Age-related changes in the human visual system and prevalence of refractive conditions in patients attending an eye clinic

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PURPOSE: To retrospectively report the trends of change in several parameters of the human visual system over a wide age range in patients attending an eye clinic.

SETTING: University of Valencia, Valencia, Spain.

METHODS: The clinical records of 2654 patients were retrospectively reviewed, and the age, sex, spherocylindrical refraction, visual acuity, keratometry, and intraocular pressure were obtained. Descriptive values for each parameter and the correlations with age and between different parameters were calculated. Vectorial components of refraction, including blur, were also derived from clinical refractive data and then analyzed.

RESULTS: Several parameters changed significantly with age, particularly in patients in their sixties and older. An increase in the blur component was mainly associated with astigmatic progression and a trend toward against-the-rule orientation and had the highest correlation with total astigmatism ($r = -0.319$; $P<.001$) and visual acuity ($r = -0.442$; $P<.001$). Refractive conditions had the most homogeneous distribution in the first decade of life and the most heterogeneous distribution in the group between 61 years and 70 years.

CONCLUSIONS: Best corrected visual acuity began to decrease after the 50s, while changes in the blur component were not patent until the 60s to 70s. This could be explained by the poorer optical quality of the human eye in adulthood and elderly persons. Clinically, these changes could be attributed to changes in ocular astigmatism and have an impact on the best visual acuity achievable with optical compensation.

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The current demographic trends in developed countries are producing a growing interest in studying the age-related changes in all functions of human beings. Old age is responsible for several changes to the visual system. Because some eye-related changes, such as presbyopia, affect all people, the search for technological solutions to eliminate the limitations of these conditions has been an area of major research interest.[1] However, another major concern leading to research of the visual system in the elderly is intraocular pressure (IOP) control because most problems with high IOP occur after the age of 40 years and when not properly detected and managed, the problems can have a serious effect on vision.[2–4]

The anatomical and functional changes in the human eye with age include a spherical equivalent (SE) refraction shift toward myopia during college school years[5] and from myopia to hyperopia in the elderly,[6] change from with-the-rule to against-the-rule corneal astigmatism,[6] steepening of apical corneal curvature,[7–9] and a decrease in the overall corneal diameter.[10] The optical quality is also reduced in the adult eye, particularly after 50 years of age,[11] with an increase in coma mainly due to corneal coma and an increase in spherical aberration attributed to the internal optics of the eye.[12] There is evidence that age-related changes in certain ocular parameters, including corneal curvature, endothelial changes, and the onset of presbyopia, can be different between men and women.[7,13,14] In a recent study, we observed a trend toward a decrease in the central and peripheral IOP measured with rebound tonometry,[15] although sex did not seem to have a significant effect.[16]

Intraocular lens design, laser excimer algorithm computation, and IOP-correcting factors after corneal refractive surgery require knowledge of several ocular

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parameters at different ages. The purpose of this study was to gather clinical data on several ocular parameters at different stages of life to use in theoretical and practical research.

PATIENTS AND METHODS

The clinical forms of 2654 patients attending a primary eyecare center in Valencia, Spain, were retrospectively reviewed to obtain age, sex, spherocylindrical refraction (clinical and Thibos nomenclature), best corrected visual acuity (BCVA) in decimal and logMAR notation, keratometry, and IOP.

Clinical notation of refractive error was converted using the formulation of Thibos et al.[17] for SE (M), astigmatic components (J_0, J_{45}), and blur (B) using the following equations:

$$M = S + \frac{C}{2}$$

$$J_0 = -\frac{C}{2}\cos 2\alpha$$

$$J_{45} = -\frac{C}{2}\sin 2\alpha$$

$$B = \sqrt{M^2 + J_0^2 + J_{45}^2}$$

where S is the spherical component of the refraction, C is the cylindrical component of the refraction, and α is the angle of the cylindrical correction (minus cylinder). To classify refractive error, 3 groups were established according to their SE (M), with myopia being $M < -0.25$ diopter (D), emmetropia $-0.25\text{ D} \geq M \leq 0.25$ D, and hyperopia $M > 0.25$ D according to a previous study conducted by us in a similar population[18] and myopia being $M < -0.50$ D, emmetropia -0.50 D $\geq M \leq 0.50$ D, and hyperopia $M > 0.50$ D according to other studies.[19] A third classification similar to the second one defines myopia as $M \leq -0.50$ D, emmetropia as $-0.50\text{ D} > M < 0.50$ D, and hyperopia as $M \geq 0.50$ D.[20,21]

Visual acuity was converted to logMAR units using the following equation[22]:

$$\text{LogMAR} = \text{minus;}\log(\text{VA}_{\text{dec}})$$

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Data were stored in an Excel spreadsheet and then converted to an SPSS data file (SPSS Inc.) for further statistical processing. Statistical analysis was performed using SPSS software (version 15). Descriptive statistics were obtained for each parameter according to each age group. Bivariate correlations were produced using parametric (Pearson r coefficient) or nonparametric (Spearman coefficient) correlation analysis, depending on normal or non-normal distribution of variables. Normal distribution of variables was previously assessed by the Kolmogorov-Smirnov test. Because variables were non-normally distributed between male and female groups, the Mann-Whitney nonparametric test for independent samples was performed to compare values. The level of statistical significance was $P < .05$.

RESULTS

Figure 1 shows the age distribution of the men and women. Table 1 shows the descriptive statistics for the clinical parameters, statistical significance of the differences between men and women, and correlation coefficients between each parameter and age for men, women, and the entire sample. Visual acuity, both keratometric radii, corneal astigmatism, IOP, and near addition (add) were statistically different between men and women ($P < .05$). Visual acuity was statistically significantly better in men than in women. All remaining parameters with statistically significant differences between sexes, including keratometric readings, corneal astigmatism, mean IOP, and mean near add, had a higher value in women. Despite the statistical significance, only keratometric readings showed what could be considered clinically significant differences, with the mean keratometric readings steeper in women than in men by at least 0.50 D, or 0.10 mm.

Table 2 shows the same results for the vector components of refraction and visual acuity in logMAR units. On average, J_0 values were significantly higher in women than in men by a difference of 0.05 D. The mean blur value was also statistically higher in women than in men by approximately 20%. The blur

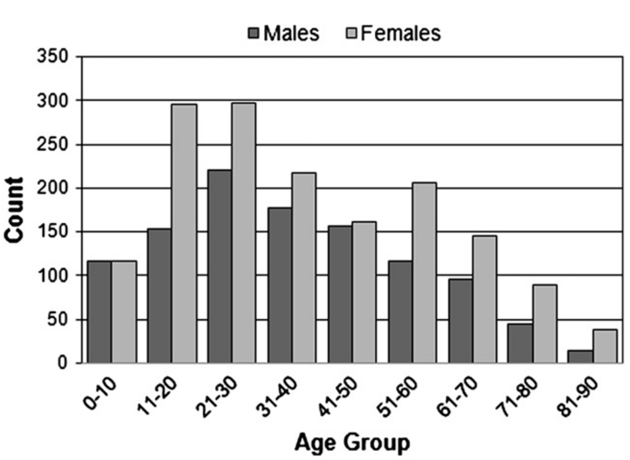


Figure 1. Histogram of the age distribution in men and women.

Table 1. Descriptives of clinical parameters and statistical comparisons. The last column shows the correlation of age with each variable in each group (male, female, total sample).

Parameter/Group	Mean	SD	Minimum	Maximum	Significance*	Correlation†
Sphere (D)					.086	
Male	0.03	2.91	−24.00	14.00		0.160§
Female	−0.34	3.29	−21.50	13.00		0.301§
Total	−0.19	3.14	−24.00	14.00		0.247§
Cylinder (D)					.192	
Male	−0.66	0.88	−6.00	0.00		−0.196§
Female	−0.62	0.92	−10.50	0.00		−0.194§
Total	−0.64	0.90	−10.50	0.00		−0.194§
Axis (degrees)					.048*	
Male	102.30	52.59	0.00	180		−0.174§
Female	107.56	57.65	0.00	180		−0.106§
Total	105.34	55.61	0.00	180		−0.133§
VA (decimal)					.000§	
Male	0.97	0.26	0.05	1.50		−0.200§
Female	0.93	0.26	0.05	1.50		−0.318§
Total	0.95	0.26	0.05	1.50		−0.269§
K1 (D)					.000§	
Male	43.00	1.61	37.50	53.00		0.106§
Female	43.49	1.57	38.75	53.00		0.049
Total	43.29	1.60	37.50	53.00		0.074§
K2 (D)					.000§	
Male	43.84	1.61	39.25	55.00		0.089§
Female	44.40	1.62	39.50	53.00		0.048
Total	44.17	1.64	39.25	55.00		0.067§
Astigmatism (D)					.000§	
Male	−0.84	0.90	−6.75	0.00		0.001
Female	−0.84	0.90	−5.50	0.00		0.051
Total	−0.88	0.96	−6.75	0.00		0.020
IOP (mm Hg)					.012‡	
Male	14.95	3.55	10.00	37.00		0.431§
Female	15.20	3.36	10.00	37.00		0.356§
Total	15.10	3.44	10.00	37.00		0.388§
Add (D)					.000§	
Male	2.20	0.82	0.50	3.50		0.845§
Female	2.44	0.79	0.50	3.50		0.904§
Total	2.34	0.81	0.50	3.50		0.884§

Add = addition; IOP = intraocular pressure; K1 = flat keratomeric reading; K2 = steep keratomeric reading
*Mann-Whitney nonparametric test for independent samples between men and women
†Spearman rho for correlation between each parameter and age
‡$P<0.05$
§$P<.001$

parameter (B) was significantly correlated with several other parameters and some of them could be considered independent variables that may be involved with blur changes; these included age ($r = 0.144$; $P<.001$), corneal cylinder ($r = -0.231$; $P<.001$), near addition ($r = 0.316$; $P<.001$), and SE refraction (M) ($r = -0.168$; $P<.01$). However, the highest correlations of blur corresponded to visual acuity ($r = -0.319$; $P<.001$) and total astigmatism ($r = -0.442$; $P<.001$).

Figure 2 shows the mean values of each parameter for men and women separately. The graphs do not represent longitudinal changes but rather the mean values in each age group. The most significant trends occurred after the decades of the 40s and 50s. There was a significant trend toward higher hyperopia, higher astigmatism, higher keratometric power values, and higher near add values. Figure 3 shows that these trends were accompanied by a progressive increase in logMAR acuity (Figure 3, *A*), which in clinical terms would represent a loss of decimal visual acuity (Figure 3, *B*) at a rate of 2 lines for each decade after the 50s. Also, there was a statistically significant

Table 2. Descriptives of refractive parameters converted to vector nomenclature and visual acuity in logMAR units. The last column shows the correlation of age with each variable for each group (male, female, total sample).

Parameter	Mean	SD	Minimum	Maximum	Significance*	Correlation†
M (D)					.187	
Male	−0.30	2.88	−24.00	12.00		−0.131‡
Female	−0.65	3.30	−23.00	11.50		0.266‡
Total	−0.50	3.14	−24.00	12.00		0.214‡
J_0 (D)					.000‡	
Male	−0.01	0.48	−2.50	3.00		−0.334‡
Female	0.04	0.48	−5.25	5.17		−0.205‡
Total	0.02	0.49	−5.25	5.17		−0.257‡
J_{45} (D)					.859	
Male	0.01	0.25	−1.72	1.64		0.032
Female	0.01	0.27	−3.45	1.88		0.001
Total	0.01	0.26	−3.45	1.88		0.013
B (D)					.000‡	
Male	1.66	2.43	0.00	24.00		0.123‡
Female	2.06	2.72	0.00	23.09		0.151‡
Total	1.89	2.61	0.00	24.00		0.144‡
VA (logMAR)					.000‡	
Male	0.04	0.20	−0.18	1.31		0.200‡
Female	0.06	0.20	−0.18	1.31		0.318‡
Total	0.05	0.20	−0.18	1.31		0.269‡

B = blur; J_0 and J_{45} = astigmatic components; M = spherical equivalent; VA = visual acuity
*Mann-Whitney nonparametric test for independent samples between men and women
†Spearman rho for correlation between each parameter and age
‡$P<.001$

change in IOP from the first decades on at a mean rate of approximately 0.7 mm Hg per decade from a mean initial value of 12 mm Hg (Figure 4).

For the whole sample, age was positively correlated with spherical refraction ($r = 0.247$; $P<.001$), SE (M) ($r = 0.214$; $P<.001$), IOP ($r = 0.388$; $P<.001$), blur ($r = 0.144$; $P<.001$), and logMAR ($r = 0.269$; $P<.001$) and was negatively correlated with ocular astigmatism ($r = -0.194$; $P<.001$), decimal visual acuity ($r = -0.269$; $P<.001$), and J_0 ($r = -0.257$; $P<.001$).

There was a progressive and continuous trend toward an increase in the J_0 component of astigmatism after the 30s, while the J_{45} component remained almost equal to zero and decreased in late old age (Figure 5). The blur component showed a phasic behavior, with a slight increase during the first 3 decades of life and remaining almost constant during the following decades until the 60s, when a marked increase begins in the blur component to the higher values in the 80s and 90s.

Figure 6 shows the prevalence of myopia, emmetropia, and hyperopia across the entire sample by age group. The distribution of refractive conditions (33%, 39%, and 28% for myopia, emmetropia, and hyperopia, respectively) was similar in the youngest group, which had the highest prevalence of emmetropia. The largest asymmetry in the distribution of refractive conditions (31%, 8%, and 61%, respectively) was in the 61- to 70-year group, which had the lowest prevalence of emmetropia. Figure 7 shows the prevalence of different refractive conditions considering the 3 criteria to define ametropia and emmetropia, as outlined in Patients and Methods.

DISCUSSION

The results in this study should not be interpreted as longitudinal changes in the human visual system. However, they provide a significant pool of clinical data on the parameters of the visual system at different stages of life in patients currently attending an eyecare facility.

Overall, the blur component increased continuously after the 50s, a finding that was coincident with a progressive deterioration in the clinically measured visual acuity during the same period. The blur component and visual acuity have a significant correlation with each other. Thus, visual acuity is a good reflection of the mathematical expression of refractive error as represented by the blur component and vice versa. Apart from near add, which did not account for the calculation of the blur parameter, the parameter that showed

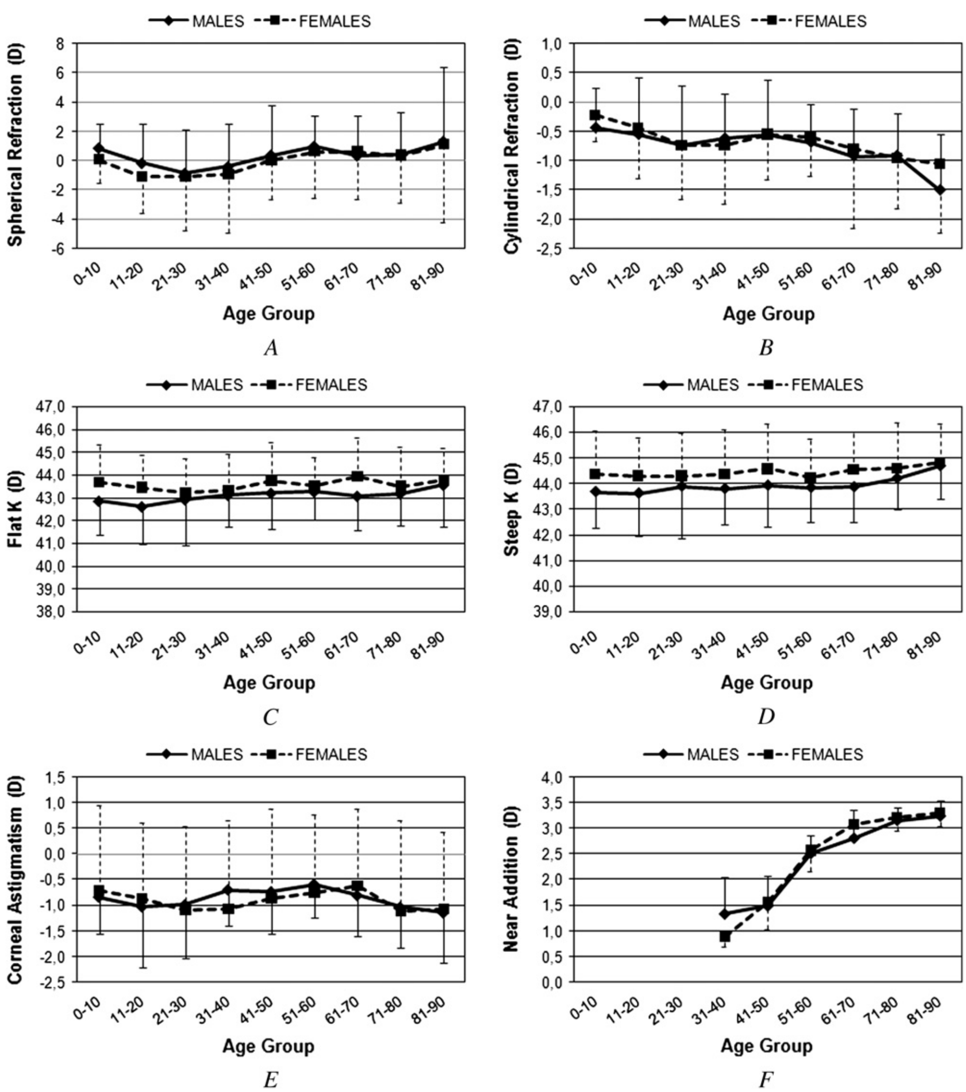
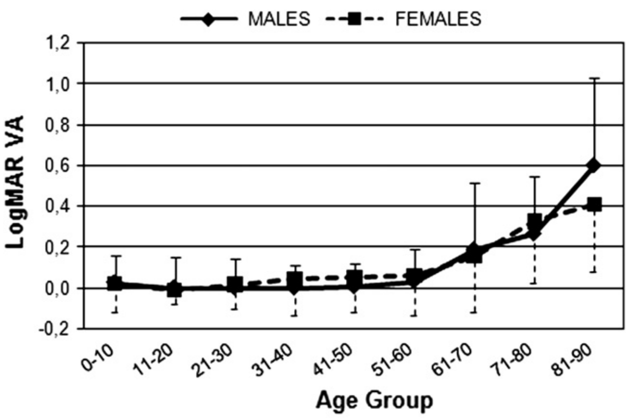


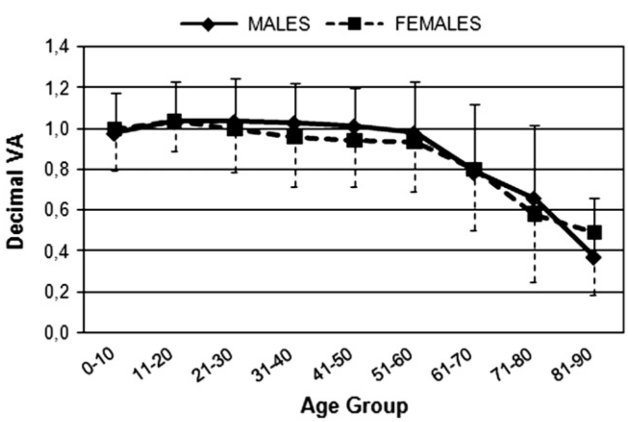
Figure 2. Mean refractive parameters in and women by age group.

a pattern of change consistent with this finding was ocular astigmatism. In fact, this parameter had the highest correlation with the blur parameter. This finding agrees with the results of Remón et al.,[23] who report the impact of astigmatism on the blur component. The correlation found in the present study was negative, which means that blur increased as the value of the cylinder decreased (increased in negative value). In addition, blur's relationship with J_0, although weak, was significant and positive, which means that blur increased as J_0 increased in positive values. The observed increase in the value of total refractive astigmatism is in agreement with findings in previous studies, even those of different ethnic groups. Asano et al.[24] found the prevalence of astigmatism increased with age in a Japanese population from 40 to 79 years of age. The mean of the astigmatism also increased in their age groups. We also found an increase in the prevalence of astigmatism, from 35% in the 0- to 10-year group (mean −0.94 D ± 0.61 [SD]) to 40% in patients the 11- to 20-year group (mean −1.20 ± 1.07 D) to 72% in the 71- to 80-year group (mean −1.30 ± 0.66 D) to 64% in the 81- to 90-year group (mean −1.86 ± 0.81 D). This should not be understood as the prevalence of astigmatism, or other refractive conditions in the general population, as the cohort comprised patients attending a primary eyecare clinic.

In the present study, we observed that overall, the spherical refraction and SE refraction had an initial trend toward myopia until the 30s; this was followed by a trend toward hyperopia until the 50s, a relatively stable refraction for the following 2 decades, and an increase in hyperopia in the 80s. The mean refraction values showed a trend toward higher hyperopia in the older groups. This could be related to the findings of Montés-Micó and Ferrer-Blasco,[18] which showed a higher prevalence of hyperopia in middle-aged and elderly persons. The decrease in myopia from the 30s



A



B

Figure 3. Mean logMAR (*A*) and decimal (*B*) visual acuity in men and women by age group.

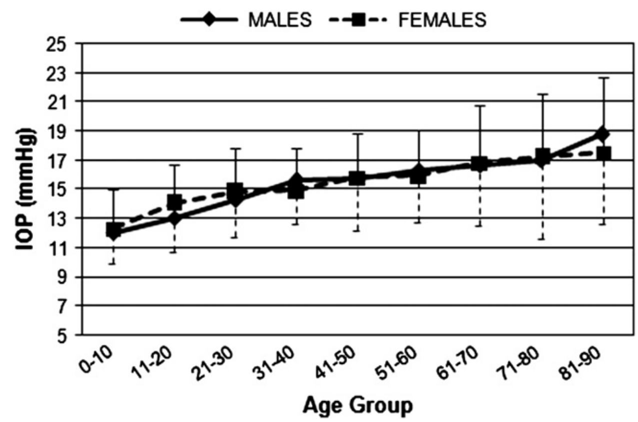
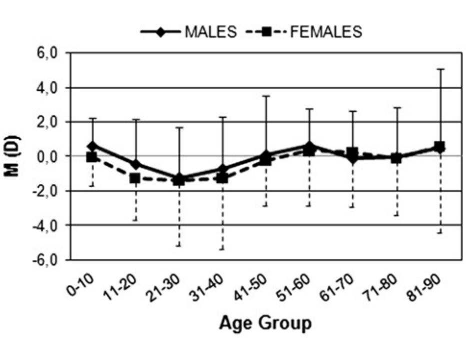
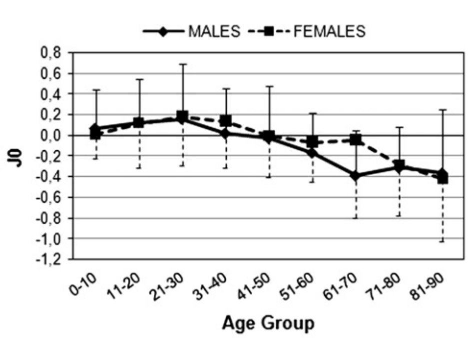


Figure 4. Mean IOP in men and women by age group.

is supported by the results of Wensor et al.,[20] who found a decrease in the prevalence of myopia between 40 to 49 years of age and 70 to 79 years of age in an Australian population. The results in Figure 6 agree with those in studies supporting the hypothesis that the higher hyperopia values in the elderly are due to a higher prevalence of this condition, while the decrease in myopia is due in part to the lowest prevalence of this condition in middle age. Other classifications of myopia, emmetropia, and hyperopia will render different prevalences of refractive conditions but will give the same trends for the prevalence of hyperopia and myopia with age. If we consider the second or third criteria outlined in Patients and



A



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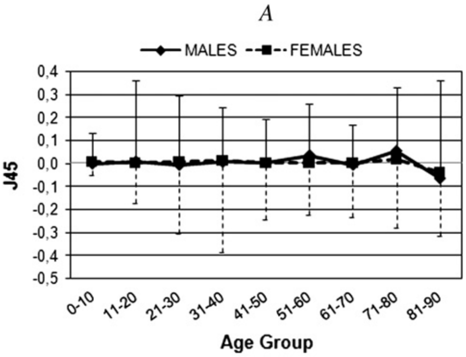
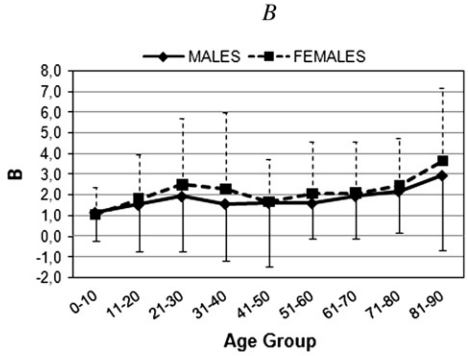


C



D

Figure 5. Mean values of vector refractive components in men and women by age group.

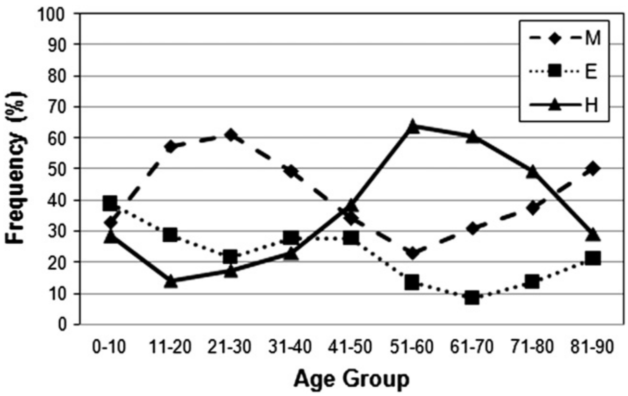


Figure 6. Prevalence of refractive conditions in different age groups (M = myopia [M < −0.25 D]; E = emmetropia [−0.25 D ≥ M ≤ 0.25 D]; H = hyperopia [M > 0.25 D]).

Methods, prevalence of myopia decreased approximately 10% between the youngest age group and the 41- to 50-year group, decreasing approximately 5% thereafter. Conversely, criteria to define hyperopia render approximately the same prevalence in the first 3 decades and a 5% to 10% difference thereafter. Emmetropia was most sensitive to prevalence changes when considering different criteria to define ametropia, with differences exceeding 25% in some cases. We emphasize that these classifications are based on noncycloplegic subjective refraction. However, considering the second criteria used in this paper to define ametropia, Jorge[25] found that the prevalence of myopia was similar with noncycloplegic subjective refraction in a young adult population of university students. Also, when performed under noncycloplegic conditions, retinoscopy is the best starting point to achieve a reliable subjective prescription.[26,27] This methodology was followed systematically in the present study in all cases, when possible.

The higher prevalence of myopia in the young population is in agreement with the results of Pointer.[28] In his longitudinal study, Pointer found a more significant shift toward increased myopia between the age of 9 years and 11 years. The continuation of myopic shift after the first decade of life agrees with recent results of Jorge et al.,[5] showing a trend toward myopia in young college students. They found, however, that the annual progression of myopia decreased as age increased. In the present study, there was a trend toward adults older than 40 years being less myopic than younger adults and adolescents. In older groups, there was also a trend toward a decrease in myopia, which agrees with results of Wojciechowski et al.,[29] who found a higher prevalence of hyperopia in adults until 75 years of age. The hyperopic shift from the 30s, with a maximum mean hyperopic value in the elderly, also agrees with previous 2000 results of Montés-Micó and

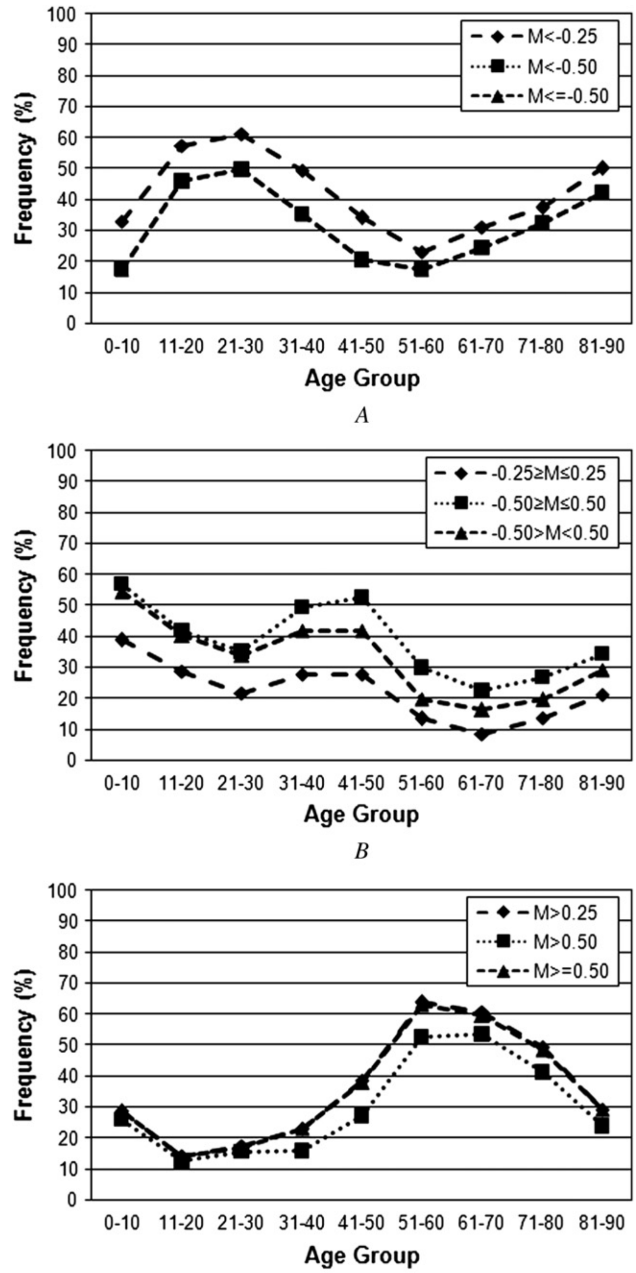


Figure 7. Prevalence of refractive conditions in different age groups according to different definition criteria for myopia (*A*), emmetropia (*B*), and hyperopia (*C*).

Ferrer-Blasco[18] for a much larger population in the same region of Spain. Their study also showed a maximum myopic value in the third decade, which also agrees with our results.

The astigmatic component J_0 showed a clear trend toward mean values of zero and negative values with aging, particularly after the 50s, which supports the commonly accepted trend of astigmatic refraction changing from with the rule to against the rule.[6]

Despite the inverse correlation between blur and decimal visual acuity (positive correlation with logMAR visual acuity), there was not a direct correlation between the paths of both variables when considering mean values by decades (Figures 3, *A* and *B*, against Figure 5, *D*). In fact, although the decrease in visual acuity was patent after the decade of the 50s, changes in average blur were evident only after the 60s and 70s. Pathological changes could account for the lack of correspondence, although other factors could be involved. First, lens opalescence begins in most people in the 50s; however, such changes in lens transparency and the corresponding scatter are not clinically significant at this stage, with no impact on BCVA, even when it reaches moderate levels on the Lens Opacities Classification System scale. Second, the increase in against-the-rule astigmatism after the 50s could be related to the increase in blur; in fact, the 2 parameters were significantly correlated across our sample. However, this astigmatism should be correctable and not affect BCVA. Thus, a loss of optical quality of the eye beyond clinical refractive error must be considered. Several studies document an increase in optical aberrations, particularly those arising from the crystalline lens, with age.[30] Accordingly, significant relationships between coma and spherical aberration with age have been reported.[11,12] Thus, the lack of correlation between ametropia, an early decrease in BCVA, and a later increase in blur vector related purely to refractive error could be explained on the basis of the poorer optical quality of the human eye after the 50s.

In this cross-sectional study, there was an association between age and higher values of blur, probably due to higher against-the-rule ocular and corneal astigmatism and the decrease in the optical quality of the eye caused by a combination of increased optical aberrations and light scatter. We found several significant relationships between refractive and visual parameters that combine to show the natural change in the visual system in terms of performance of distance and near tasks as well as in the values of the average shape of the central corneal cap. These data provide normative values of the main refractive, visual, and keratometric parameters and allow estimations of sample size in future experiments according to the age range to be used in future theoretical and practical research.

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