Clinical and Experimental Ophthalmology (2002) **30**, 84–93

Original Article

Population-based assessment of refractive error in India: the Andhra Pradesh eye disease study

Rakhi Dandona PhD,[1,2,3] Lalit Dandona MD MPH,[1,2] Marmamula Srinivas BA,[1] Pyda Giridhar PhD,[1] Catherine A McCarty PhD MPH,[3] and Gullapalli N Rao MD[1]

[1]International Centre for Advancement of Rural Eye Care, LV Prasad Eye Institute, and [2]Centre for Social Services, Administrative Staff College of India, Hyderabad, India, and [3]Centre for Eye Research Australia, University of Melbourne, Melbourne, Australia

ABSTRACT

Purpose: To assess the prevalence, distribution, and demographic associations of refractive error in the population of the southern Indian state of Andhra Pradesh.

Methods: From 94 clusters in one urban and three rural areas of Andhra Pradesh, 11 786 persons of all ages were sampled using a stratified, random, cluster, systematic sampling strategy in the Andhra Pradesh Eye Disease Study, a population-based cross-sectional study. A total of 10 293 people underwent an interview and detailed dilated eye examination. Refraction was performed by ophthalmic personnel trained in the study procedures. Objective refraction under cycloplegia was assessed for participants ≤ 15 years of age and subjective refraction for those > 15 years of age. Myopia was defined as spherical equivalent worse than –0.50 D and hyperopia as spherical equivalent worse than +0.50 D.

Results: In the participants ≤ 15 years of age, the prevalence of myopia was 3.19% (95% confidence interval [CI] 2.24–4.13%) and of hyperopia was 62.62% (95% CI 57.10–68.13%). In this age group, myopia increased with increasing age and was more prevalent in the urban study area, and hyperopia prevalence was greater in the participants < 10 years of age. In participants > 15 years of age, the prevalence of myopia was 19.45% (95% CI 17.88–21.02%) and of hyperopia was 8.38% (95% CI 6.91–9.85%). Myopia and hyperopia increased with increasing age. Myopia was more common in males, those with education higher than class 12, those with nuclear cataract, and those living in rural study areas. Hyperopia was more common in females, those with any level of formal education, and those living in the urban area and in the well-off rural study area.

Conclusions: There is significant refractive error in this population. These data on the distribution and associations of refractive error can be useful for the planning of refractive eye-care services.

Key words: children, India, myopia, population-based, refractive error.

INTRODUCTION

In many parts of the world, refractive error is the second largest cause of treatable blindness after cataract,[1–7] in addition to being one of the most common causes of visual impairment.[3–9] Because of increasing realization of the enormous need for correction of refractive error worldwide, it has been considered as one of the priorities in VISION 2020 – The Right to Sight, the recently launched global initiative for the elimination of avoidable blindness.[10–13]

Most of the refractive error can be easily corrected with spectacles, which makes it imperative that effective strategies be developed to eliminate this easily treatable cause of blindness and visual impairment. Reliable data on the prevalence of refractive errors from population-based studies are needed to plan eye-care services to reduce the burden of blindness and visual impairment caused by refractive error.

In the population-based Andhra Pradesh Eye Disease Study (APEDS), we found that the prevalence of refractive error blindness, defined as presenting distance visual acuity worse than 6/60, was 0.30% in the population of the Indian state of Andhra Pradesh.[2] This made refractive error the second most frequent cause of blindness in this population, accounting for 16.3% of the total blindness.[2]

The APEDS was conducted in one urban and three rural areas of Andhra Pradesh.[2,14] From the urban area of APEDS, we have previously reported the prevalence, distribution, and demographic associations of refractive error in the population of Hyderabad.[15] We now report the data on refractive error for all the four areas of APEDS combined.

■ *Correspondence:* Dr Rakhi Dandona, Centre for Social Services, Administrative Staff College of India, Bella Vista, Raj Bhavan Road, Hyderabad 500 082, India. Email: rakhi@asci.org.in

METHODS

Study design

The APEDS was a population-based epidemiology study in four areas representative of the population of the Indian state of Andhra Pradesh. The detailed methodology of APEDS for sampling and clinical examination is reported elsewhere.[2,8,14–16] Description of refractive error assessment in the urban study area of APEDS, Hyderabad, has been reported previously.[15]

A brief description of the sampling strategy of APEDS follows. In the first stage, stratification was performed for the urban–rural distribution of the population of the state by selecting one-quarter of the sample as urban and three-quarters as rural. The urban sample was selected from Hyderabad, which was further stratified by socioeconomic status and religion as described earlier.[2,8,14–16] A total of 2954 subjects of all ages were sampled from 24 clusters in Hyderabad using a multistage sampling procedure.[2,8,14–16] These 24 clusters were chosen by stratified random sampling with equal probability of selection to meet the stratification criteria mentioned. These clusters were then mapped and the number of households and members in each household listed. Every second to fifth household was systematically selected in each cluster to obtain roughly equal numbers of households in each cluster. Approximately half the clusters were randomly assigned to have persons of all ages in the selected households eligible for the study, and the other half to have only those 30 years of age or more eligible for the study to obtain similar numbers of participants in the less than and more than 30-year-old age groups.[2,8,14–16]

The rural sample of APEDS was chosen from West Godavari, Adilabad, and Mahbubnagar districts of the state of Andhra Pradesh. West Godavari represented the relatively 'well-off' rural population whereas Adilabad and Mahabubnagar represented the relatively poor rural population of Andhra Pradesh. The major difference in the rural sampling as compared with the urban sampling was that the rural sample was selected from villages (clusters) stratified by caste as caste is a surrogate measure of socioeconomic status in our rural populations.[2,14] In order to get a sample with a caste distribution similar to that in the population in each of the three rural areas, the villages were stratified according to the two castes with the largest population in each eligible village. This was done to ensure a large enough number of subjects for each selected village. Around 23 to 24 villages were selected in each of the three rural study areas under the four caste strata using stratified random sampling with probability of selection proportionate to size, such that the proportion of each caste in the sample was similar to that in the population in each of the three rural study areas. In each selected village, demarcation of the area was done where the caste selected according to the sampling scheme lived (the different castes mostly live in homogenous clusters in Indian villages). The procedure of mapping the selected villages and the households was similar to the procedures followed in the urban study area. A total of 8832 subjects were sampled from 70 villages (clusters) in the three rural study areas.

Data were collected between July 1997 to May 1998 in West Godavari, June 1998 to March 1999 in Adilabad, and April 1999 to February 2000 in Mahabubnagar. This study was approved by the Ethics Committee of the LV Prasad Eye Institute, Hyderabad, India.

Clinical examination

Clinical examination performed in APEDS has been described in detail elsewhere.[2,8,14–16] The procedures related to refractive error are described here. For subjects ≤ 15 years of age, objective refraction under cycloplegia (cyclopentolate 1% and tropicamide 1%) was attempted using streak retinoscope by optometrists trained in the study procedures. For those > 15 years of age, refraction was attempted on all those who presented with distance and/or near visual acuity worse than 6/6 in either eye. Objective refraction was followed by subjective refraction. For subjects with distance and near visual acuity of 6/6 or better with current refractive correction, this correction was considered as the refractive error. Subjects who had distance and near visual acuity of 6/6 or better without any refractive correction were considered as not having refractive error. Nuclear cataract was graded by the ophthalmologist using Lens Opacity Classification System (LOCS) III.[17]

Statistical analyses

Data were analysed separately for subjects ≤ 15 years of age as objective refraction under cycloplegia was considered for analyses for this age group. For subjects > 15 years of age subjective refraction was considered for analysis. Data were analysed for the worse eye (eye with higher refractive error) by using spherical equivalent (SE). This was calculated by adding half of the cylindrical value to the spherical value of the refractive error. The eye with the natural crystalline lens was considered for analysis for the subjects who had aphakia or pseudophakia in one eye. Subjects who had aphakia or pseudophakia in both eyes were excluded from the analysis.

Myopia was defined as SE worse than –0.50 D and hyperopia as SE worse than +0.50 D. In subjects with antimetropia (myopia in one eye and hyperopia in the other eye) the eye with the higher refractive error (in terms of magnitude) was classified as the worse eye. Further analysis based on definition of refractive error using cut-off value of – 1.00 D was also performed.

Data were analysed for all the four study areas combined. The demographic associations of refractive error were assessed with age, sex, education, socioeconomic status and study area. Association of myopia was also assessed with nuclear cataract for subjects > 15 years of age. Education was not considered in the analysis for subjects ≤ 15 years of age. These associations were assessed by univariate analyses followed by multiple logistic regression. The effect of each category of a multicategorical variable was assessed by keeping the first or the last category as the reference. All the variables were introduced in the model simultaneously and none of the variables were optimized. Likely interactions between age and nuclear cataract, sex and nuclear cataract, and education and socioeconomic status were assessed in a separate multiple logistic model where ever applicable, simultaneously with all the variables. In the logistic models, subjects with myopia were compared to subjects with emmetropia and hyperopia, and subjects with hyperopia were compared to subjects with emmetropia and myopia. Analyses were performed using SPSS software (SPSS for Windows 1999; SPSS, Chicago, IL, USA). The estimates were adjusted for the age, sex and urban–rural distribution of the population of India for the year 2000,[18,19] including the urban data reported previously.[15] Based on the rates in each cluster, the design effect for the cluster sampling strategy was calculated for the prevalence estimates,[20] and the 95% confidence intervals (CI) adjusted accordingly.

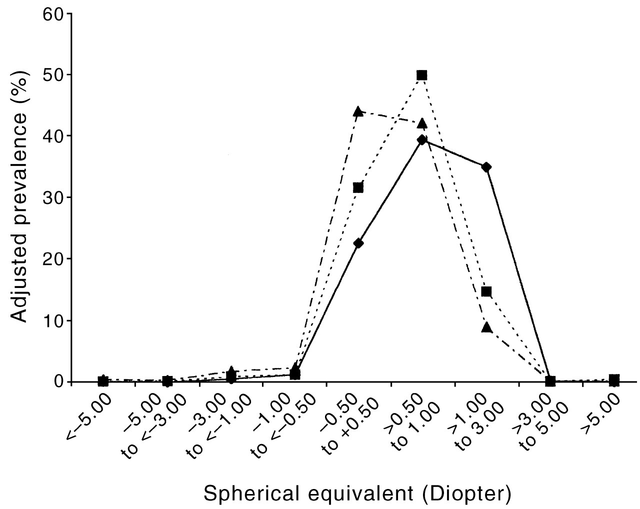

Figure 1. Sex and urban–rural distribution adjusted prevalence of spherical equivalent under cycloplegia based on age in subjects ≤ 15 years of age for all the four study areas combined. (◆) 0–5 years; (■) 6–9 years; (▲) 10–15 years.

RESULTS

Of the 11 786 subjects sampled for APEDS, 10 293 (87.3%) participated in the study. Of these 10 293 participants, 7771 (75.5%) subjects were in the three rural study areas; 2859 (27.8%) were ≤ 15 years of age, and 5438 (52.8%) were female. Data on refractive error were analysed for 9882 (96.0%) subjects (excluding 327 subjects on whom data were not available and 84 subjects with aphakia/pseudophakia in both eyes). Data on refractive error from the urban segment of APEDS have been reported earlier.[15]

Subjects ≤ 15 years of age

Of the 2859 subjects ≤ 15 years of age, data on objective refraction under cycloplegia were available for 2603 (91%) subjects. Of these 2603 subjects, 1597 (61.3%) were less than 10 years of age, and 1283 (49.3%) were female. Figure 1 shows the prevalence of the different categories of SE for 0–5, 6–9 and ≥ 10 years of age, adjusted for the sex and urban–rural distribution. The prevalence estimates of myopia and hyperopia with the different definitions for the three rural study areas and all the four study areas combined are shown in Table 1.

Myopia

Myopia (SE worse than –0.50 D) in the worse eye was present in 81 subjects, a prevalence of 3.19% (95% CI 2.24–4.13%) after adjusting for age, sex and urban–rural distribution. The prevalence of myopia −3.00 D or worse was 0.49% (95% CI 0.21–0.92%) and –5.00 D or worse was 0.27% (95% CI 0.10–0.57%).

Table 2 presents results from the univariate and multiple logistic regression analyses for myopia worse than –0.50 D. Those ≥ 10 years of age were more likely to have myopia. Those living in West Godavari and Adilabad rural areas were less likely to have myopia, but the results for Adilabad were of borderline statistical significance. On combining some categories of the variables to increase the power of the analysis, the odds of having myopia were significantly higher for those living in urban Hyderabad (odds ratio [OR] 1.83; 95% CI 1.12–2.99) as compared with those living in the rural study areas. The results of multiple logistic regression for myopia worse than or equal to −1.00 D were essentially similar to those for worse than –0.50 D analysis (data not shown). The sex-adjusted prevalence of myopia for the different age groups in the four study areas is shown in Fig. 2.

Hyperopia

Hyperopia (SE worse than +0.50 D) in the worse eye was present in 1645 subjects, a prevalence of 62.62% (95% CI 57.01–68.13%) after adjusting for age, sex and urban–rural distribution. The prevalence of hyperopia +3.00 D or worse was 0.37% (95% CI 0.13–0.77%) and +5.00 D or worse was 0.20% (95% CI 0.07–0.47%).

Table 2 presents results from univariate and multiple logistic regression analysis for hyperopia worse than +0.50 D. Those ≤ 10 years of age, and those living in West Godavari and Adilabad were more likely to have hyperopia. Those living in Mahaboobnagar were least likely to have hyperopia. The results of multiple logistic regression for hyperopia worse than +1.00 D were essentially similar to those for worse than +0.50 D analysis except that the

Table 1. Age-sex-adjusted prevalence estimates for the different definitions of myopia and hyperopia

Study area	% prevalence (95% confidence interval; design effect)			
	Myopia > 0.50 D	Myopia ≥ 1.00 D	Hyperopia > 0.50 D	Hyperopia ≥ 1.00 D
Age ≤ 15 years				
West Godavari*	2.41 (0.67–4.16; 1.81)	1.47 (0.40–2.55; 1.11)	77.44 (70.45–84.44; 3.91)	55.05 (44.64–65.46; 6.11)
Adilabad*	2.28 (1.03–3.53; 1.45)	1.26 (0.34–2.19; 1.41)	69.31 (65.15–73.47; 1.68)	37.76 (34.38–41.14; 1.00)
Mahabubnagar*	2.96 (1.43–4.49; 1.44)	1.62 (0.48–2.77; 1.44)	49.06 (40.65–57.46; 4.97)	32.90 (26.22–39.58; 3.55)
All three rural areas combined†	2.54 (1.70–3.38; 1.48)	1.44 (0.85–2.03; 1.28)	64.66 (59.02–70.30; 7.25)	40.75 (35.90–45.59; 5.06)
All four study areas combined‡	3.19 (2.24–4.13; 1.96)	2.03 (1.28–2.78; 1.91)	62.62 (57.10–68.13; 8.81)	40.27 (34.99–45.55; 7.85)
Age > 15 years				
West Godavari*	15.76 (13.16–18.37; 2.47)	14.01 (11.63–16.56; 2.42)	10.39 (8.10–12.68; 2.73)	8.83 (6.85–10.81; 2.35)
Adilabad*	17.79 (15.02–20.57; 2.52)	15.81 (13.25–18.38; 2.35)	5.27 (3.85–6.70; 1.95)	4.33 (3.14–5.52; 1.64)
Mahabubnagar*	23.85 (20.94–26.76; 2.22)	20.76 (18.10–23.42; 2.04)	5.53 (3.88–7.17; 2.45)	3.96 (2.60–5.33; 2.33)
All three rural areas combined†	19.11 (17.26–20.40; 3.19)	16.87 (15.19–18.55; 2.89)	7.08 (5.80–8.35; 3.56)	5.72 (4.61–6.84; 3.29)
All four study areas combined‡	19.45 (17.88–21.02; 2.98)	16.66 (15.25–18.07; 2.72)	8.38 (6.91–9.85; 5.30)	6.96 (5.64–8.28; 5.09)
Age 16–39 years				
West Godavari*	4.48 (3.03–5.94; 1.17)	3.37 (2.23–4.51; 0.94)	2.17 (1.25–3.09; 0.94)	1.89 (1.05–2.72; 0.88)
Adilabad*	5.14 (3.73–6.55; 1.07)	3.48 (2.41–4.56; 0.90)	1.99 (1.22–2.76; 0.79)	1.63 (1.04–2.22; 0.57)
Mahabubnagar*	10.04 (7.76–12.32; 1.31)	7.52 (5.16–9.89; 1.82)	1.22 (0.65–1.78; 0.61)	0.42 (0.01–0.84; 0.90)
All three rural areas combined†	6.46 (5.26–7.67; 1.73)	4.71 (3.66–5.76; 1.77)	1.81 (1.35–2.27; 0.87)	1.34 (0.91–1.76; 0.99)
All four study areas combined‡	8.92 (7.24–10.61; 3.35)	6.56 (5.28–7.83; 2.55)	1.90 (1.48–2.33; 0.92)	1.48 (1.10–1.85; 0.94)
Age ≥ 40 years				
West Godavari*	33.98 (29.95–38.41; 2.17)	31.42 (26.94–35.90; 2.30)	23.66 (19.55–27.76; 2.31)	20.04 (16.58–23.51; 1.85)
Adilabad*	38.22 (34.85–41.59; 1.04)	35.71 (32.51–38.91; 0.96)	10.57 (7.93–13.22; 1.60)	8.70 (6.48–10.91; 1.34)
Mahabubnagar*	46.16 (42.21–50.11; 1.56)	42.15 (38.21–46.09; 1.58)	12.48 (9.46–15.51; 2.08)	9.68 (7.05–12.30; 1.96)
All three rural areas combined†	39.51 (36.87–42.15; 2.08)	36.46 (33.90–39.02; 2.02)	15.80 (13.37–18.21; 3.13)	12.99 (10.89–15.08; 2.77)
All four study areas combined‡	36.54 (33.90–39.18; 2.80)	33.07 (30.43–35.70; 2.93)	18.92 (16.22–21.64; 4.47)	15.90 (13.44–18.36; 4.23)

*Rural study area, age and sex-adjusted prevalence; †prevalence adjusted for age and sex distribution; ‡one urban and three rural study areas combined, data from urban study area reported previously,[15] prevalence adjusted for age, sex and urban–rural distribution.

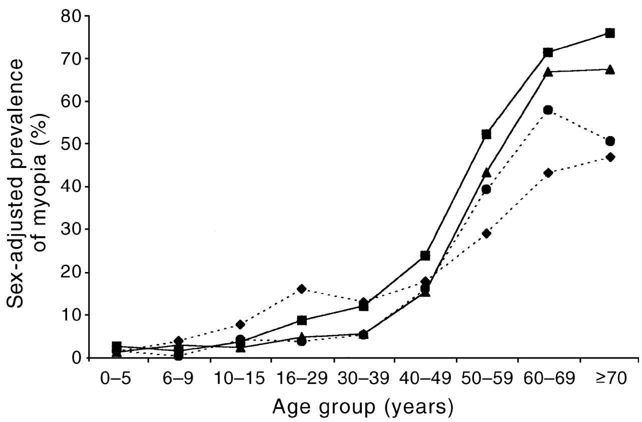

Figure 2. Sex-adjusted prevalence of myopia (worse than −0.50 D) for different age groups in the four study areas. Refractive error under cycloplegia is shown for subjects ≤ 15 years of age and with subjective refraction for subjects > 15 years of age. (◆) Hyderabad; (●) West Godavari; (▲) Adilabad; (■) Mahabubnagar.

subjects living in Adilabad did not have significantly higher odds of having hyperopia (data not shown).The sex-adjusted prevalence of hyperopia for the different age groups in the four study areas is shown in Fig. 3.

Subjects > 15 years of age

Of the 7434 subjects >15 years of age, data on subjective refraction were available for 7276 (97.9%) subjects. Of these 7276 subjects, 3690 (50.7%) were between 16 and 39 years of age and 3958 (54.4%) were female. The prevalence estimates of myopia and hyperopia with different definitions for the three rural study areas and for all the four study areas combined are shown in Table 1. The adjusted prevalence of SE for the study areas is shown in Fig. 4. The age and area adjusted prevalence of SE were essentially similar for males and females for myopia (data not shown); however, for hyperopia, the adjusted prevalence of SE of +0.50 to +1.00 D was 3.7% and 2.5%, and of +1.00 to +3.00 D was 6.3% and 3% for females and males, respectively.

Myopia

Myopia (SE worse than −0.50 D) in the worse eye was present in 1711 subjects, a prevalence of 19.45% (95% CI 17.88–21.02%) adjusted for age, sex and urban–rural distribution. The prevalence of myopia −3.00 D or worse was 9.14% (95% CI 8.05–10.22%) and of −5.00 D or worse was 4.54% (95% CI 3.91–5.16%).

Table 2. Effect of age, sex, socioeconomic status and study area on myopia (worse than –0.50 D) and hyperopia (worse than +0.50 D) for subjects 15 years of age or less

	Total (n = 2603)	Myopia n (%)	Odds ratio for myopia (95% confidence interval)	Hyperopia n (%)	Odds ratio for hyperopia (95% confidence interval)
Age group (years)*					
0–5	793	15 (1.9)	1.00	603 (76.0)	3.34 (2.69–4.14)
6–9	804	19 (2.4)	1.25 (0.63–2.48)	529 (65.8)	1.72 (1.41–2.10)
10–15	1006	47 (4.7)	2.30 (1.27–4.18)	513 (51.0)	1.00
Sex					
Male	1320	38 (2.9)	1.00	837 (63.4)	1.00
Female	1283	43 (3.4)	1.19 (0.76–1.86)	808 (63.0)	0.97 (0.82–1.15)
Socioeconomic status*†					
Extreme lower	396	6 (1.5)	1.00	275 (69.4)	1.00
Lower	1440	42 (2.9)	1.76 (0.74–4.19)	904 (62.8)	0.89 (0.69–1.14)
Middle	634	28 (4.4)	2.21 (0.89–5.50)	374 (59.0)	0.80 (0.60–1.07)
Upper	68	4 (5.9)	2.27 (0.59–8.77)	45 (66.2)	1.23 (0.68–2.22)
Study area*‡					
Hyderabad	600	30 (5.0)	1.00	350 (58.3)	1.00
West Godavari	536	13 (2.4)	0.50 (0.25–0.98)	415 (77.4)	2.84 (2.16–3.75)
Adilabad	792	18 (2.3)	0.53 (0.28–1.00)	549 (69.3)	1.50 (1.17–1.92)
Mahabubnagar	675	20 (3.0)	0.63 (0.34–1.16)	331 (49.0)	0.69 (0.54–0.89)

*$P < 0.05$, chi-square test. †Socioeconomic status defined according to monthly per capita income in rupees: extreme lower ≤ 200 (US $4.5), lower 201–500, middle 501–2000, and upper > 2000; data on socioeconomic status not available for 65 subjects. ‡Hyderabad is urban study area, and West Godavari, Adilabad, and Mahabubnagar are rural study areas. Odds ratios determined with multiple logistic regression.

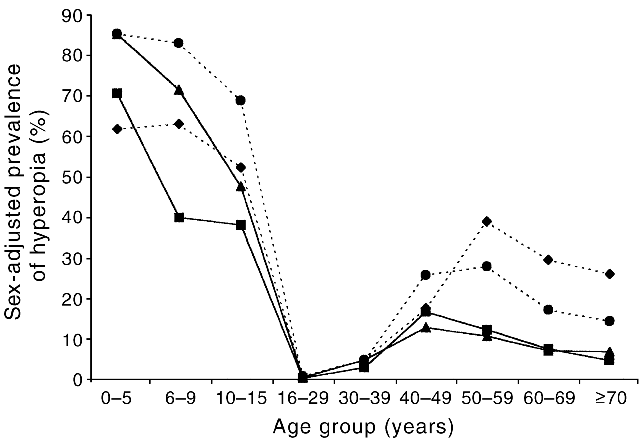

Figure 3. Sex-adjusted prevalence of hyperopia (worse than +0.50 D) for different age groups in the four study areas. Refractive error under cycloplegia is shown for subjects ≤ 15 years of age and with subjective refraction for subjects > 15 years of age. (◆) Hyderabad; (●) West Godavari; (▲) Adilabad; (■) Mahabubnagar.

Table 3 presents results from univariate and multiple logistic regression analyses for myopia worse than –0.50 D without the interaction variables for those > 15 years of age. Those ≥ 40 years of age, males, those with education higher than class 12, those with LOCS III nuclear cataract grade ≥ 2, and those living in Adilabad and Mahabubnagar (the poor rural study areas), were more likely to have myopia. In the multiple logistic model with the interaction variables (data not shown), there was significant interaction between sex and nuclear cataract (OR 1.20; 95% CI 1.10–1.31) and education and socioeconomic status (OR 1.13; 95% CI 1.05–1.22), and borderline interaction between age and nuclear cataract (OR 1.01; 95% CI 1.00–1.02).

The risk of different associations with myopia were analysed in various multivariate models for subjects > 15 years of age because of significant interactions between nuclear cataract, age and sex, and the results are selectively presented. In the model with subjects having LOCS III nuclear cataract grade < 2, the risk of myopia was significantly higher in those ≥ 70 years of age (OR 4.98; 95% CI 1.02–24.25), females (OR 1.35; 95% CI 1.02–1.79), and for those living in the urban study area (OR 2.49; 95% CI 1.82–3.39). However, on considering the subjects with LOCS III nuclear cataract grade ≥ 2, the risk of myopia was significantly higher for those ≥ 40 years of age (OR 2.41; 95% CI 1.88–3.08), males (OR 1.64; 95% CI 1.38–1.95), those with LOCS III nuclear cataract grade ≥ 3.5 (OR 10.40; 95% CI 8.74–12.37), and in those living in rural study areas (OR 1.67; 95% CI 1.36–2.04). The risk of myopia was significantly lower in those belonging to upper socioeconomic strata (OR 0.37; 95% CI 0.20–0.67). There was a significant interaction between sex and nuclear cataract (OR 1.51; 95% CI 1.35–1.68) in the multiple logistic model with the interaction variables.

In similar multivariate models the risk of different associations with myopia were analysed for subjects ≥ 40 years of age, and the results are selectively presented. In the model with subjects having LOCS III nuclear cataract grade < 2, the risk of myopia was significantly lower for West Godavari, the 'well-off' study area (OR 0.27; 95% CI 0.07–0.99). However, on considering the subjects with LOCS III nuclear cataract grade ≥ 2, the risk of myopia was significantly higher for those ≥ 50 years of age (OR 1.59; 95% CI

Table 3 Effect of age, sex, education, socioeconomic status, nuclear cataract, and study area on myopia (worse than –0.50 D) and hyperopia (worse than +0.50 D) for subjects more than 15 years of age

	Total (*n* = 7276)	Myopia *n* (%)	Odds ratio for myopia (95% confidence interval)	Hyperopia *n* (%)	Odds ratio for hyperopia (95% confidence interval)
Age group (years)*					
16–29	1842	155 (8.4)	1.00	9 (0.5)	1.00
30–39	1848	166 (9.0)	0.89 (0.69–1.15)	83 (4.5)	10.38 (5.20–20.72)
40–49	1407	260 (18.5)	1.46 (1.12–1.90)	271 (19.3)	53.89 (27.56–105.38)
50–59	1020	419 (41.1)	2.24 (1.68–2.99)	238 (23.3)	77.42 (39.40–152.13)
60–69	849	519 (61.1)	2.92 (2.13–4.01)	122 (14.4)	44.64 (22.40–88.94)
≥ 70	310	192 (61.9)	2.10 (1.40–3.15)	39 (12.6)	41.52 (19.68–87.61)
Sex*					
Male	3318	817 (24.6)	1.00	250 (7.5)	1.00
Female	3958	894 (22.6)	0.83 (0.72–0.96)	512 (12.9)	2.43 (2.03–2.92)
Education*†					
I	3789	1112 (29.3)	1.00	341 (9.0)	1.00
II	1346	271 (20.1)	0.63 (0.52–0.77)	205 (15.2)	1.80 (1.45–2.23)
III	1343	191 (14.2)	0.82 (0.66–1.02)	134 (10.0)	1.76 (1.36–2.27)
IV	362	57 (15.7)	1.03 (0.71–1.48)	31 (8.6)	1.83 (1.16–2.89)
V	427	76 (17.8)	1.47 (1.04–2.08)	50 (11.7)	1.94 (1.28–2.95)
Socioeconomic status*‡					
Extreme lower	876	211 (24.1)	1.00	65 (7.4)	1.00
Lower	3572	884 (24.7)	0.93 (0.75–1.16)	307 (8.6)	1.09 (0.81–1.46)
Middle	2422	529 (21.8)	0.85 (0.67–1.08)	330 (13.6)	1.44 (1.06–1.94)
Upper	285	52 (18.2)	0.81 (0.52–1.26)	54 (18.9)	1.78 (1.13–2.80)
Study area*§					
Hyderabad	1759	372 (21.1)	1.00	257 (14.6)	1.00
West Godavari	1857	385 (20.7)	0.78 (0.63–0.97)	259 (13.9)	1.03 (0.83–1.28)
Adilabad	1836	390 (21.2)	1.26 (1.01–1.58)	115 (6.3)	0.56 (0.43–0.73)
Mahabubnagar	1824	564 (30.9)	1.90 (1.55–2.34)	131 (7.2)	0.52 (0.41–0.67)
Nuclear cataract (LOCS III grade)*¶					
< 2	3189	260 (8.2)	1.00		
≥ 2 to < 3.5	2679	476 (17.8)	1.67 (1.35–2.06)		
≥ 3.5	1281	954 (74.5)	16.99 (12.91–22.36)		

*$P < 0.05$, chi-square test. †Education categories defined as: I, no education; II, class 1–5; III, class 6–10; IV, class 11–12; V, higher than class 12 (including technical courses); data on education not available for nine subjects. ‡Socioeconomic status defined according to monthly per capita income in rupees: extreme lower ≤ 200 (US $4.5), lower 201–500, middle 501–2000, and upper > 2000; data on socioeconomic status not available for 121 subjects. §Hyderabad is urban study area, and West Godavari, Adilabad, and Mahabubnagar are rural study areas. ¶Data on nuclear cataract not available for 127 subjects. Odds ratios determined with multiple logistic regression.

1.29–1.96), males (OR 1.75; 95% CI 1.45–2.12), those belonging to extreme lower or lower socioeconomic strata (OR 1.30; 95% CI 1.07–1.57), those with LOCS III nuclear cataract grade ≥ 3.5 (OR 11.20; 95% CI 8.96–14.01), and in those living in rural study areas (OR 2.08; 95% CI 1.64–2.64). There was a significant interaction between sex and nuclear cataract (OR 1.58; 95% CI 1.41–1.77) in the multiple logistic model with the interaction variables.

The results of multiple logistic regression for myopia worse than or equal to −1.00 D were essentially similar to those for worse than –0.50 D analysis (data not shown). The sex-adjusted prevalence of myopia for the different age groups in the four study areas is shown in Fig. 2.

Hyperopia

Hyperopia (SE worse than +0.50 D) in the worse eye was present in 762 subjects, a prevalence of 8.38% (95% CI 6.91–9.85%) adjusted for age, sex and urban–rural distribution. The prevalence of hyperopia +3.00 D or worse was 0.94% (95% CI 0.69–1.18%) and of +5.00 D or worse was 0.32% (95% CI 0.20–0.49%).

Table 3 presents results from univariate and multiple logistic regression analyses for hyperopia worse than +0.50 D without the interaction variables for those > 15 years of age. The highest odds of having hyperopia were in the 50–59 years age group. Females, those with any level of education, and those belonging to middle and upper socioeconomic strata, were more likely to have hyperopia. The odds of having hyperopia were significantly lower for those living in Adilabad and Mahabubnagar, the poor rural study areas. No statistically significant interaction was found between education and socioeconomic status in the multiple logistic model with the interaction variable (data not shown).

The multiple logistic regression models for hyperopia run separately for subjects 16–39 years of age and

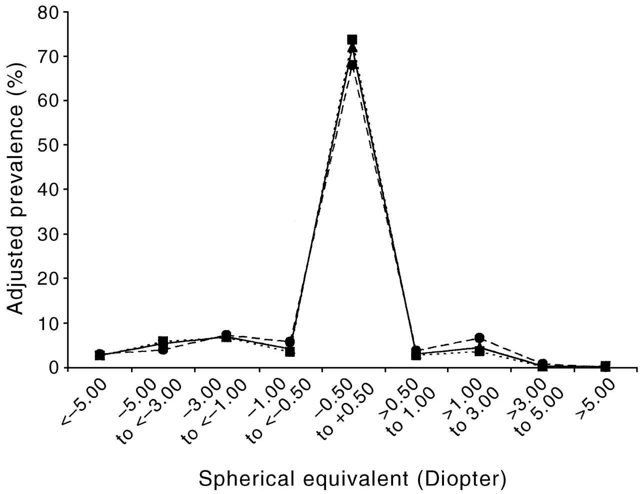

Figure 4. Adjusted prevalence of spherical equivalent in subjects > 15 years of age. Prevalence for (●) urban study area and (■) rural study area adjusted for age and sex, and prevalence for (▲) all the study areas combined adjusted for age, sex and urban–rural distribution.

for ≥ 40 years of age produced similar results for association of hyperopia with sex, education, socioeconomic status and study area. In the model for subjects 16–39 years of age, those 30–39 years of age (OR 9.39; 95% CI 4.66–18.90) were significantly more likely to have hyperopia as compared with those 16–29 years of age. Similarly, in the model for subjects ≥ 40 years of age, those 50–59 years of age (OR 1.48; 95% CI 1.20–1.82) were significantly more likely to have hyperopia as compared with those 40–49 years of age.

The results of multiple logistic regression for hyperopia worse than +1.00 D were essentially similar to those for worse than +0.50 D analysis (data not shown). The sex-adjusted prevalence of hyperopia for the different age groups in the four study areas is shown in Fig. 3.

DISCUSSSON

The APEDS was a large population-based, cross-sectional, epidemiology study of visual impairment and eye diseases in the population of the Indian state of Andhra Pradesh. The participation rate in this study was high. We have previously reported data on refractive error from the urban study area of APEDS.[15] We now report the refractive error data for all the four study areas combined, including three rural areas, to provide an overview of the prevalence, distribution, and demographic associations of refractive error in Andhra Pradesh.

Subjects ≤ 15 years of age

Refraction under cycloplegia has been reported for subjects ≤ 15 years of age. The prevalence estimates of myopia and hyperopia in those ≤ 3 years could be biased as refraction could not be performed on 27% of the subjects in this age group. Myopia prevalence was estimated at 2.8% for this age group. We found a higher prevalence of myopia in children in the urban study area (4.99%) as compared with those in the rural study areas (2.54%). It is possible that this increased prevalence of myopia in the urban study area is related to increased schooling in these children as compared with those living in the rural study areas. Only 20% of the children in the urban study area had no education as compared with 80% in the rural study areas. Similar results of higher prevalence of myopia in children in the urban area as compared with those in the rural area, probably related to difference in the level of schooling, have been reported from recent refractive error studies conducted in urban and rural populations in India.[21,22] Prevalence of myopia (–0.50 D or worse) for children 5–15 years of age has been reported at 1.2%, 6.8%, 7.4%, and 16.2% from recent studies performed in rural Nepal, Chile, urban New Delhi in India, and China.[22–25] On using this definition of myopia in our study, the prevalence of myopia was 5.3% in the urban study area and 3.8% in the rural study areas for subjects ≤ 15 years of age. Though these data cannot be directly compared because of the different age groups considered, there is a suggestion that the prevalence of myopia in our rural population is higher than that reported for rural Nepal, but the prevalence of myopia in our urban population is lower than Chile and urban Delhi, and much lower than China.[22–25] Myopia increased with increasing age in our study, which is similar to what has been reported from New Delhi and China.[22,25] We did not find any significant association of sex with myopia but females were more likely to have myopia in New Delhi and China.[22,25] The cross-sectional nature of our study allows us to comment only on the association of possible risk factor that have been assessed and not on the causal effect of these risk factors on the prevalence of myopia.

Hyperopia prevalence in this study was estimated at 60.3%, and was more in those < 10 years of age as expected. We found a higher prevalence of hyperopia in children in the rural study areas (64.6%) as compared with those in the urban study area (58.3%). It is possible that the lower prevalence of hyperopia in the rural study areas is related to less schooling in the rural study areas, which probably resulted in lesser push towards myopia during the emmetropization process as compared with the children in the urban study area. Prevalence of hyperopia (+2.00 D or worse) in children 5–15 years of age has been reported as 1.4%, 16.3%, 7.7%, and 3.5% from studies in rural Nepal, Chile, New Delhi and China.[22–25] The prevalence of hyperopia (+2.00 D or worse) in our study was 7.8% for children in the urban study area and 0.5% in the rural study areas for subjects ≤ 15 years of age, suggesting that the prevalence of higher magnitude of hyperopia was more in the urban study area as compared with the rural study areas. The prevalence of hyperopia (+2.00 D or worse) in children in the urban study area in our population is similar to that reported from the urban population in New Delhi, but lower than that reported from Chile for children 5–15 years of age. However, the prevalence of hyperopia in children in rural study areas in our population is lower than that reported from a rural population in Nepal for children 5–15 years of age. These studies reported a higher prevalence of hyperopia in females as compared with males but we did not find any significant association between sex and refractive error for children in our population.

A significant difference in the prevalence of myopia and hyperopia was found between children in our urban and rural populations. Interestingly, the prevalence of myopia and hyperopia in the urban population in our study was similar to that reported from urban New Delhi.[22] This similarity suggests the role of education with regards to refractive error, and possibly explains the difference between the urban and rural populations as mentioned earlier.

Subjects > 15 years of age

The prevalence of myopia was estimated at 19.4% and that of hyperopia at 8.4% in subjects > 15 years of age. We did not perform refraction on subjects > 15 years of age who had distance and near visual acuity of 6/6 or better and were not using any refractive correction as these subjects were considered as not having refractive error. This may have resulted in underestimation of the prevalence of hyperopia, thereby overestimating emmetropia, but should not have affected the estimates for myopia.

The majority of the data on prevalence and associations of myopia and hyperopia for adults are available for populations 40 years of age or more from the developed world, except for the Blue Mountains Eye Study (≥ 49 years of age) and the Beaver Dam Eye Study (43–84 years of age).[26–31] The prevalence of myopia in subjects ≥ 40 years of age in our study (36.5%) is higher than that reported from studies performed in Australia and the United States, which ranged from 15% to 28%,[26–30] but is similar to that reported from Singapore recently, 38.7%.[31] In contrast, the prevalence of hyperopia in our population ≥ 40 years (18.9%) is much lower than that reported from the studies from Australia, the United States of America and Singapore, which ranged from 28.4% to 57%.[27–31]

Myopia increased with advancing age for subjects ≥ 40 years of age. As the risk of myopia was the highest with nuclear cataract, multivariate analysis was performed separately for those with nuclear cataract LOCS III grade < 2 and for those with nuclear cataract LOCS III grade ≥ 2. No significant association of age and myopia was found for subjects with nuclear cataract LOCS III grade < 2, whereas myopia increased with advancing age for those with nuclear cataract LOCS III grade ≥ 2. This clearly demonstrates that grade of nuclear cataract is an important determinant of age-related increase in myopia, and hence supports the theory of change in the refractive index gradient of the lens with age.[32] Higher prevalence of myopia associated with nuclear opacities has also been reported from other studies.[26,28,31] A possible reason for higher prevalence of myopia in those ≥ 40 years of age in our population as compared with the developed world is that the proportion of those visually impaired due to age-related cataract is much higher in our population as compared with the developed world where it is negligible. The possible reasons for this include a higher predisposition to nuclear cataract in India, and more frequent cataract surgery in the developed world for lower levels of visual impairment.[2,8,33] As the majority of the age-related cataract in our population is nuclear cataract,[2,8] and our data demonstrates a strong relationship between nuclear cataract and myopia, it is likely that the prevalence of myopia in our population would continue to be high unless there is a decrease in the prevalence of visual impairment due to age-related cataract.

Increasing age was also associated with higher prevalence of hyperopia in our study, which increased between 50 and 59 years of age and then declined in those 60 years of age or more. Age-related increase in hyperopia has also been reported from other studies.[27–29,31] However, the prevalence of hyperopia in our population ≥ 40 years of age is lower than that reported from other studies as mentioned previously. A possible reason for this lower prevalence could be the higher prevalence of unoperated higher grades of nuclear cataract in our population as compared with the developed world, which results in a higher prevalence of myopia and a lower prevalence of hypeopia.[2,33] Our data supports the trend of hyperopic shift that was shown by Slatapar between the ages of 31 and 64.[34] There could also be some genetic factors resulting in higher prevalence of nuclear cataract-related myopia and a lower prevalence of hyperopia in our population, but it is not possible to speculate on genetic factors based on our data.

In our study, males were more likely to have myopia on considering either all the subjects irrespective of the grade of nuclear cataract, or only those with nuclear cataract LOCS III grade ≥ 2. Females were more likely to have hyperopia in our population. Females have been reported to have a higher prevalence of myopia from Singapore and the Beaver Dam Eye Study, although the difference in the prevalence of myopia between the two sexes was small.[28,31] Females have also been reported to have a higher prevalence of hyperopia from Australia and the Barbados Eye Study.[27,28] The relationship between refractive error and sex has not been well established as suggested by the results from different studies.

We found a higher prevalence of myopia in those with education level of class 12 or higher, which is similar to what has been reported from other studies.[26,28,30,31] However, on considering only those ≥ 40 years of age, those with no education were more likely to have myopia. This is possibly explained by the fact those with no education were more likely to have higher grades of nuclear cataract as compared with those with any level of education ($P = 0.012$), and were also more likely to be living in the rural study areas than in the urban study area ($P < 0.0001$). We found hyperopia to be associated with those with any level of education. The reasons for this association are not clear. In the Baltimore Eye Survey, hyperopia declined with increasing years of education, and was also reported to be less in those with education from the Barbados Eye Study.[28,30]

We did not find any significant association of myopia with socioeconomic status in our population. A higher prevalence of myopia has been associated with higher income groups in Singapore.[31] However, we found that those belonging to middle and upper socioeconomic strata in our population were more likely to have hyperopia and were less likely to have myopia. This is probably related to nuclear cataract as those belonging to these strata were less likely to have higher grades of nuclear cataract, and hence lower prevalence of myopia ($P < 0.0001$).

Those in the rural study areas in our population were more likely to have myopia and less likely to have hyperopia as compared with those in the urban study area. However, on considering only those with nuclear cataract LOCS III grade < 2, those in the urban study area were more likely to have myopia. This again highlights the important association between nuclear cataract and myopia. The proportion of those with higher grades of nuclear cataract was higher in the rural study areas as compared with the urban study areas ($P < 0.0001$). The higher prevalence of nuclear cataract-related myopia in our rural population could be related to their outdoor occupation of agriculture. In addition, the eye-care service delivery for cataract surgery in our rural areas is much less developed than in the urban areas, which has resulted in higher prevalence of visual impairment due to age-related cataract in the rural populations,[2] and hence higher prevalence of myopia related to nuclear cataract.

This report from APEDS has documented in detail the refractive error status in the population of Andhra Pradesh. Population-based data on the refractive error status of a population are important in the context of VISION 2020, as these data can indicate the groups that need to be targeted for vision screening programs for identification and correction of refractive errors. These data are of particular significance for our population because in APEDS we found that refractive error was the cause of blindness (presenting distance visual acuity < 6/60 in the better eye) in 0.3% of our population; that is, one of every 333 persons in our population.[2] Furthermore, among those with visual impairment (presenting visual acuity < 6/18 in the better eye) in the same population, those with refractive error as cause of visual impairment were significantly less likely to utilize eye-care services.[35]

Extrapolating these data on refractive error (worse than – 0.50 D) from APEDS to the 50 million population > 15 years of age in Andhra Pradesh in the year 2000,[36] it is estimated that 9.7 million people had myopia (95% CI 8.9–10.5) and 4.2 million people had hyperopia (95% CI 3.5–4.9). In addition, an estimated 0.8 million children had myopia (95% CI 0.6–1.0) in Andhra Pradesh in the year 2000. In conclusion, these data suggest that there is significant refractive error in this population. In order to meet the goal of VISION 2020 – The Right to Sight, these data on the prevalence, distribution and demographic associations of refractive error can help to plan eye-care services in the Indian state of Andhra Pradesh.

ACKNOWLEDGEMENTS

The Andhra Pradesh Eye Disease Study was supported by the Hyderabad Eye Research Foundation, Hyderabad, India, and Christoffel-Blindenmission, Bensheim, Germany. Dr Rakhi Dandona was supported in part by RB McComas and Hugh Noel Puckle scholarships from the University of Melbourne, Melbourne, Australia. The authors acknowledge Mr S Narasiah for contribution to the clinical examination of the subjects, and Mr K Vilas and Mr MN Prasad for mapping of the study clusters and recruitment of the subjects. The authors also acknowledge the guidance of Professor Hugh R Taylor, Centre for Eye Research Australia, University of Melbourne, Melbourne, Australia.

REFERENCES

1. Dandona R, Dandona L. Refractive error blindness. *Bull. World Health Organ.* 2001; **79**: 237–43.
2. Dandona L, Dandona R, Srinivas M, Giridha P, Vilas K, Prasad MN *et al.* Blindness in the Indian state of Andhra Pradesh. *Invest. Ophthalmol. Vis. Sci.* 2001; **42**: 908–16.
3. Attebo K, Mitchell P, Smith W. Visual acuity and the causes of visual loss in Australia: the Blue Mountain Eye Study. *Ophthalmology* 1996; **103**: 357–64.
4. Mansour AM, Kassak K, Chaya M, Hourani T, Sibai A, Alameddine MN. National survey of blindness and low vision in Lebanon. *Br. J. Ophthalmol.* 1997; **81**: 905–6.
5. Zerihun N, Mabey D. Blindness and low vision in Jimma Zone, Ethiopia: results of a population-based survey. *Ophthalmic Epidemiol.* 1997; **4**: 19–26.
6. Taylor HR, Livingston PM, Stanislavsky YL, McCarty CA. Visual impairment in Australia. Distance visual acuity, near vision, and visual field findings of the Melbourne Visual Impairment Project. *Am. J. Ophthalmol.* 1997; **123**: 328–37.
7. Negrel AD, Minassian DC, Sayek F. Blindness and low vision in southeast Turkey. *Ophthalmic Epidemiol.* 1996; **3**: 127–34.
8. Dandona L, Dandona R, Naduvilath TJ, McCarty CA, Srinivas M, Mandal P *et al.* Burden of moderate visual impairment in an urban population in southern India. *Ophthalmology* 1999; **106**: 497–504.
9. Tielsch JM, Sommer A, Witt K, Katz J, Royall RM. Blindness and visual impairment in an American urban population. The Baltimore Eye Survey. *Arch. Ophthalmol.* 1990; **108**: 286–90.
10. World Health Organization. *Programme for the Prevention of Blindness and Deafness. Global Initiative for the Elimination of Avoidable Blindness*. Geneva: WHO, 1997.
11. Thylefors B. A global initiative for the elimination of avoidable blindness [editorial]. *Am. J. Ophthalmol.* 1998; **125**: 90–93.
12. Pararajasegram R. VISION 2020 – The Right to Sight: from strategies to action [editorial]. *Am. J. Ophthalmol.* 1999; **128**: 359–60.
13. Foster A. Vision 2020: the Right to Sight [editorial]. *IAPB News* 2000; **25**: 3–4.
14. Dandona R, Dandona L, Naduvilath TJ, Nanda A, McCarty CA. Design of a population-based study of visual impairment in India: the Andhra Pradesh Eye Disease Study. *Indian J. Ophthalmol.* 1997; **45**: 251–7.

15. Dandona R, Dandona L, Naduvilath TJ, Srinivas M, McCarty A, Rao GN. Refractive errors in an urban population in southern India: the Andhra Pradesh Eye Disease Study. *Invest. Ophthalmol. Vis. Sci.* 1999; **40**: 2810–18.
16. Dandona L, Dandona R, Naduvilath TJ, McCarty CA, Nanda A, Srinivas M *et al.* Is current eye-care-policy focus almost exclusively on cataract adequate to deal with blindness in India? *Lancet* 1998; **351**: 1312–16.
17. Chylack LT, Wolfe JK, Singer DM, Leske MC, Bullimore MA, Bailey IL *et al.* The Lens Opacity Classification System III. *Arch. Ophthalmol.* 1993; **111**: 831–6.
18. US Census Bureau. *International Data Base.* http://www.census.gov (accessed December 2000).
19. United Nations. *World Urbanization Prospectus*. New York: United Nations, 1998.
20. Bennett S, Woods T, Liyanage WM, Smith DL. A simplified general method for cluster-sample surveys of health in developing countries. *World Health Stat. Q.* 1991; **44**: 98–106.
21. Dandona R, Dandona L, Srinivas M *et al.* Refractive error in children in a rural population in India. *Invest. Ophthalmol. Vis. Sci.* 2002; in press.
22. Murthy GVS, Gupta SK, Ellwein LB *et al.* Refractive error in children in an urban population in New Delhi. *Invest. Ophthalmol. Vis. Sci.* 2002; in press.
23. Pokharel GP, Negrel AD, Munoz SR, Ellwein LB. Refractive error study in children: results from Mechi zone, Nepal. *Am. J. Ophthalmol.* 2000; **129**: 436–44.
24. Maul E, Barroso S, Munoz SR, Sperduto RD, Ellwein LB. Refractive error study in children: results from La Florida, Chile. *Am. J. Ophthalmol.* 2000; **129**: 445–54.
25. Zhao J, Pan X, Sui R, Munoz SR, Sperduto RD, Ellwein LB. Refractive error study in children: results from Shunyi district, China. *Am. J. Ophthalmol.* 2000; **129**: 427–35.
26. Wensor MD, McCarty CA, Taylor HR. The prevalence and risk factors of myopia in. Victoria, Australia. *Arch. Ophthalmol.* 1999; **117**: 658–63.
27. Attebo K, Ivers RQ, Mitchell P. Refractive errors in an older population: the Blue Mountains Eye Study. *Ophthalmology* 1999; **106**: 1066–72.
28. Wu SY, Nemesure B, Leske MC. Refractive errors in a black adult population: the Barbados Eye Study. *Invest. Ophthalmol. Vis. Sci.* 1999; **40**: 2179–84.
29. Wang Q, Klein BEK, Klein R, Moss S. Refractive status in the Beaver Dam Eye Study. *Invest. Ophthalmol. Vis. Sci.* 1994; **35**: 4344–7.
30. Katz J, Tielsch JM, Sommer A. Prevalence and risk factors for refractive errors in an adult inner city population. *Invest. Ophthalmol. Vis. Sci.* 1997; **38**: 334–40.
31. Wong TY, Foster PJ, Hee J, Ng TP, Tielsch JM, Chew SJ *et al.* Prevalence and risk factors for refractive errors in adult Chinese in Singapore. *Invest. Ophthalmol. Vis. Sci.* 2000; **41**: 2486–94.
32. Hemenger RP, Garner LF, Ooi CS. Change with age of the refractive index gradient of the human ocular lens. *Invest. Ophthalmol. Vis. Sci.* 1995; **36**: 703–7.
33. Taylor HR. Cataract: how much surgery do we have to do? *Br. J. Ophthalmol.* 2000; **84**: 1–2.
34. Slataper FJ. Age norms of refraction and vision. *Arch. Ophthalmol.* 1950; **43**: 466–81.
35. Dandona R. Barriers to eye-care services in the Indian state of Andhra Pradesh: recommendations for action. Unpubl. PhD Thesis. University of Melbourne, Melbourne, Australia, 2001.
36. Registrar General, India. *Population Projections for India and States 1996–2016.* New Delhi: Ministry of Home Affairs, Government of India, 1996.