Refractive Errors in an Urban Population in Southern India: The Andhra Pradesh Eye Disease Study

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Purpose. To assess the prevalence, distribution, and demographic associations of refractive error in an urban population in southern India.

Methods. Two thousand five hundred twenty-two subjects of all ages, representative of the Hyderabad population, were examined in the population-based Andhra Pradesh Eye Disease Study. Objective and subjective refraction was attempted on subjects >15 years of age with presenting distance and/or near visual acuity worse than 20/20 in either eye. Refraction under cycloplegia was attempted on all subjects ≤15 years of age. Spherical equivalent >0.50 D in the worse eye was considered as refractive error. Data on objective refraction under cycloplegia were analyzed for subjects ≤15 years and on subjective refraction were analyzed for subjects >15 years of age.

Results. Data on refractive error were available for 2,321 (92.0%) subjects. In subjects ≤15 years of age, age-gender–adjusted prevalence of myopia was 4.44% (95% confidence interval [CI], 2.14%–6.75%), which was higher in those 10 to 15 years of age (odds ratio, 2.75; 95% CI, 1.25–6.02), of hyperopia 59.37% (95% CI, 44.65%–74.09%), and of astigmatism 6.93% (95% CI, 4.90%–8.97%). In subjects >15 years of age, age-gender–adjusted prevalence of myopia was 19.39% (95% CI, 16.54%–22.24%), of hyperopia 9.83% (95% CI, 6.21%–13.45%), and of astigmatism 12.94% (95% CI, 10.80%–15.07%). With multivariate analysis, myopia was significantly higher in subjects with Lens Opacity Classification System III nuclear cataract grade ≥3.5 (odds ratio, 9.10; 95% CI, 5.15–16.09), and in subjects with education of class 11 or higher (odds ratio, 1.80; 95% CI, 1.18–2.74); hyperopia was significantly higher in subjects ≥30 years of age compared with those 16 to 29 years of age (odds ratio, 37.26; 95% CI, 11.84–117.19), in females (odds ratio, 1.86; 95% CI, 1.33–2.61), and in subjects belonging to middle and upper socioeconomic strata (odds ratio, 2.10; 95% CI, 1.09–4.03); and astigmatism was significantly higher in subjects ≥40 years of age (odds ratio, 3.00; 95% CI, 2.23–4.03) and in those with education of college level or higher (odds ratio, 1.73; 95% CI, 1.07–2.81).

Conclusions. These population-based data on distribution and demographic associations of refractive error could enable planning of eye-care services to reduce visual impairment caused by refractive error. If these data are extrapolated to the 255 million urban population of India, among those >15 years of age an estimated 30 million people would have myopia, 15.2 million hyperopia, and 4.1 million astigmatism not concurrent with myopia or hyperopia; in addition, based on refraction under cycloplegia, 4.4 million children would have myopia and 2.5 million astigmatism not concurrent with myopia or hyperopia. (*Invest Ophthalmol Vis Sci.* 1999;40:2810–2818)

Most refractive errors can usually be corrected with the use of spectacles or contact lenses. Data on refractive errors are available for some populations,[1–7] although myopia has mostly been the center of interest.[8,9]

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Little is known about the prevalence, distribution, and demographic associations of refractive error in India.[10] There are no population-based estimates of the prevalence, distribution, and demographic associations of refractive error on which the need for refractive correction can be based. We report these data for the urban population of Hyderabad in southern India, obtained as part of the population-based Andhra Pradesh Eye Disease Study. These data are expected to help in better planning of eye-care services, because refractive errors were responsible for a significant proportion of blindness and moderate visual impairment in this population.[11,12]

Methods

The Andhra Pradesh Eye Disease Study

The Andhra Pradesh Eye Disease Study (APEDS) is a population-based epidemiologic study of 10,000 people in four areas representative of the Indian state of Andhra Pradesh. Detailed methodology of the APEDS is reported elsewhere.[11,13] In brief, the sample size was determined on the basis of the eye diseases of interest with the least assumed prevalence and the power to detect odds ratios for risk factors.[13] The demographic distribution of India is pyramidal, with approximately 70% of the population <30 years of age.[14] Because we needed to obtain data on both, the populations less than and greater than 30 years of age, the sample was designed to recruit 5,000 subjects in each of the two age groups. For an actual prevalence of 0.5% for an eye disease in either of these age groups, this sample would estimate it to be between 0.3% and 0.8% at the 95% confidence interval (CI).[13] The oversampling of subjects >30 years of age was adjusted for in the calculation of the estimates.[11–13] In the first stage, stratification was done for urban-rural distribution of the population by selecting one fourth of the sample as urban and three fourths as rural. Expecting to achieve a recruitment rate of 85%, 2,954 subjects were sampled for the urban segment of the APEDS in Hyderabad city using a multistage sampling procedure.[11,13] The blocks (clusters) in Hyderabad were stratified by socioeconomic status and religion.[11,13] Twenty-four clusters (including one cluster of homeless people) were chosen by stratified random sampling with equal probability of selection to meet the stratification criteria.[11] Every third to fifth household (a household defined as all people eating from the same kitchen) was selected randomly, dependent on the total number of households in each cluster to obtain a similar number of households in the chosen clusters.[11] Participants of all ages were eligible in 13 randomly selected clusters and one cluster of homeless people; however, in the other 10 clusters only participants >30 years were eligible, in an attempt to obtain a roughly equal number of participants younger and older than 30 years of age.[11] Subjects were interviewed in detail before the clinical examination.[13] The urban segment of APEDS was conducted in Hyderabad from October 1996 to June 1997. All subjects were treated in accordance with the tenets of the Declaration of Helsinki. This study was approved by the Ethics Committee of the L. V. Prasad Eye Institute, Hyderabad.

Clinical Examination

Subjects were brought to a clinic set up for this study. Informed consent was obtained before the examination. For subjects ≤15 years of age, this consent was obtained from the parent or the guardian. The clinical examination included measurement of distance and near visual acuity with logMAR charts, refraction, and a detailed examination of anterior segment, gonioscopy, dilatation, a detailed examination of lens, vitreous and posterior segment, and visual fields based on uniform predefined criteria.[11–13] Nuclear cataract was graded using Lens Opacity Classification System (LOCS) III.[15] Those subjects who were physically debilitated and unable to come to the clinic were examined at home with portable equipment.[13]

For subjects >15 years of age, refraction was attempted on all those who presented with distance and/or near visual acuity worse than 20/20 in either eye. Objective refraction was performed by an optometrist using a streak retinoscope, which was further refined by subjective refraction. For subjects with distance and near visual acuity of 20/20 or better with current refractive correction, this correction was considered as the refractive error. Subjects who were not using optical correction and had distance and near visual acuity of 20/20 or better were considered as not having refractive error.

Objective refraction under cycloplegia (cyclopentolate 1% and tropicamide 1%) was attempted on all subjects ≤15 years of age.[13]

Statistical Analyses

Data were analyzed separately for subjects ≤15 years of age, because 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 analyzed for the worse eye (eye with higher refractive error). Spherical equivalent (SE) was used to analyze data for myopia and hyperopia. Spherical equivalent was calculated by adding half of the cylindrical value to the spherical value of the refractive error. Subjects with SE higher than −0.50 D were considered as having myopia and those with SE higher than +0.50 D were considered as having hyperopia. 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. Astigmatism higher than 0.50 D was considered for analysis. Astigmatism was analyzed on the basis of the type of astigmatism, against-the-rule astigmatism, with-the-rule astigmatism, and oblique astigmatism.

Analysis for myopia and hyperopia was also done for SE higher than or equal to 0.75 D and for SE higher than or equal to 1.00 D; for astigmatism, analysis was also done for magnitudes higher than or equal to 0.75 D and for magnitudes higher than or equal to 1.00 D.

The demographic associations of refractive error were assessed with age, gender, education, socioeconomic status, and religion. Association of myopia was also assessed with nuclear cataract and self-reported diabetes for subjects >15 years of age. Education was not considered in the multivariate model 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. Analyses were done using the SPSS software (SPSS for Windows, Rel.7.0.0.1995; SPSS, Chicago, IL). Adjustment of the estimates for the age and gender distributions of the Hyderabad population was done.[16] Based on the rates in each cluster, the design effect of the sampling strategy was calculated for the prevalence estimates,[17] and the 95% CIs adjusted accordingly.

Results

Two thousand five hundred twenty-two subjects were examined in Hyderabad for the urban segment of the APEDS, representing a participation rate of 85.4%. The number of subjects assessed ranged from 46 to 203 in 23 clusters and was 15 in the cluster of homeless people; the clusters in which only those 30 years of age or older were sampled had fewer subjects. Data for refractive errors were analyzed for 2,321 (92.0%) subjects (excluding 92 subjects who were aphakic or pseudophakic in either eye and 109 on whom data were not available).

Subjects ≤15 Years of Age

Of the 2,321 subjects, 663 (28.6%) were ≤15 years of age. Data on objective refraction under cycloplegia were available for

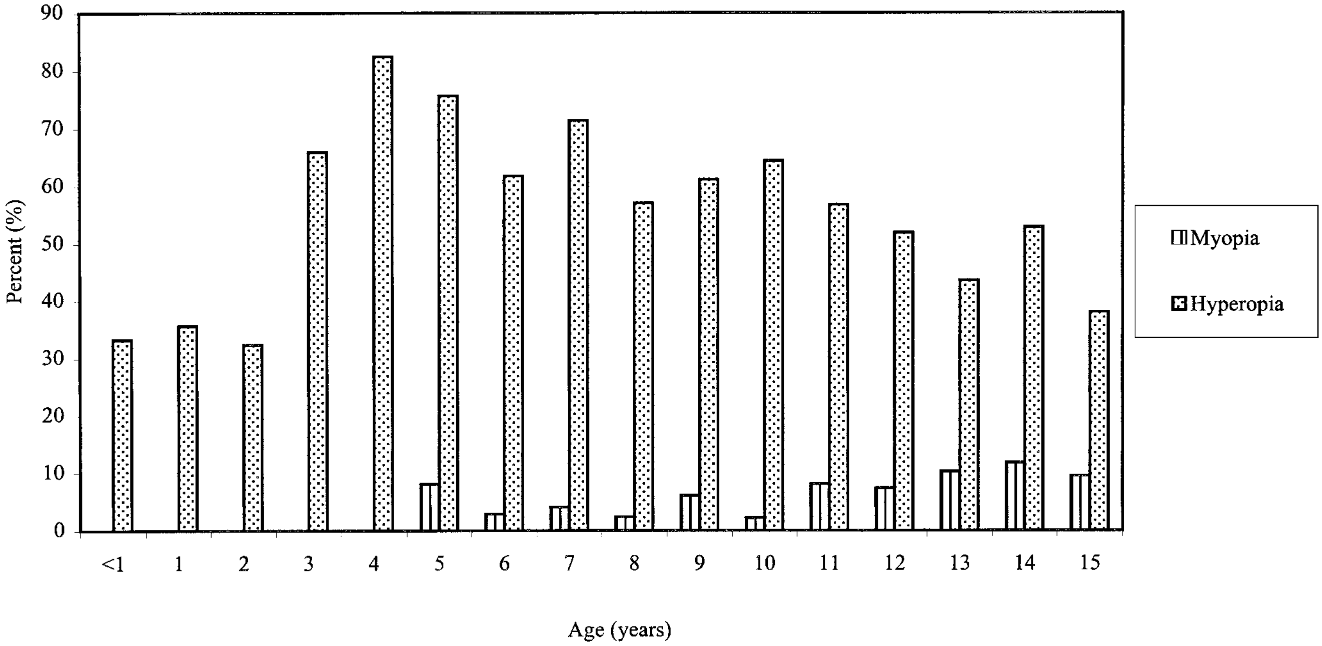

FIGURE 1. Distribution of myopia and hyperopia with age for subjects ≤15 years of age.

599 (90.3%) subjects. Of these 599 subjects, 352 (58.8%) were between 0 and 9 years, and 295 (49.2%) were females.

Myopia in the worse eye was present in 30 subjects, an age-gender–adjusted prevalence of 4.44% (95% CI, 2.14%–6.75%). On applying multiple logistic regression, myopia was significantly more frequent in subjects 10 to 15 years of age (odds ratio, 2.75; 95% CI, 1.25–6.02). Hyperopia in the worse eye was present in 350 subjects, an age-gender–adjusted prevalence of 59.37% (95% CI, 44.65%–74.09%). The distributions of myopia and hyperopia for ≤15 years of age are shown in Figure 1. Astigmatism in the worse eye was present in 44 subjects, an age-gender–adjusted prevalence of 6.93% (95% CI, 4.90%–8.97%). No significant associations of hyperopia and astigmatism with age, gender, socioeconomic status, and religion were found on applying multiple logistic regression.

The prevalence estimates of myopia, hyperopia, and astigmatism with different definitions are shown in Table 1. The prevalence estimates with definitions using ≥0.75 D were almost the same as those with >0.50 D. The results of multiple logistic regression for demographic associations for myopia, hyperopia, and astigmatism ≥1.00 D were essentially similar to those for >0.50 D.

Nineteen percent of subjects with against-the-rule astigmatism also had myopia, and 38.1% had hyperopia; 47.6% of those

TABLE 1. Age-Gender–Adjusted Prevalence Estimates with Different Definitions of Myopia, Hyperopia, and Astigmatism

	>0.50 D	≥0.75 D	≥1.00 D
Age ≤15 years			
Myopia	4.44 (2.14–6.75; 1.95)	4.32 (2.00–6.64; 2.04)	3.23 (1.34–5.12; 1.79)
Hyperopia	59.37 (44.65–74.09; 14.0)	57.12 (42.47–71.78; 13.67)	41.14 (24.29–58.0; 18.29)
Astigmatism	6.93 (4.90–8.97; none)	6.93 (4.90–8.97; none)	3.83 (2.21–5.45; 1.11)
Against-the-rule astigmatism	3.41 (1.95–4.86; none)	3.41 (1.95–4.86; none)	1.46 (0.50–2.42; none)
With-the-rule astigmatism	3.28 (1.85–4.72; none)	3.28 (1.85–4.72; none)	2.13 (0.74–3.51; 1.43)
Oblique astigmatism	0.24 (0–0.78; 1.86)	0.24 (0–0.78; 1.86)	0.24 (0–0.78; 1.86)
Age >15 years			
Myopia	19.39 (16.54–22.24; 2.33)	18.75 (15.88–21.62; 2.43)	15.20 (13.05–17.34; 1.60)
Hyperopia	9.83 (6.21–13.45; 6.63)	9.76 (6.14–13.38; 6.67)	8.50 (5.13–11.88; 6.58)
Astigmatism	12.94 (10.80–15.07; 1.81)	12.94 (10.80–15.07; 1.81)	9.80 (7.99–11.61; 1.67)
Against-the-rule astigmatism	7.90 (6.42–9.38; 1.35)	7.90 (6.42–9.38; 1.35)	5.64 (4.34–6.94; 1.41)
With-the-rule astigmatism	3.60 (2.72–4.48; none)	3.60 (2.72–4.48; none)	2.93 (2.13–3.73; none)
Oblique astigmatism	1.44 (0.63–2.24; 2.06)	1.44 (0.63–2.24; 2.06)	1.23 (0.51–1.95; 1.91)

Values are % prevalence (95% CI, design effect).

TABLE 2. Effect of Age, Gender, Education, Socioeconomic Status, Religion, Nuclear Cataract, and Self-Reported Diabetes on Myopia and Hyperopia for Subjects >15 Years of Age

	Total, *n* = 1722	Myopes, No. (%)	Odds Ratio for Myopia with Multiple Logistic Regression, 95% CI	Hyperopes, No. (%)	Odds Ratio for Hyperopia with Multiple Logistic Regression, 95% CI
Age groups, y*					
16–29	460	74 (16.1)	1.00	3 (0.7)	1.00
30–39	451	59 (13.1)	0.88 (0.58–1.31)	22 (4.9)	8.07 (2.39–27.27)
40–49	382	68 (17.8)	1.04 (0.67–1.61)	72 (18.8)	36.09 (11.20–116.27)
50–59	230	68 (29.6)	0.76 (0.44–1.33)	91 (39.6)	127.54 (39.32–413.64)
60–69	145	65 (44.8)	0.88 (0.46–1.68)	43 (29.7)	77.99 (23.30–261.00)
≥70	56	28 (50.0)	0.65 (0.29–1.48)	17 (30.4)	92.44 (25.35–337.07)
Gender†					
Male	763	169 (22.1)	1.00	95 (12.5)	1.00
Female	959	193 (20.1)	1.03 (0.78–1.36)	153 (16.0)	1.86 (1.33–2.61)
Socioeconomic status‡					
Extreme lower	147	24 (16.3)	1.00	12 (8.2)	1.00
Lower	610	128 (21.0)	1.21 (0.71–2.07)	82 (13.4)	1.57 (0.81–3.01)
Middle	725	162 (22.3)	1.16 (0.67–2.01)	117 (16.1)	2.04 (1.06–3.93)
Upper	193	36 (18.7)	1.03 (0.53–2.02)	34 (17.6)	2.53 (1.18–5.43)
Education (category)§					
I	501	117 (23.4)	1.00	68 (13.6)	1.00
II	257	51 (19.8)	0.92 (0.60–1.40)	47 (18.3)	1.82 (1.15–2.90)
III	476	82 (17.2)	1.12 (0.74–1.65)	69 (14.5)	2.00 (1.29–3.12)
IV	165	41 (24.8)	2.05 (1.23–3.42)	23 (13.9)	2.12 (1.13–3.97)
V	187	35 (18.7)	1.36 (0.79–2.34)	25 (13.4)	2.34 (1.23–4.45)
VI	21	1 (4.8)	0.31 (0.03–2.58)	4 (19.0)	2.36 (0.63–8.86)
VII	106	31 (29.2)	3.14 (1.73–5.71)	11 (10.4)	1.41 (0.61–3.26)
Religion‖					
Hindu	1091	223 (20.4)	1.00	147 (13.5)	1.00
Muslim	591	133 (22.5)	1.17 (0.89–1.55)	94 (15.9)	1.32 (0.98–1.77)
Others	40	6 (15.0)	0.59 (0.22–1.59)	7 (17.5)	1.29 (0.53–3.15)
Nuclear cataract (LOCS III grade)¶					
Grade <2	592	93 (15.7)	1.00	—	—
Grade 2 to <3.5	838	113 (13.5)	0.92 (0.64–1.31)	—	—
Grade ≥3.5	272	150 (55.1)	9.10 (5.15–16.09)	—	—
Self-reported diabetes#					
Yes	1619	445 (20.2)	1.00	—	—
No	103	32 (31.1)	1.00 (0.59–1.70)	—	—

* $P < 0.0001$ for myopia and hyperopia, chi-square test in univariate analysis.

† $P = 0.31$ for myopia and $P = 0.04$ for hyperopia, chi-square test in univariate analysis.

‡ $P = 0.33$ for myopia and $P = 0.04$ for hyperopia, chi-square test in univariate analysis. Socioeconomic status defined according to monthly per capita income in rupees: extreme lower ≤200 (US $5.10), lower 201–500, middle 501–2000, and upper >2000. Data on socioeconomic status not available for 47 subjects.

§ $P = 0.01$ for myopia and $P = 0.49$ for hyperopia, chi-square test in univariate analysis. Education categories defined as follows: I, no education; II, class 1–5; III, class 6–10; IV, class 11–12; V, technical course; VI, college; and VII, advanced studies. Data on education not available for 9 subjects.

‖ $P = 0.39$ for myopia and $P = 0.34$ for hyperopia, chi-square test in univariate analysis.

¶ $P < 0.0001$, chi-square test in univariate analysis. Nuclear cataract analyzed only for myopia.

$P = 0.11$, chi-square test in univariate analysis. Self-reported diabetes analyzed only for myopia.

with-the-rule astigmatism also had myopia, and 14.3% had hyperopia; and those with oblique astigmatism (2 subjects) were concurrent only with myopia.

Subjects >15 Years of Age

Of the 2,321 subjects, 1,722 (74.2%) were >15 years of age. Of these 1,722 subjects, 1,264 (73.4%) were ≥30 years of age, 959 (55.7%) were females, and 1,091 (63.3%) were Hindus.

Myopia in the worse eye was present in 362 subjects with an age-gender–adjusted prevalence of 19.39% (95% CI, 16.54%–22.24%). When multiple logistic regression was applied (Table 2), myopia was significantly higher in subjects with LOCS III nuclear cataract grade ≥3.5 (odds ratio, 9.10; 95% CI, 5.15–16.09) and in subjects with education of class 11 or higher (odds ratio, 1.80; 95% CI, 1.18–2.74). Although univariate analysis showed that myopia increased with increase in age ($P < 0.0001$), it was not significant in multivariate logistic regression. This was due to a significant interaction between age and nuclear cataract (data not reported). There was no significant interaction between edu-

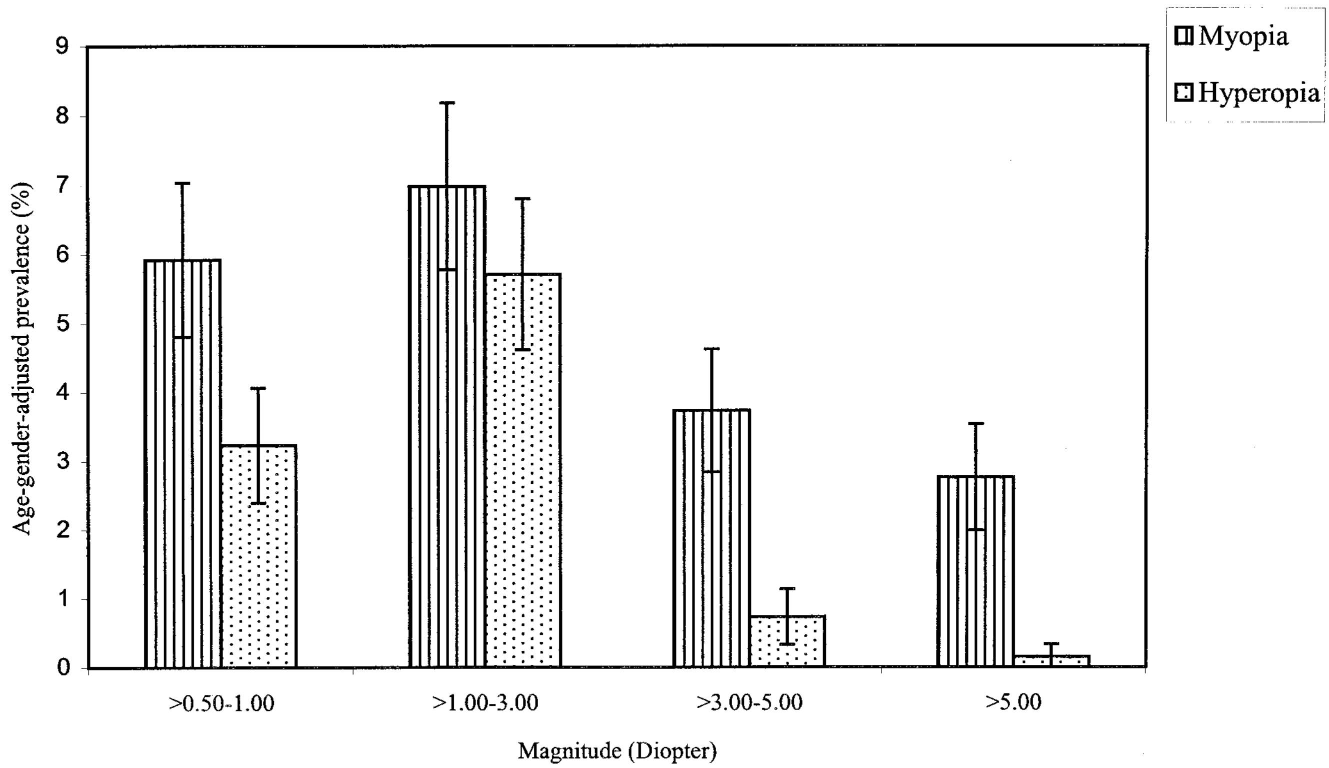

FIGURE 2. Age-gender-adjusted prevalence of myopia and hyperopia by magnitude for subjects >15 years of age. Bars denote 95% CIs.

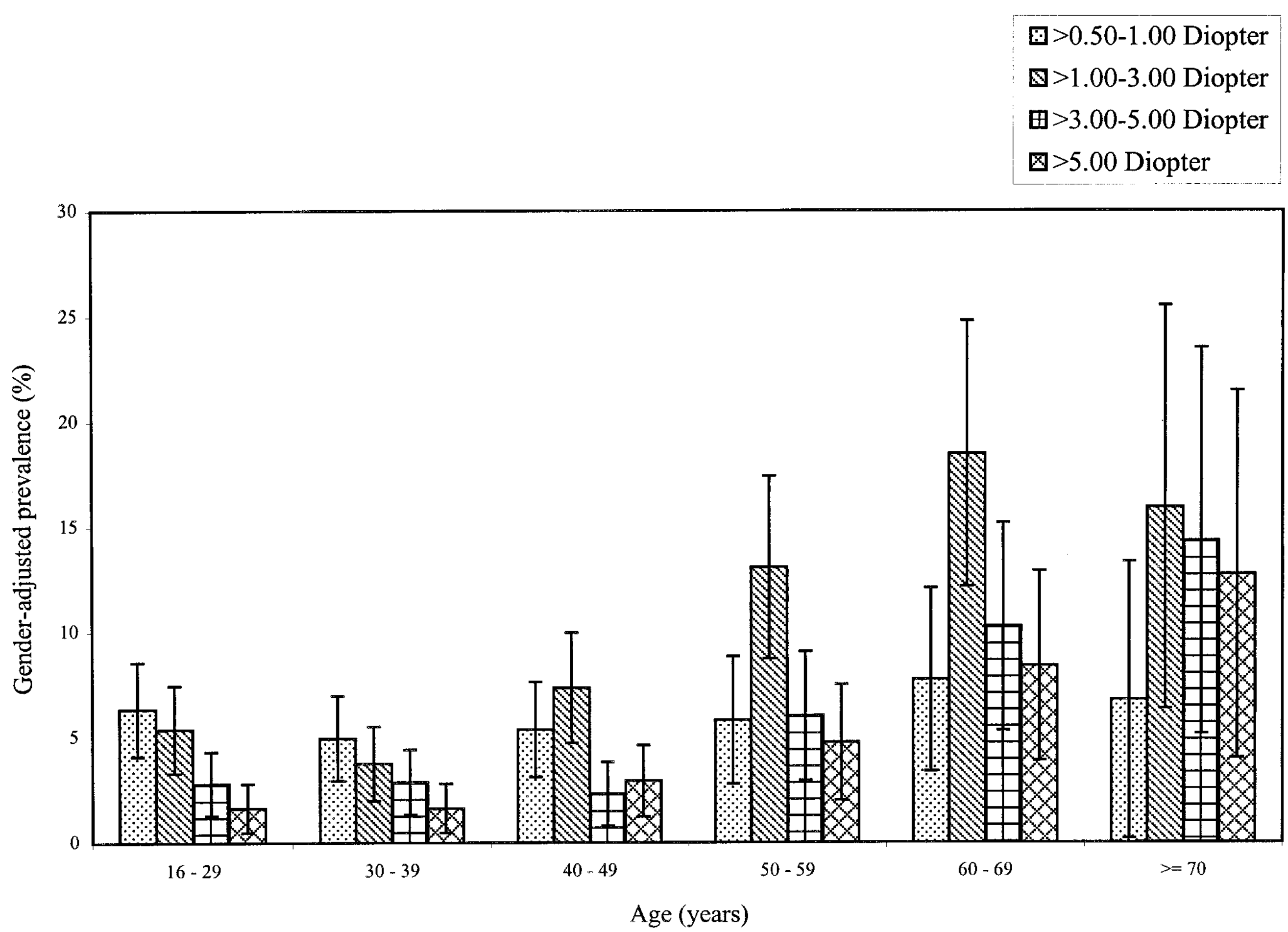

FIGURE 3. Gender-adjusted prevalence for the various magnitudes of myopia in the different age groups for subjects >15 years of age. Bars denote 95% CIs.

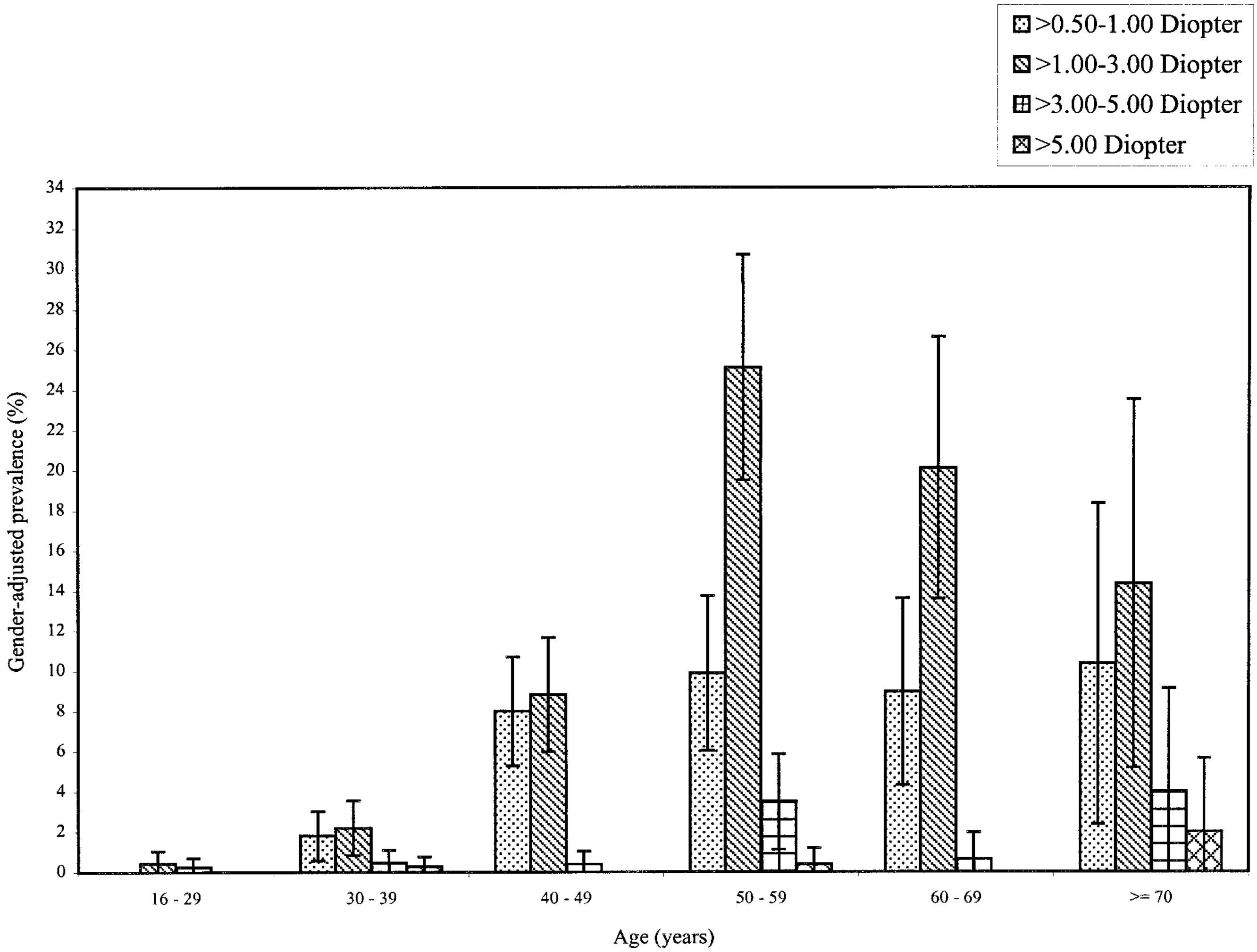

FIGURE 4. Gender-adjusted prevalence for the various magnitudes of hyperopia in the different age groups for subjects >15 years of age. Bars denote 95% CIs.

cation and socioeconomic status and no significant association of myopia with gender, socioeconomic status, religion, or self-reported diabetes.

Hyperopia in the worse eye was present in 248 subjects with an age-gender–adjusted prevalence of 9.83% (95% CI, 6.21%–13.45%). When multiple logistic regression was applied (Table 2), manifest hyperopia in the worse eye was significantly higher in subjects ≥30 years of age (odds ratio, 37.26; 95% CI, 11.84–117.19), in females (odds ratio, 1.86; 95% CI, 1.33–2.61), and in subjects belonging to middle and upper socioeconomic strata (odds ratio, 2.10; 95% CI, 1.09–4.03). Although the odds of having hyperopia for subjects with any level of education were higher than for those with no education, they were of borderline statistical significance (odds ratio, 1.41; 95% CI, 1.00–1.97). There was no significant interaction between education and socioeconomic status for hyperopia and no significant association of hyperopia with religion.

Figure 2 shows the age-gender–adjusted prevalence of the various magnitudes of myopia and hyperopia. The gender-adjusted prevalences of the various magnitudes of myopia in the different age groups are shown in Figure 3, and of hyperopia in Figure 4.

Astigmatism in the worse eye was present in 262 subjects, an age-gender–adjusted prevalence of 12.94% (95% CI, 10.80%–15.07%). When multiple logistic regression was applied (Table 3), astigmatism was significantly higher in subjects ≥40 years of age (odds ratio, 3.00; 95% CI, 2.23–4.03) and with education of college level or higher (odds ratio, 1.73; 95% CI, 1.07–2.81). There was no significant interaction between education and socioeconomic status for astigmatism and no significant association of astigmatism with gender, socioeconomic status, or religion. The distribution of astigmatism based on type and magnitude is shown in Figure 5.

The prevalence estimates of myopia, hyperopia, and astigmatism with different definitions are shown in Table 1. The prevalence estimates with definitions using ≥0.75 D were almost the same as with >0.50 D. The results of multiple logistic regression for demographic associations for myopia, hyperopia, and astigmatism with definition ≥1.00 D compared with those for >0.50 D were mostly similar; the minor difference was that the associations with education became weaker: myopia with education of class 11 or higher (odds ratio, 1.40; 95% CI, 0.96–2.02), hyperopia with any education (odds ratio,

TABLE 3. Effect of Age, Gender, Education, Socioeconomic Status, and Religion on Astigmatism for Subjects >15 Years of Age

	Total, n = 1722	Astigmatism, No. (%)	Odds Ratio for Astigmatism with Multiple Logistic Regression, 95% CI
Age groups, y*			
16–29	460	38 (8.3)	1.00
30–39	451	44 (9.8)	1.37 (0.85–2.20)
40–49	382	52 (13.6)	2.02 (1.27–3.22)
50–59	230	68 (29.6)	5.64 (3.54–8.98)
60–69	145	45 (31.0)	6.01 (3.55–10.18)
≥70	56	15 (26.8)	4.59 (2.19–9.61)
Gender†			
Male	763	119 (15.6)	1.00
Female	959	143 (14.9)	1.14 (0.85–1.55)
Socioeconomic status‡			
Extreme lower	147	16 (10.9)	1.00
Lower	610	82 (13.4)	1.09 (0.60–1.97)
Middle	725	130 (17.9)	1.34 (0.74–2.43)
Upper	193	28 (14.5)	1.00 (0.48–2.08)
Education (category)§			
I	501	72 (14.4)	1.00
II	257	38 (14.8)	1.12 (0.71–1.76)
III	476	71 (14.9)	1.42 (0.95–2.14)
IV	165	22 (13.3)	1.15 (0.63–2.08)
V	187	30 (16.0)	1.89 (1.08–3.31)
VI	21	3 (14.3)	1.32 (0.35–4.94)
VII	106	23 (21.7)	2.66 (1.39–5.08)
Religion‖			
Hindu	1091	160 (14.7)	1.00
Muslim	591	98 (16.6)	1.10 (0.82–1.48)
Others	40	4 (10.0)	0.47 (0.15–1.42)

* $P < 0.0001$, chi-square test in univariate analysis.

† $P = 0.69$, chi-square test in univariate analysis.

‡ $P = 0.05$, chi-square test in univariate analysis. Socioeconomic status defined according to monthly per capita income in rupees: extreme lower ≤200 (US $5.1), lower 201–500, middle 501–2,000 and upper >2,000. Data on socioeconomic status not available for 47 subjects.

§ $P = 0.62$, chi-square test in univariate analysis. Education categories defined as follows: I, no education; II, class 1–5; III, class 6–10; IV, class 11–12; V, technical course; VI, college; and VII, advanced studies. Data on education not available for 9 subjects.

‖ $P = 0.37$, chi-square test in univariate analysis.

1.32; 95% CI, 0.92–1.90), and astigmatism with education of college or higher (odds ratio, 1.45; 95% CI, 0.94–2.24).

Astigmatism showed higher concurrence with myopia than hyperopia. Fifty-one percent of subjects with against-the-rule astigmatism also had myopia, and 27.5% had hyperopia; 52.3% of subjects with with-the-rule astigmatism also had myopia, and 21.5% had hyperopia; and 61.5% of subjects with oblique astigmatism had myopia, and 23.1% had hyperopia.

DISCUSSION

These are probably the first descriptive population-based data on the distribution and demographic associations of refractive error in all age groups of an Indian population. These data are of particular importance because in the same population we found that refractive errors were responsible for 12.5% of the blindness[11] and 59.4% of the moderate visual impairment.[12]

We have reported refractive error under cycloplegia for subjects ≤15 years of age. Myopia prevalence in this age group was 4.44%, and it increased with age from 10 years onward. Other studies that have included younger age groups have shown that prevalence of myopia increases with age.[18,19] As expected, in refraction under cycloplegia, hyperopia dominated in those ≤15 years of age, with a prevalence of 59.37%. Our estimates of the prevalence of myopia and hyperopia in those ≤3 years of age could be biased because it is difficult to perform refraction on subjects in this age group. In our data, 47 subjects (31.8%) in this age group were excluded from analyses because refraction could not be performed on these subjects. There was a similar prevalence of against-the-rule and with-the-rule astigmatism under cycloplegia in those ≤15 years of age.

Subjective refraction has been reported by us for subjects >15 years of age. We found a prevalence of 19.39% for myopia in our population >15 years of age. Univariate analysis revealed that prevalence of myopia increased with age, but this was not significant in the multivariate model, which included nuclear cataract. Our data show a significant increase in myopia with nuclear cataract. Because nuclear cataract is an age-related change in the lens, a significant interaction between

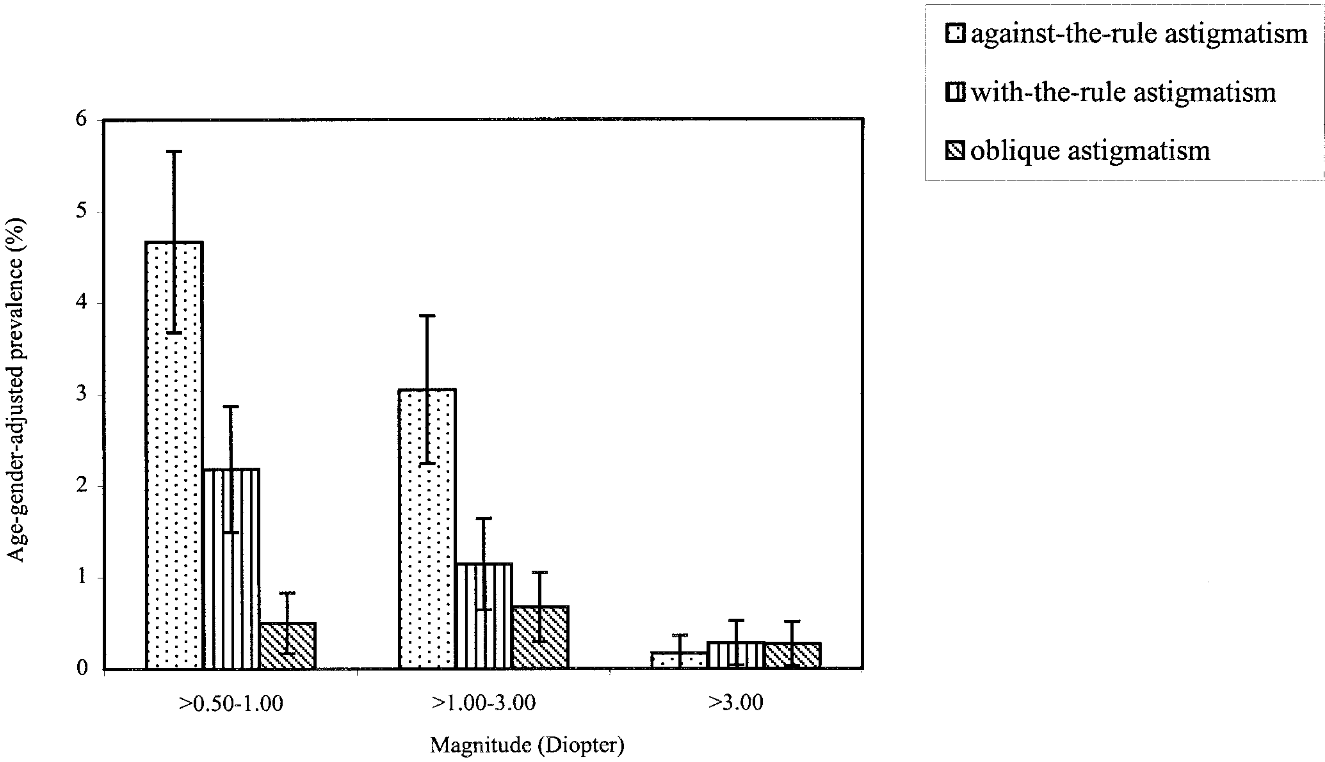

FIGURE 5. Age-gender–adjusted prevalence of astigmatism by type and magnitude for subjects >15 years of age. Bars denote 95% CIs.

age and nuclear cataract is responsible for this finding. Myopic shift in the very old age group has been associated with age-related changes in the lens in a recent study in Melbourne.[9]

We found a significant but weak association of myopia with higher levels of education in our study compared with the associations reported in some previous studies.[2,8,9] Educational status has been shown to be closely related to near-work, and association between near-work activities and myopia has been reported previously,[7] which has also been used in support of the use-abuse theory of myopia.[18]

Prevalence of hyperopia in our population >15 years of age was 9.83%. There was an increase in prevalence of hyperopia beyond 30 years of age. The odds of having hyperopia are quite high for subjects ≥30 years of age in the multivariate model, possibly because of lower prevalence of hyperopia in the age group used as reference in the model. The increase in hyperopia beyond 30 years of age seen in our population is unlikely to be explained by residual accommodation. This hyperopic shift could be explained by a decrease in the power of the aging lens, either a decrease in the curvature of its surface as it grows throughout life or an increase in the density of the cortex that makes the lens more uniformly refractive.[20]

We found a significantly higher prevalence of hyperopia in females than in males. It could possibly be explained by the fact that females have smaller eyes than males as shown in studies on normal eyes[21,22] and, hence, have a higher chance of being hyperopic. We found an association of hyperopia with education, which had borderline statistical significance. However, previous studies have shown a link between hyperopia and academic underachievement.[23–25] We also found a significant association of hyperopia with middle and higher socioeconomic strata. We are not aware of any other study that has revealed these associations, and these findings need to be understood further.

Refraction was not performed on subjects >15 years of age who had distance and near visual acuity of 20/20 or better and who were not using optical correction because they were considered as not having refractive error. This approach in our study should not have affected the prevalence of myopia but may have underestimated the prevalence of hyperopia.

The prevalence of astigmatism in our population >15 years of age was 12.94%. This prevalence of astigmatism included those who had either myopia or hyperopia concurrent with astigmatism. Age-gender–adjusted prevalence of "pure" astigmatism not concurrent with myopia or hyperopia in this population was 2.67% (95% CI, 1.91%–3.43%). Few distribution curves for astigmatism have been published.[26–29] The most common astigmatism in our population was against-the-rule astigmatism. However, with-the-rule astigmatism has been reported to be the most common astigmatism in other populations.[26–29] The trend toward against-the-rule astigmatism beyond the age of 40 years has been shown previously.[29] In our population, against-the-rule astigmatism was dominant in all age groups, and the shift toward against-the-rule astigmatism increased from 40 years of age onward. The hypothesis that eyelid tension is responsible for with-the-rule astigmatism by steepening the vertical corneal meridian and flattening the horizontal meridian[30] explains the changes associated with age. As lid tension reduces with age, so does the with-the-rule astigmatism. Such a high proportion of against-the-rule astigmatism as in our population has not been documented previously. It could be speculated that the lid tension may be less in our population to begin with, which reduces further with age. However, there could be other unidentified reasons for our finding. Our data also show a mild association of astigmatism with higher education. Astigmatism showed a higher concurrence with myopia than with hyperopia, and myopia was associated with a higher education level in our population. This could be a reason why astigmatism was associated with higher education.

Extrapolating the age-gender–adjusted prevalence of myopia, hyperopia, and astigmatism, defined as >0.50 D, in our study to the urban population of India >15 years of age, 155 million in 1997,[14] 30 (95% CI, 24.3–35.6) million people would have myopia, 15.2 (95% CI, 8.5–21.7) million have hyperopia, and 4.1 (95% CI, 3.0–5.3) million have astigmatism without concurrent myopia or hyperopia. Therefore, a total of 49.3 million people is estimated to have refractive error in the urban population of India >15 years of age. If our data on refraction under cycloplegia were extrapolated to the 100 million children in urban India,[14] 4.4 (95% CI, 2.1–6.8) million children would have myopia, and 2.5 (95% CI, 1.3–3.8) million would have astigmatism without concurrent myopia or hyperopia. With the stricter definitions of refractive errors, these projections would not change substantially for ≥0.75 D and would be reduced modestly for ≥1.00 D.

Data about the distribution and demographic associations of refractive errors reported in this article can help in estimating the need for refractive correction and in planning of effective eye-care services in India to reduce the visual impairment due to refractive errors.

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