Glaucoma is the leading cause of irreversible blindness in the world. Primary open angle glaucoma (POAG) has been reported to be the predominant type of glaucoma among African-derived populations and white populations, while primary angle closure glaucoma (PACG) appears to be more common in East Asian populations, such as Mongolian, Singaporean, and Chinese. Foster and Johnson estimated that PACG is approximately 10 times more visually destructive than POAG in China.

Short eye, shallow anterior chamber depth (ACD), and thickening lens have been identified as biometric characteristics for angle closure. In contrast to these biometric features, myopic eyes tend to have deeper ACD, larger anterior chamber volumes, as well as longer axial lengths. This suggests that myopia is associated with decreased risk of developing PACG.

The prevalence of myopia has been increased over the past few decades, especially in East Asians. Among Singaporean adults aged over 40 years, the overall prevalence of myopia was reported to be 38.7%. Such a trend was even prominent in the younger generations. In the sequential nationwide surveys conducted in Taiwan, the prevalence of myopia among the teenagers between 16 and 18 years has increased from 7.4% in 1983 to 84% in 2000. In addition, the prevalence of myopia in freshmen at National Taiwan University reached 91.3% in 2005. Whether the increasing prevalence of myopia would lead a commensurate reduction in the prevalence of PACG in the East Asian population remains unclear. To the best of our knowledge, no studies have been performed to examine the impact of increased rates of myopia on the prevalence of angle closure in the population perspective. The aim of this paper is to examine this relationship using a simulation study based on data collected in the Liwan Eye Study, a population-based study conducted in urban China.

**METHODS**

Ethical approval for this study was obtained from the Ethics Committee of the Zhongshan Ophthalmic Center, and approval was granted by the Research Governance Committee of Moorfields Eye Hospital and Liwan District government. All subjects were treated in accordance with the Declaration of Helsinki. Written informed consent was obtained from all participants after the nature of the study was explicated.

Study procedures regarding field examinations have been described elsewhere in detail. In brief, by using the cluster random sampling method, 1864 subjects aged 50 years and older were enrolled from Liwan District, Guangzhou, Guangdong Province. All the examinations of the 1405 participants were performed between September 2003 and February 2004. Nontycloplegic refraction was measured using a handheld
autorefractor (ARK-30; Nidek Corp., Gamagori, Japan). Eight refraction values with a machine-calculated confidence index were produced by the autorefractor. An error was recorded by the examiner if the handheld autorefractor failed to give valid readings.

Gonioscopy was performed using a Goldmann-type, one-mirror lens (Haag Streit Diagnostics, Bern, Switzerland) before other biometric measurement so that the observation of the examiner would not be affected by the biometry. In detail, gonioscopy was performed by an experienced ophthalmologist (MH) at ×25 magnification with low ambient illumination.

The overall angle status of each subject was classified as occludable, nonoccludable. In epidemiologic studies, occludable anterior chamber (AC) is synonymous with narrow angle and suspect primary angle closure (PAC) and is usually considered as a predictive index of angle closure.

The distance from anterior corneal epithelial surface to the anterior lens capsule, was measured before pharmacologic dilation of the pupils using A-mode ultrasound (Echoscan US1800; Nidek Corp.). The best trace from 10 individual measurements for each parameter was taken. The records with greatest variation were deleted when the standard deviation was greater than 0.13 mm, and the measurements were repeated. The ACD records obtained from this measurement included the corneal thickness according to the operation protocol.

All data in this study were presented for the right phakic eyes only, and spherical equivalent (SE, sphere + 1/2 cylinder) data from autorefraction were used for analysis. Myopia was defined as SE less than −0.5 diopter (D). Several subcohorts with predefined prevalence of myopia at 10%, 20%, 40%, 50%, and 60% were randomly drawn from the sampling according to the multinomial distribution from the eligible data. The sampling procedure was performed using R software (The R Foundation for Statistical Computing, Vienna, Austria). Fifty subcohorts were drawn for each predefined rate of myopia. Normality was checked with a skewness test. Since the SE and ACD data were not normally distributed, a Kruskal-Wallis test was used for analysis of variance among different groups. A Mann-Whitney U test was applied to analyze the variance of age-specific prevalence of myopia as well as age-specific prevalence of OA. A logistic function model of nonlinear least-squares estimation was fitted to assess the expected relationship between the proportion of OA and ACD and to estimate the age-specific prevalence of OA with different rates of myopia. All data analyses were performed by Stata 12.0 (Stata Corp., College Station, TX, USA).

### Results

The whole study population included a total of 1864 eligible subjects; among them 1405 (75.3%) subjects aged 50 years or older were successfully examined. A total of 245 subjects were excluded, which consisted of subjects with data missing either on refraction (145), ocular biometry (64), or gonioscopy (3), as well as subjects with aphakic or pseudophakic eyes (33). This provided 1160 subjects aged 50 to 91 years eligible for analysis.

Among the 1160 subjects, the mean age was 64.2 ± 9.5 years, and 499 (43.0%) were men. There was no significant difference of mean age between men and women (t-test, P = 0.411).

Table 1 provides the age-specific SE, prevalence of myopia, measurements of ACD, and prevalence of OA. The distribution of SE was skewed (skewness-kurtosis tests, P < 0.001) in this population. The median, first and third quartiles of SE were −0.94 D, and −0.94 D, and −1.06 D, respectively.

The mean ACD in the six myopia cohorts with increasing prevalence were 2.68 mm, 2.70 mm, 2.70 mm, 2.71 mm, 2.72 mm, and 2.74 mm, respectively. In Figure 2, a group of Lowess curves depict the changing trends of age-specific ACD by different myopia cohorts. In each myopia cohort, the mean ACD showed a decreasing trend with age in an approximately linear fashion. With the increase of myopia prevalence, ACD increased in each age group, and OA percentage was predicted to be the lowest in the 60% myopia cohort.

In Figure 2, a group of Lowess curves depict the changing trends of age-specific ACD by different myopia cohorts. In each myopia cohort, the mean ACD showed a decreasing trend with age in an approximately linear fashion. With the increase of myopia prevalence, ACD increased in each age group, and OA percentage was predicted to be the lowest in the 60% myopia cohort.

In Figure 3, a group of Lowess curves depict the changing trends of age-specific ACD by different myopia cohorts. In each myopia cohort, the mean ACD showed a decreasing trend with age in an approximately linear fashion. With the increase of myopia prevalence, ACD increased in each age group, and OA percentage was predicted to be the lowest in the 60% myopia cohort.

Figure 3 illustrates the relationship between OA prevalence and ACD. Anterior chamber depth was divided into six groups from 2.00 mm to 3.20 mm by an interval of 0.20 mm. A category representing ACD greater than 3.20 mm was also included. Figure 3 suggested that OA proportions increased rapidly from approximately 3% to 35% when ACD decreased from 2.60 mm to 2.00 mm. No significant changes in OA...
proportions were observed when ACD was greater than 2.60 mm.

The predictive age-specific rate of OA in different myopia cohorts was illustrated in Figure 4. In each myopia group, the rates of OA increased with age in an approximately linear fashion. The rates of OA increased slightly in each age group with increasing myopia prevalence.

**DISCUSSION**

To our knowledge, this study, to date, provides the first published data predicting the age-specific prevalence of OA with different rates of myopia in elderly Chinese aged 50 years and older based on a cohort from mainland China. In general, this simulation study found a mildly inverse association between the prevalence of myopia and the prevalence of OA, but the impact on the prevalence of angle closure was moderate when the prevalence of myopia increases from 30% to 60%.

As previous studies reported, a shallower ACD has been considered as a risk factor for PACG, and the measurement of ACD has been used as a screening tool for angle closure. Myopia tends to be associated with deep ACD and has been regarded as a protective factor against angle closure. Our research has previously confirmed that there is an inverse association between ACD and SE, and a mean decrease of 0.03 mm ACD per SE diopter was found. Interestingly, although ACD increased with the elevation of myopia rate, the prevalence of OA was found to have changed very moderately across groups, dropping from 11.1% in a 10% myopia group to 9.6% in a 60% myopia group.

There might be several explanations for the current findings. The four-parameter logistic function model of nonlinear least-squares estimation suggested that there is a clear threshold for ACD at around 2.6 mm, and OA is very uncommon when ACD is greater than this threshold. When ACD decreases from 2.6 mm to 2.0 mm, the rate of OA increases rapidly (Fig. 3). Similar observation has also been published by Aung et al. in Mongolian people. In our study, the mean ACDs in different myopia cohorts ranged from 2.64 mm to 2.71 mm, which were all above the threshold, and this might explain the moderate increase of OA rates with the increase of the mean ACDs. Researchers have conducted substantial studies on the relationship between refractive status and angle closure. Some stated that axial myopia is characterized with elongation of the vitreous cavity length (VL) and axial length (AL), but not necessarily ACD. Yong et al. found that among 427 angle-closure cases, a quarter of them manifested myopia, and these myopic angle closure cases tended to have longer AL and VL in comparison with emmetropic and hyperopic angle closure cases. This may explain the phenomenon that although the Chinese population has a much higher prevalence of myopia compared with European populations, they also have a higher prevalence of angle closure.

**TABLE 2.** SE, ACD, and Prevalence of OA in Simulated Myopia Cohorts With Different Prevalences

<table>
<thead>
<tr>
<th>Myopia, %</th>
<th>No.</th>
<th>Age, y</th>
<th>SE, D*</th>
<th>ACD, mm*</th>
<th>AL, mm</th>
<th>LT, mm</th>
<th>AO, %†</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>9,924</td>
<td>63.9 ± 9.3</td>
<td>0.62 (−0.06, 1.37)</td>
<td>2.64 (2.45, 2.88)</td>
<td>23.1 ± 1.01</td>
<td>4.32 ± 0.68</td>
<td>11.1 (10.5–11.8)</td>
</tr>
<tr>
<td>20</td>
<td>10,044</td>
<td>63.9 ± 9.3</td>
<td>0.44 (−0.32, 1.19)</td>
<td>2.66 (2.45, 2.91)</td>
<td>23.2 ± 1.15</td>
<td>4.30 ± 0.68</td>
<td>10.7 (10.1–11.4)</td>
</tr>
<tr>
<td>32.5</td>
<td>1,160</td>
<td>64.2 ± 9.5</td>
<td>0.19 (−0.94, 1.06)</td>
<td>2.67 (2.46, 2.92)</td>
<td>23.3 ± 1.31</td>
<td>4.28 ± 0.68</td>
<td>10.3 (8.65–12.2)</td>
</tr>
<tr>
<td>40</td>
<td>10,029</td>
<td>64.4 ± 9.6</td>
<td>−0.06 (−1.37, 1.00)</td>
<td>2.68 (2.46, 2.93)</td>
<td>23.4 ± 1.36</td>
<td>4.27 ± 0.68</td>
<td>9.88 (9.30–10.5)</td>
</tr>
<tr>
<td>50</td>
<td>10,001</td>
<td>64.4 ± 9.6</td>
<td>−0.50 (−1.94, 0.75)</td>
<td>2.69 (2.46, 2.94)</td>
<td>23.5 ± 1.49</td>
<td>4.25 ± 0.68</td>
<td>9.55 (8.77–9.92)</td>
</tr>
<tr>
<td>60</td>
<td>6,578</td>
<td>64.7 ± 9.7</td>
<td>−0.81 (−2.44, 0.50)</td>
<td>2.71 (2.49, 2.96)</td>
<td>23.6 ± 1.53</td>
<td>4.22 ± 0.67</td>
<td>9.55 (8.85–10.5)</td>
</tr>
</tbody>
</table>

AL, axial length.
*S Spherical equivalent and ACD were presented as median (25th, 75th percentiles).
† Occludable angle was presented as percentage prevalence (95% CI).

**FIGURE 1.** Association of predicted anterior chamber depth (mm) in simulated cohorts with different prevalence of myopia.
ACD is regarded as the distance between the anterior surface of the lens and the posterior surface of cornea along the visual axis, which is determined by the position of the anterior lens surface and the height of the corneal dome. Friedman et al.\(^3\) reported that lens thickness was the most cardinal determinant. When comparing normal controls and the contralateral eyes of acute PAC, only a small difference (4%) was found on relative lens position in Singaporean Chinese. Based on a case-control study in Australian Caucasians, Lowe\(^3\) estimated that lens thickness could explain 35% of the variation in ACD, and the remaining 65% was probably due to a more anteriorly positioned lens. All of these studies suggest that shallow anterior chamber is a risk factor of OA and the subsequent angle closure, regardless of the refractive status of the eye.

“True” ACD is regarded as the distance between the anterior surface of the lens and the posterior surface of cornea along the visual axis, which is determined by the position of the anterior lens surface and the height of the corneal dome. Friedman et al.\(^3\) reported that lens thickness was the most cardinal determinant. When comparing normal controls and the contralateral eyes of acute PAC, only a small difference (4%) was found on relative lens position in Singaporean Chinese. Based on a case-control study in Australian Caucasians, Lowe\(^3\) estimated that lens thickness could explain 35% of the variation in ACD, and the remaining 65% was probably due to a more anteriorly positioned lens. All of these studies suggest that shallow anterior chamber is a risk factor of OA and the subsequent angle closure, regardless of the refractive status of the eye.

Our research has the advantage of being a population-based study with a reasonably large sample size, thus presenting a representative sample of the Chinese population. Given that it is not possible to obtain comparable cohorts with varied rates of myopia, we performed repeated sampling according to the multinomial distribution from the eligible database and acquired the needed data that best simulate the cohorts with various rate of myopia. This may not fully apply to the real-world situation. The distribution of ACD may depend on not only the myopic rates but also the severity of myopia. In this study, we did not attempt to simulate the impact of severity of myopia in terms of degree of diopter because there are too many possibilities and scenarios. On the other hand, certain manifest myopia in older people, such as those 60 years and older, may be attributable to refractive index changes.

How Does Myopia Affect Angle Closure Prevalence?

Our research has the advantage of being a population-based study with a reasonably large sample size, thus presenting a representative sample of the Chinese population. Given that it is not possible to obtain comparable cohorts with varied rates of myopia, we performed repeated sampling according to the multinomial distribution from the eligible database and acquired the needed data that best simulate the cohorts with various rate of myopia. This may not fully apply to the real-world situation. The distribution of ACD may depend on not only the myopic rates but also the severity of myopia. In this study, we did not attempt to simulate the impact of severity of myopia in terms of degree of diopter because there are too many possibilities and scenarios. On the other hand, certain manifest myopia in older people, such as those 60 years and older, may be attributable to refractive index changes.

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**Figure 2.** Lowess curves of anterior chamber depth (mm) as a function of age by sampling cohorts with different myopia prevalence. The actual prevalence of myopia in the Liwan Eye Study was 32.5%.

**Figure 3.** Simulated curve of the association between the prevalence of OA (%) and mean ACD (mm) from 2.00 mm to 3.4 mm, with 0.2-mm interval.
secondary to lens nucleus sclerosis. Therefore, the identified association between ACD and myopic rates may not fully represent the true association in the scenario of purely axial myopia, although as indicated in Table 2, axial length did increase with the myopic rates in the simulation cohorts. Another potential limitation of this study is that the predictive prevalence of OA among different myopia cohorts may be population specific; thus, the conclusion may not be generalizable to different populations. Further research with larger sample sizes and better designs is needed.

In summary, our study is, to our knowledge, the first simulation study on age-specific prevalence of OA by different rates of myopia in the Chinese population. We predict that with the elevated prevalence of myopia, the prevalence of OA would be decreased, but at a very moderate rate of change, even when the myopia rates double from 30% to 60%. We deduce that ACD would override refractive error as a risk factor for OA or angle closure. Primary angle closure glaucoma rates would remain high in the Chinese population even when myopia rates increase substantially, and therefore PACG may deserve the same level of public health attention in the future, even when myopia is getting more common than ever before.

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