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Distribution of axial, corneal, and combined ametropia in a refractive surgery unit

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PURPOSE. *To group eyes in our refractive surgery unit on the basis of the origin of their ametropia and to assess the percentage of eyes in the different groups.*

METHODS. *Refractive parameters and the axial eye length (AL) of 131 eyes of 131 persons with different refraction were measured. The eyes were initially classified into five groups on the basis of the grade of their ametropia: hypermetropic (>+0.5 D, n=35), emmetropic (between ±0.5 D, n=24), low myopic (between –0.75 and –4.0 D, n=24), medium myopic (between –4.25 and –8.0 D, n=24), and high myopic (over –8.0 D, n=24). Then a classification scheme was made to group the origin of the ametropia on the basis of AL and corneal refractive power.*

RESULTS. *In the hypermetropic group pure corneal origin was found in 8.6%, pure axial origin in 62.8%, and combined origin in 28.6% of the eyes. In the low myopic group these values were 20.9%, 29.2%, and 45.8%, respectively. In the medium and high myopic groups no pure corneal myopia was found, while axial myopia was found in 16.7% and combined myopia in 83.3% of the eyes.*

CONCLUSIONS. *With the help of the classification scheme, an objective decision could be made as to whether the ametropia of a particular eye had axial, corneal, or mixed origin. The most interesting result was that in 83% of medium and high myopic eyes not only AL but also corneal refractive power contributed to the refractive error instead of the eyes being purely axially myopic. (Eur J Ophthalmol 2003; 13: 739-44)*

KEY WORDS. *Ametropia, Axial eye length, Corneal refractive power, Emmetropia*

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INTRODUCTION

An eye is called emmetropic if its axial length (determining the image distance where the image should be formed) and its refraction are in correct relation to each other (1). Otherwise, the result will be ametropia. The terms axial ametropia and corneal ametropia, depending on which factor plays the main role, are used ophthalmology literature (2).

The aim of our study was to determine the distribution of the eyes in which ametropia is mainly caused by deviation from the emmetropic mean values of the axial eye length (AL), the corneal refractive power, or both of these parameters in different combinations in a group of cases of our refractive surgery unit.

METHODS

The study population was randomly selected from those who visited the excimer laser refractive surgery unit of our department over a 1-year period. The emmetropic eyes were either fellow eyes of mildly ametropic ones or eyes of age-matched healthy vol-

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TABLE I - PARTICIPANTS

	Number	Age (years)			
		mean	S.D.	min	max
Male	65	36.0	16.8	17	75
Female	66	37.6	16.2	18	74
Total	131	36.8	16.4	17	75

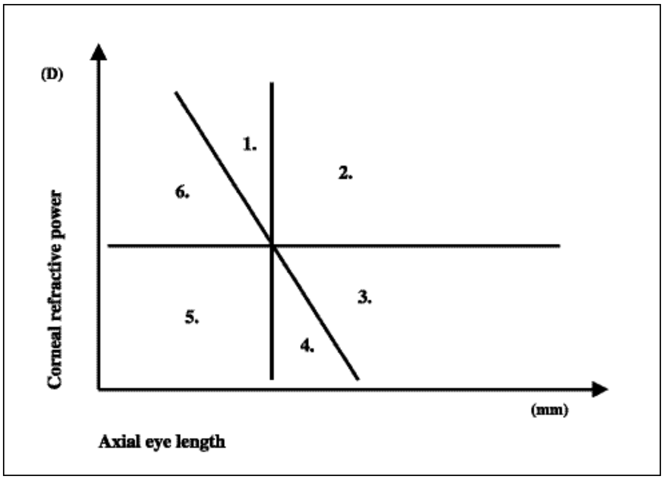

Fig. 1 - *The six sectors in the classification system, where x-axis = axial eye length (AL) and y-axis = corneal refractive power (K). The horizontal line is the mean K for emmetropes (43.0 D), the vertical line the mean AL for emmetropes (23.4 mm), and the oblique line is the regression line of the emmetropic group (K = -1.37 * AL + 75.0). Key to the sectors: 1 = corneal myopia; 2 = combined myopia; 3 = axial myopia; 4 = corneal hyperopia; 5 = combined hyperopia; 6 = axial hyperopia. For more details, see Methods.*

unteers. Altogether the parameters of 131 subjects were measured, and the data of one randomly selected eye of each subject were included in the analysis. We excluded those eyes with any sign of ocular disease including severe myopic complications (retinal detachment, staphyloma). The age and sex distribution of the subjects is shown in Table I. The following parameters were measured: AL, anterior chamber depth, lens thickness, corneal refractive power (keratometric parameters), best visual acuity corrected for 5 meters, and spherical and cylindrical diopters of the correction. Spherical equivalent (sph. eq.) was calculated using the formula sph. eq .= $D_{sph} + D_{cyl}/2$, where D_{sph} is the spherical component and D_{cyl} the cylindrical component of the correction (3).

AL and its components were measured with contact method using a 10 MHz A-scan ultrasound (Alcon Ultrascan Digital B 2000). The validity and reproducibility of this method has been well documented by Németh (4). This measurement has been taken by an experienced examiner to keep the chance of impressing the corneal surface as low as possible. In each case the average value of five measurements was used (criteria for accepting a measurement were the height and steepness of the echo spikes).

The determination of the refraction of the eyes was based on the best far distance (5 m) subjective spectacle correction. In the beginning of this process a convex lens was always tried first, and if the visual acuity got better or there was no change due to the convex lens, cycloplegia was performed.

Corneal refractive power was measured by means of a TMS-1 Cornea Topograph (Computed Anatomy Inc., New York), and the simulated keratometric values were used in the analysis.

The statistical analysis methods used for the data included two-sampled t-test, analysis of variance with LSD *post hoc* test, linear regression, and graphic representation.

The 131 eyes were classified into five refractive groups on the basis of their overall refractive error: hypermetropic group (sph. eq. over +0.5 D, n=35), emmetropic group (sph. eq. between ±0.5 D and visual acuity better than 0.7, n=24), low myopic group (sph. eq. between –0.75 and –4.0 D, n=24), medium myopic group (sph. eq. between –4.25 and –8.0 D, n=24) and the high myopic group (sph. eq. equal to or over –8.25 D, n=24).

The distribution of AL and corneal refractive power (K) and then the correlation between these two parameters were examined within each group. An objective classification scheme was made to classify the eyes into groups of axial, corneal, and combined ametropia, using these empirical results. For this purpose, a system of coordinates (Fig. 1) was used (x-axis = AL; y-axis = K). This coordinate plane is divided into six sectors by three straight lines: x = 23.4 mm (mean AL of emmetropes), y = 43.0 D (mean K of emmetropes), K = -1.37 * AL + 75.0 (regression line for emmetropes) (see Fig. 4 and Tab. II in Results). The “myopic” area is upward and right from the emmetropic regression

TABLE II - THE CORRELATION BETWEEN AXIAL EYE LENGTH (AL) AND CORNEAL REFRACTIVE POWER (K)

Refractive group	p	r	a	b
Hypermetropic	<0.001	-0.66	-1.03	66.41
Emmetropic	<0.001	-0.80	-1.37	74.95
Low myopic	<0.001	-0.79	-1.62	83.11
Medium myopic	=0.005	-0.56	-0.92	67.60
High myopic	=0.002	-0.51	-0.67	62.58

K = a* AL + b

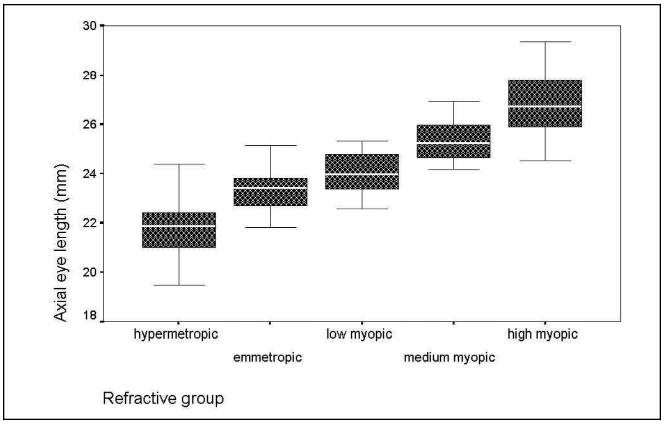

Fig. 2 - *The distribution of axial eye length (AL) for the different groups. White line within box = median; area of the box = interquartiles; "T"-lines above/below the box = extreme values.*

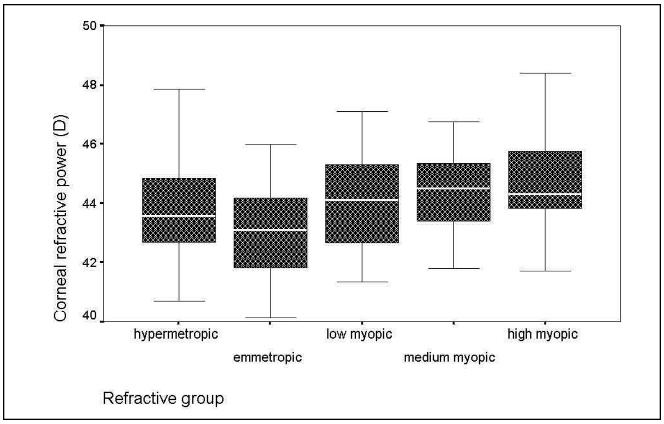

Fig. 3 - *The distribution of corneal refractive power. White line within box = median; area of the box = interquartiles; "T"-lines above/below the box = extreme values.*

line (sectors 1, 2, 3), and the "hypermetropic" area is downward and left from this line (sectors 4, 5, 6). Sector 1 is corneal myopia (AL is less than the mean AL value for emmetropes, but corneal refractive power is greater than the corresponding mean K value). Sector 2 is combined myopia (both parameters are over the mean values for emmetropes, both causing myopia). Sector 3 is axial myopia (the value of corneal refractive power is less than the mean value for emmetropes, but AL is greater than the mean AL, tending to cause myopia). In a similar way, sector 4 is corneal hypermetropia, sector 5 is combined hypermetropia, and sector 6 is axial hypermetropia.

RESULTS

The distributions of AL and corneal refractive power in the five refractive groups defined above are shown in Figures 2 and 3.

As might be expected, hypermetropic eyes had the shortest, emmetropic eyes had medium length, and myopic eyes had the greatest axial length. Although the differences of AL between the groups were all statistically significant (the result of the general analysis of variance (ANOVA) was $p<0.001$, and the LSD *post hoc* test showed $p<0.001$ between each pair except between the emmetropic and the low myopic groups where $p=0.04$), fairly large overlaps were found between the groups (Fig. 2).

Corneal refractive power showed even more considerable overlaps between the groups (Fig. 3), although the result of the general ANOVA was $p=0.01$. Using the LSD *post hoc* test, the differences between three pairs were statistically significant: between the emmetropic and the low myopic groups ($p=0.02$), the emmetropic and the medium myopic groups ($p=0.006$), and the emmetropic and high myopic groups ($p=0.001$). The corneal refractive power was lower in the emmetropic group than in any of the ametropic groups.

Figure 4 and Table II show corneal refractive power as the function of AL in the five refractive groups. In all groups, longer eyes had a flatter cornea. The regression line of the hypermetropic group was shifted to a lower range of axial length, while the lines of the myopic groups were shifted to higher ranges of axial length compared to that of the emmetropic group. In addition, the correlation between AL and corneal

TABLE III - THE PERCENTAGE OF EYES WITH CORNEAL, COMBINED AND AXIAL AMETROPIA WITHIN THE REFRACTIVE GROUPS (see Methods, Results and Fig. 5)

Refractive group	Type of ametropia		
	corneal	combined	axial
Hypermetropic	8.6%	28.6%	62.8%
Low myopic	20.9%	45.8%	29.2%
Medium myopic	0.0%	83.3%	16.7%
High myopic	0.0%	83.3%	16.7%

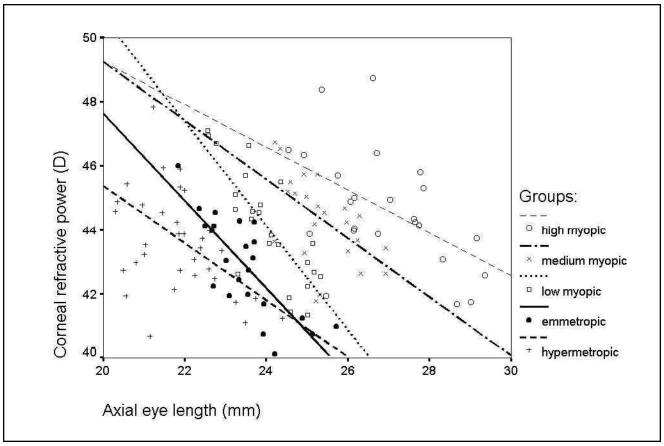

Fig. 4 - *The correlation between axial eye length and corneal refractive power within the refractive groups. The lines show the results of linear regression within each group.*

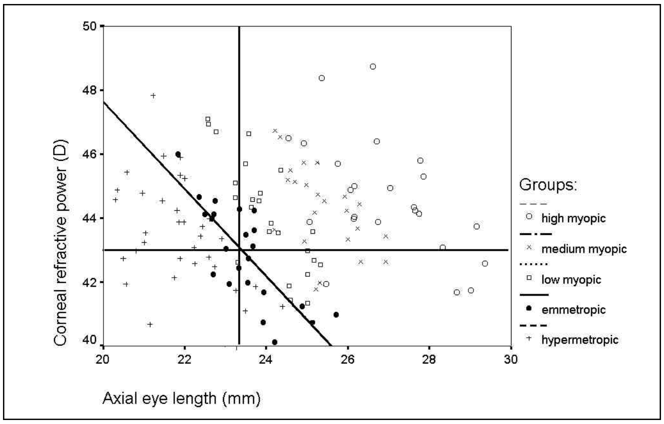

Fig. 5 - *The data for the examined eyes shown superimposed on the classification scheme.*

refractive power was stronger in the emmetropic group than in any of the ametropic groups and the regression line in the emmetropic and in the low myopic group was steeper than in the other groups (Tab. II).

Figure 5 shows the data for the examined eyes plotted onto the system of coordinates described in Methods. Table III shows the percentage of the eyes in which ametropia was mainly caused by deviant AL, by deviant corneal refractive power, or by these two together. There were a few cases of hypermetropic eyes in a myopic sector and a low myopic eye in a hypermetropic sector; in these, AL and corneal refractive power deviations would be expected to cause a refractive error of opposite sign compared to the actual measured value of ametropia.

DISCUSSION

We constructed a new objective classification scheme for differentiating among axial, corneal, and combined ametropia in this study. This scheme is a system of coordinates containing three hypermetropic and three myopic sectors (see detailed description in Methods). This is a simplified scheme and does not take into account several factors that may affect the final refraction of the eyes, such as the refractive power of the crystalline lens or the anterior chamber depth. Small pupils may produce a pinhole effect and change the result of the visual acuity test, but though mydriatic drops were not used in all of the patients, their pupils were never that small, owing to the rather mesopic light conditions in the examination rooms. The origin of the ametropia of an eye – which may be important in connection with the risk of myopic or hyperopic complications – can be determined by plotting its data parameters on this diagram (Fig. 1). Presumably, the outcome of refractive surgery procedures and the stability of these results may also be different in the six subgroups. Therefore, in a future study we plan to correlate our results to preoperative pachymetry readings and post-photorefractive keratectomy (PRK) refractive status and stability.

With the data of the examined eyes placed onto our scheme, some of the hypermetropic eyes fell into a myopic sector and one low myopic eye fell into a hypermetropic sector. Most of these eyes needed correction between ±1.0 and 2.0 D. This inconsistency between the values of AL, corneal refractive power, and the measured ametropia might be caused by the deviation of other refractive parameters (curvatures and refractive index of the lens that we could not measure; chamber depth). Other possible reasons may be errors in AL measurements or in keratometry, or may result from the subjectivity of refraction measurements. However, hyperopic eyes falling into sector 1 (Fig. 5) were considered to have axial hyperopia (Tab. III), because in this sector AL is lower and corneal refractive power is higher than the mean value of emmetropes, just as in sector 6. One eye from the low myopic group fell into sector 5 (this is not represented in Tab. III).

In Table III we can see the percentage of ametropia caused by the alteration of AL, corneal refractive power, and these two together within each group. For the hypermetropic eyes the percentage of combined hypermetropia (28.6%) was about half of that of axial hyperopia (62.8%), while only 8.6% of the cases were corneal hypermetropia. In the low myopic group the percentages of eyes with ametropia of axial, corneal, and combined origin were 29.2%, 20.9%, and 45.8%, respectively. In the medium and high myopic groups, 16.7% of the eyes had pure axial myopia, 83.3% had combined myopia, and none had pure corneal myopia. This is a surprising result because it is a common idea that medium and high myopic eyes most often have axial myopia. However, in more than four fifths of these eyes corneal refractive power also contributes to the myopia; therefore, most of the eyes that are said to have axial myopia actually have combined myopia. This also means that refractive laser surgery – as it affects the corneal refractive power – corrects not only the effect of a longer AL, but in part it corrects the origin of the refractive error in the cornea.

The two main determinant factors of refraction that are easily measurable (AL and corneal refractive power) are not independent of each other in emmetropic eyes. Our results showing the inverse correlation between AL and corneal refractive power (Fig. 4) are similar to the published results of previous studies. Francois and Goes (5) examined 100 emmetropic eyes and found the mean axial length to be 23.37 mm (23.4 mm in our study). The correlation they found between AL and the radius of corneal curvature was somewhat weaker (r=0.69) than in our study, perhaps due to the different grouping criteria. (They considered eyes with a refractive error ±1 D to be emmetropic, while in our study the criterion of emmetropia was a refractive error less than ±0.5 D). The results of Koretz et al (6) were similar to ours: they found correlation between AL and corneal refractive power both in emmetropic and myopic eyes, stronger in emmetropes than in myopes.

In emmetropic eyes the correlation between AL and corneal refractive power shows that these two factors compensate each other's deviation from the mean value, demonstrating the result of the developmental process called emmetropization. In our study similar correlation was found in ametropic eyes, but it was somewhat weaker and the regression lines were shifted to different ranges of AL. This suggests that the mechanisms of emmetropization – at least partially – also work during childhood in eyes that later do not achieve emmetropia. The developing ametropia may be due to the insufficiency of the mechanisms of emmetropization, or to its poor calibration. The fact that in about 83% of medium to highly myopic eyes both parameters contribute to the overall refractive error also points to the defects of the emmetropization.

The fact that AL and corneal refractive power vary within wide ranges overlapping considerably between the refraction groups has clinical consequences. The incidence and severity of myopic complications depends on the length and the equatorial diameter of the eye (7) and not on its refraction. Severe complications certainly develop in very long, highly myopic eyes, but as our results show there are eyes in the group of medium myopia reaching 26 to 27 mm in length, thus having the same chance of myopic complications as highly myopic eyes. Moreover, emmetropic and even hypermetropic eyes can be found having the same AL as most of the eyes in the low and medium myopic groups. We believe that among these emmetropic and hypermetropic eyes the incidence of myopic complications may be the same as among eyes with the same length but with myopic refraction. This is not excluded if the eye is not in fact elongated but merely spherically enlarged, because the amount of tissue forming the coats of the eye is constant, and bigger eyes consequently have thinner coats than smaller ones (8, 9). The axial length of the eyes falling into the sectors of axial and combined myopia and corneal hyperopia is longer than the mean value of emmetropes; therefore these eyes may have the risk of myopic complications that is proportional to the grade of elongation. Similarly, the eyes falling into the sectors of axial and combined hyperopia and corneal myopia may be inclined to hyperopic complications even if they have myopic refraction, as they are shorter than the average emmetropic eye. These – and possibly other – clinical consequences are not fully understood and need further study.

Owing to the high variability of AL in all refractive groups, it may be better to classify eyes at least according to axial length or to both axial length and corneal refractive power rather than only refraction in studies connected with refractive surgery or myopic complications (e.g. peripheral retinal degeneration; retinal detachment) (10). In this way the errors arising from the wide range of AL in eyes with the same refractive status can be eliminated.

In our study population, all eyes with medium or high myopia had longer eyeballs than the average value of emmetropes; however, in more than 80% of these eyes corneal refractive power also contributed to the overall refractive error. Therefore, it would be more accurate to say that most medium and high myopic eyes have combined and not only axial myopia.

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