0.93).

The cost of contact lenses in a typical month was SGD$9.3 ± 7.8 or USD$7.3 ± 6.6. A total of 24 persons (21.2%) with a mean age of 53.4 years (SD = 7.7) wore contact lenses. Thirty-one (11.5%) wore contact lenses on a daily basis, 5 (2.7%) regularly, 8 (7.1%) on an occasional basis, and 89 (78.8%) never used contact lenses. Among those who used contact lenses, eight (33.3%) wore weekly disposables, eight (33.3%) wore monthly disposables, and seven (29.2%) wore permanent contact lenses.

Forty-one subjects (36.3%) used optometry and optical services in the past year, 37 (90.2%) used the service once and 4 (9.8%) used the services twice in the past year. Seventy-two (63.7%) did not visit an optometrist in the past year. The mean cost of an optometrist visit was SGD$123.8 ± 272.6, or USD$97.5 ± 214.6.
Seven subjects (6.2%) had undergone LASIK surgery in the past 10 years and the mean cost of LASIK was SGD$4885.7 ± 1599.4 or USD$3847.0 ± 1259.4. Three reported costs related to complications (i.e., eye infection) caused by the use of contact lenses or LASIK surgery, and the average cost was SGD$33.3 ± 26.2 or USD$26.2 ± 45.4. One subject reported cost of complications related to pathologic myopia (i.e., retinal hole) and the treatment cost was SGD$1000 or USD$787.4.

The total cost of myopia for the whole Singapore population was SGD$959.0 million or USD$755.2 million (Table 2). In a multivariate regression model, the total cost was not significantly associated with age, sex, spherical equivalent, education, and income level, but the total cost increased with younger age of onset of wearing spectacles (P = 0.03) (Table 3). The lifetime cost of myopia increased from SGD$295 (USD$232) for those with a 0 year’s duration to SGD$21,616 (USD$17,020) for those with 80 years’ duration. The Figure demonstrates the cumulative lifetime per capita costs by duration of disease.

**DISCUSSION**

Our study documented the economic costs of myopia in an urban Asian population with one of the highest prevalences of myopia. We showed that the annual direct costs of myopia per person was SGD$900 (USD$709). This estimate translates into an annual economic burden of SGD$959 (USD$755) million in Singapore, considering the population of Singapore permanent residents is 3.8 million.14 If the annual costs per person were similar across all the 1895 million urban populations living in Asia, the economic burden associated with myopic correction would reach SGD$417 (USD$328) billion in urban Asia. Thus, myopia is an important and often underestimated public health problem with a great economic burden.

Health economic analyses in the United States and Australia have consistently shown that the economic burden of refractive correction far exceeded those from age-related macular degeneration, primary open-angle glaucoma, and diabetic retinopathy, and was only secondary to the medical costs of age-related cataract.17-19 Given the high prevalence of myopia (approximately 30% in adults) in Singapore,20,21 the direct medical cost of myopic correction (USD$755 million) was higher than the costs of Parkinson’s disease (PD) (prevalence: 0.3%; cost: USD$23–41 million),22 chronic obstructive pulmonary disease (prevalence: 3.5%; cost: USD$9 million),23 and acute primary angle closure glaucoma (prevalence: 0.001%; cost: USD$0.2–0.3 million).24 Myopia has been misconstrued to be a benign ocular disorder. The economic burden of refractive correction is tremendous in our comparison with other prevalent chronic eye and medical conditions. Thus, myopia may warrant more attention in the international and national agendas.

As the economic costs of myopia are high, efforts and resources could be channeled toward the prevention of myopia and rapid progression of myopia to high myopia and associated visually disabling ocular complications. Interventions, such as outdoor programs integrated within school curriculums (Saw, et al. IOVS 2012;53:ARVO EAbstract 2301), atropine eye drops, or new lens design (e.g., multifocal or orthokeratology), may help slow myopia progression and reduce pathologic myopia morbidities. The cost-effectiveness of these interventions needs to be assessed.

The most significant cost domain is refractive correction (i.e., optometry visits, spectacles, and/or contact lenses), which accounted for 65.2% of the total costs. There was a variation of spectacle costs. Although the costs may be high, as expensive spectacles may be purchased for cosmetic reasons, there may be other individuals who cannot afford even low-cost spectacles, and thus refractive error may not be fully corrected. The annual costs of contact lenses (SGD$111.6 ± 446.4, or USD$87.6 ± 351.6) were lower than spectacles (SGD$359.3 ± 292.3 or USD$267.2 ± 230.2), but 100% of those who wear contact lenses retained a pair of spectacles. Contact lenses thus drive up the costs of refractive correction compared with spectacles wear only.
Our estimates in Singaporean adults (SGD$587 or USD$455 per patient per year) is significantly higher than in Singaporean children aged 7 to 9 years (SGD$222 or USD$175 per patient per year) who participated in a similar health expenditure questionnaire survey.13 Adults are more likely to undergo LASIK, wear contact lenses, or develop myopia-related ocular complications. In addition, the higher costs among adults may reflect a greater level of autonomy in health care expenditure and higher willingness to pay. Our estimate is also higher than adults living in the United States. Using private insurance and Medicare claims data, Rein and colleagues6 showed that the direct costs of refractive errors (including myopia, hyperopia, and astigmatism) for basic refractive correction was USD$199.93 in adults 40 years or older living in the United States. It should be borne in mind that the data from our study and Rein and colleagues6 study may not be directly comparable, as the former were based on individual data, whereas the latter used a societal perspective. More importantly, Rein and colleagues6 assumed that each myopic individual paid for a pair of only basic spectacles (and/or basic contact lenses) for refractive correction. This figure may not be accurate, as not all individuals purchased basic spectacles and some may have purchased more expensive spectacles.

Another important cost domain is laser refractive surgery, performed at an annual number of 2512 cases in Singapore’s major hospitals in calendar year 2011.25 Refractive surgery is now the second most common surgical procedure after cataract surgery.26 The direct medical costs of laser refractive surgery were SGD$4891 per patient, seven times higher than the costs of refractive correction. Based on the assumption that patients who have undergone laser refractive surgery do not have to pay for refractive correction, Javitt and Chiang27 showed that laser photorefractive keratectomy (USD2000 for each eye) was financially equivalent to wearing daily-wear soft contact lenses for 10 years in the United States. In our cohort, nevertheless, 28.6% (2/7) of the LASIK patients still had annual expenditure on spectacles for their distant vision.28 Other cost domains included management of myopia-related pathologies (e.g., staphyloma, retinal holes, and choroidal neovascularization). Pathologic myopia has emerged as a leading cause of blindness in many Asian countries and contributes significantly to health care costs.27 The costs of pathologic myopia from our cohort were considerably high, at SGD$1010 per patient. However, our study is limited by a small sample size and low prevalence of pathologic myopia complications.

Our multivariate regression model showed that higher socioeconomic status (e.g., higher education and income level) was not associated with higher expenditure on myopia, suggesting a lack of association between income elasticity and demand for myopia correction. The younger age of onset of wearing glasses was the only significant factor that was associated with increased costs. This is expected, as adults with younger age of onset of wearing glasses have a longer duration of disease, and, thus, longer duration of treatment, such as changing the spectacle prescription on a regular basis.

The strength of our study is the availability of detailed cost data collected from individual patients. Nevertheless, our results should be interpreted with caution for the following reasons. First, we merely sought to model health care costs directly linked to refractive correction and pathologic myopia, and did not include costs for other potentially blinding ocular complications, such as glaucoma, which may be linked to myopia. For example, given the high risk of developing open-angle glaucoma in myopic adults, an annual eye examination may be needed for them, and this would be an additional source of cost not captured in our questionnaire. There will also be difficulty in attributing the precise contribution of myopia to its potential ocular complications (including glaucoma and cataract) for each individual. Many genetic and environmental conditions can cause glaucoma and cataract, and a questionnaire survey is unlikely to disentangle these effects. An economic simulation model may be more suitable to carry out mathematical experiments that quantify the cost of ocular complications associated with myopia. Second, our results could not be used to forecast the likely health burden of myopia in the near future. Although we feel that our data are representative of the current economic burden of myopia in the general population aged 40 years or older, our findings may not be generalizable to younger adults who have higher myopia prevalence rates because of the cohort effect, are more likely to undergo surgical correction for refractive errors, and their preferences and choices for refractive correction may be very different from those older than 40 years in whom presbyopia is also a problem.

Another limitation is that the costs reported by patients may have been biased due to failure in recalling certain expenditures and/or frequency of eye care. This recall bias may lead to an under- or overestimation of patient costs. Although the use of health insurance claims data is an alternative approach for estimating costs, that approach would have been inappropriate for measuring costs of myopia based on subjective perspectives of patients. Also, our study may be subject to nonresponse bias, as nonresponders may have different cost profiles compared with responders in our study. In addition, there is a lack of indirect costs (e.g., lost workdays for treatment for LASIK surgery or treatment for pathologic myopia, caregiver costs for elderly with blindness or visual impairment due to pathologic myopia) related to basic refractive correction and management of myopia-related complications. Nevertheless, our data provide valuable information on the economic burden of myopia in urban Asia. Finally, our study was limited by the lack of generalizability: the cost of optometry service varies greatly by region, and thus our cost estimation cannot be generalized to other regions, especially to third-world countries and rural areas.

In summary, we show that the total annual cost of myopia in Singapore is SGD$959 (USD$755) million. The costs of myopia are associated with substantial out-of-pocket expenditure, causing a considerable burden for patients and their families. The public health and economic impact of refractive correction is extensive and comparable with other major chronic diseases. The prevalence of myopia is much higher in the younger adult population and because of the cohort effect, it is estimated that the overall prevalence of myopia in older adults will also increase in the next few decades. Therefore, these data may have significantly underestimated the future costs of myopia management.

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References


