

THE RELATIONSHIPS BETWEEN OCULAR OPTICAL COMPONENTS AND IMPLICATIONS IN THE PROCESS OF EMMETROPIZATION

RELACIÓN ENTRE LOS COMPONENTES ÓPTICOS OCULARES E IMPLICACIONES EN EL PROCESO DE EMETROPIZACIÓN

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ABSTRACT

Purpose: To report the relationship between different optical components and the influence of axial length on emmetropization.

Methods: 109 young university students, divided into five groups, were enrolled in this study: emmetropes, hyperopes, low myopes, moderate myopes and high myopes. Intraocular parameters and topographic corneal analyses were performed by ultrasonography and videokeratoscopy respectively.

Results: Anterior chamber depth and axial length were found to correlate significantly in eyes with axial lengths less than 24 mm ($r = 0.441$; $p < 0.001$). However this correlation was not found in eyes with longer axial lengths ($r = 0.098$; $p = 0.527$). Lens thickness showed an inverse correlation with axial length for shorter eyes ($r = 0.391$; $p < 0.001$), whereas any correlation in longer eyes was associated with moderate to high levels of myopia. Anterior corneal curvature only correlated, although weakly, with vitreous chamber depth for shorter eyes ($r = 0.363$; $p < 0.003$).

RESUMEN

Objetivo: Determinar la relación entre los diferentes componentes ópticos oculares y la emetropización en función de la longitud axial (LA).

Métodos: Participaron 109 jóvenes universitarios divididos en cinco grupos según el error refractivo: emétopes, hipermétopes, miopes bajos, miopes moderados y miopes altos. La medida de los parámetros intraoculares y el análisis de la topografía corneal se realizó mediante ultrasonografía y videokeratoscopia respectivamente.

Resultados: Se encontró una correlación estadísticamente significativa entre la profundidad de la cámara anterior (PCA) y la LA en ojos con LA menor de 24 mm ($r = 0,441$; $p < 0,001$). Sin embargo en ojos con LA mayor no se encontró tal relación ($r = 0,098$; $p = 0,527$). El espesor del cristalino (EC) mostró una correlación inversa con la LA para los ojos con LA < 24 mm ($r = 0,391$; $p < 0,001$), siendo nula en el caso de ojos con LA ≥ 24 mm. La curvatura corneal (RC) sólo mostró una débil correlación con la profundidad de la cámara

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Conclusion: Differences in optical parameters of the human eye displayed different associations in longer eyes. A lack of correlation was seen between ocular components in eyes with higher myopia, corresponding to myopia in excess of 2.00 D (*Arch Soc Esp Oftalmol* 2008; 83: 307-316).

Key words: Refractive error, axial length, ocular components, ametropia, emmetropization.

vítrea (PCV) en ojos con LA < 24 mm ($r = 0,363$; $p < 0,003$).

Conclusión: Los parámetros ópticos del ojo humano se relacionan de distinta forma según el tamaño del ojo, encontrándose en los ojos más miopes una ausencia de coordinación entre los componentes ópticos oculares, que según los resultados de este estudio, es a partir de 2,00 D.

Palabras clave: Error refractivo, componentes ópticos oculares, longitud axial, ametropía, emetropización.

INTRODUCTION

Numerous studies (longitudinal, traversal and epidemiological) have endeavored to increase our knowledge of the development and progression of refractive errors, focusing on the relationship between the ocular components, the corneal topography and its role in the development of ametropia (1-4). In the same way, interest has been shown in the implications on refractive surgery (5-7) or in the optical quality of the eye (8). The following ocular components could influence refractive error (X-ray): the radius of anterior corneal curvature (AC), the anterior chamber depth (ACD), lens thickness (CT), the vitreous chamber depth (VCD) and the axial length (AL).

The direct correlation between the ACD and the medium corneal diameter is known, in such a way that myopic eyes are bigger eyes, with greater corneal diameters and deeper anterior chambers (6). Stone et al (9), investigating on chickens, considered that the corneal surface could be a useful variable to evaluate the growth of the anterior segment during the growth of the eye (9), and a more adequate parameter than the conventional means of ACD or AC.

The average of the ACD gives information on the anterior and equatorial growth of the eye. On the other hand, the VCD and the LA are considered to be the most representative indicators for the growth of the posterior segment, as well as the main factors in the progression of myopia (3,10). However, it has still not been shown whether any threshold exists for the correlation between the sagittal and axial parameters responsible for the appearance of high or moderate myopia.

Previous studies on chickens have shown the disassociation of the mechanisms responsible for the growth of the anterior segment and the vitreous chamber. For example, under certain lighting condi-

tions the ACD has been seen to diminish, and the PCV to increase (11,12).

Hosny et al (6) found a correlation between the ACD and AL in humans, as well as between the ACD and the level of myopia, also observing an increase of the ACD with myopia. However, an inverse correlation was observed with age. A more detailed study carried out by these authors revealed that the ACD seems to increase with the AL until a certain level, from which an increase in the posterior direction would not necessarily imply an increase in the ACD; that is to say, in the equatorial direction. It has been observed that for a population with AL values between 19 and 33.2 mm the correlation between the ACD and AL that existed in smaller eyes was lost when the AL was greater than or equal to 26mm (6).

The corneal asphericity and its relationship with the remaining ocular optical components have recently been studied by the present authors (13). There are other corneal descriptors that represent the aspheric form of the cornea (14).

The objective of this study is to evaluate the relationship between the ocular optical components and their potential influence on the refractive study of the eye.

For this, the ocular optical components of a sample of subjects was determined, that included the corneal data (corneal radius and asphericity) and the biometric values (AL, ACD, VCD and CT).

SUBJECTS, MATERIAL AND METHODS

Sample

After obtaining informed consent the RE of 109 Caucasian patients (67 women, 42 men), aged bet-

ween 15 and 35 years (22.27; SD 3.24 years), was examined.

Only subjects who had a visual acuity (VA) equal to or greater than 20/20 were included in the study. Subjects that presented corneal pathology examined with slit lamp or pathology of the posterior pole by means of direct ophthalmology were not included, and no subject presented any corneal pathology, or was taking ocular or systemic medication that could produce changes in the cornea or lens. Before the study all the procedures were approved by the Bioethical Committee for research into humans from the University of Santiago de Compostela.

The refractive state of the sample obtained by means of cycloplegic refraction showed an average spherical equivalence of -1.66, DE 2.52 D (range of +3.00 D a -11.00 D). The astigmatism was less than 1.50 D.

The sample was divided into 5 refractive groups following the criteria established by Carney et al, with a similar number of subjects, age and sex, (2): «emmetropes» [spherical equivalence (SE), -0.25 a +0.25 D], n=30; «hypermetropes» (SE \geq +0.50 y " +3.25 D), n=20; «low myopic» (SE \geq -0.50 y \leq -2.00 D), n=20; «moderate myopic» (SE > -2.00 y < -4.00 D), n=20 y «high myopic» (SE > -4,00 D), n=19.

Procedures

The anterior corneal curvature values (ACC) and asphericity (Q) were determined by means of videokeratoscope (EyeSys Laboratories, Salt Lake City, UT) between 14:00 and 17:00 h. with the aim of avoiding the slant induced by the diurnal variations of the corneal curvature. The ACC was obtained from the keratometric map, while the Q was calculated in the zone of 4.5mm using the Holladay Diagnostic Summary (4). In both cases the final value corresponded to the average of the three measurements. Previous to each session the videokeratoscope was calibrated with a set of known radius spheres. Later, and after the application of a tetracain drop at 0.5%, the ACD, CT, VCD and AL ocular optic parameters were determined with the Ophthasonic® A-scan/Pachometer III (Teknar Inc., St. Louis, MO) ultrasonic biometer, taking five readings in each case and then averaging. They were only accepted if the SD of the five measurements was equal to or below 0.1 mm. The measurements

were repeated if this was not the case. All the measurements were made under cycloplegia with the aim of eliminating the influence of the CT accommodation and in other potentially influential structures such as the ACD and VCD (15).

Statistical analysis

For data analysis the statistical software SPSS v. 12.0.1 for Windows (SPSS Inc., Chicago, USA) was used. Once the equality of variances corresponding to the five refractive groups with the Levene test had been checked, an ANOVA test was applied among the groups to compare the average value obtained in each case. The relationship between the different ocular parameters (Q, RC, ACD, CT, VCD and AL) was studied by means of a linear regression analysis, with a total of twenty one possible combinations and to a significance level of $p < 0.0024$.

RESULTS

Table I shows the refractive, topographic and biometric values corresponding to each refractive group. It can be seen that the CT, VCD and AL vary with the refractive state. In this way, it was found that the AL and the VCD were greater in myopics than in hypermetropes, increasing with the level of myopia. However, the CT showed no significant relationship, although a trend to increase with the level of myopia was observed. The ACD showed no significant statistical differences between the different refractive groups.

In table II the correlation between the distinct ocular parameters is indicated. The ACD showed a significant statistical correlation with the CT and the AL, but not with the VCD. In Figure 1 the straight regression line is illustrated between CT and ACD where the negative relationship between both can be appreciated.

Figure 2 shows a model square regression graph that describes the relationship between ACD and AL. This representation is adapted to the entire data ($r^2 = 0.188$; $p < 0.001$) in a more reliable manner than the linear model ($r^2 = 0.156$; $p < 0.001$), making a positive correlation evident up to a turning point situated between 23 and 25 mm of AL. For this reason it was decided to establish the limit at 24 mm

Table I. Descriptive statistics for the ocular biometric and topographic measurements, showing the distribution by age and sex for the five refractive groups

		Hypermetropes (n=20)		Emmetropes (n=30)		Low Myopia (n=20)		Moderate Myopia (n=20)		High Myopia (n=19)	
Male/Female		9/11		13/17		6/14		6/14		8/11	
Age (years)		22,30 SD 3,33		21,70 SD 2,71		22,20 SD 2,57		22,50 SD 2,86		22,95 SD 4,79	
	Sig. p*	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Rx	<0.001	0.99	0.72	-0.05	0.15	-1.33	0.56	-3.10	0.50	-5.83	1.95
RC	N.S	7.87	0.21	7.81	0.22	7.82	0.23	7.86	0.27	7.82	0.25
Q	N.S	-0.20	0.08	-0.23	0.07	-0.22	0.09	-0.26	0.10	-0.4	0.06
PCA	N.S	3.42	0.28	3.61	0.30	3.56	0.27	3.66	0.32	3.52	0.30
EC	0.003	3.66	0.23	3.57	0.17	3.56	0.18	3.64	0.23	3.81	0.26
PCV	<0.001	15.72	0.80	16.16	0.60	16.43	0.74	17.02	0.77	17.92	1.10
LA	<0.001	22.80	0.85	23.34	0.65	2.55	0.75	24.32	0.9	25.25	1.10

Statistical significance for the ANOVA test between refractive groups.

Rx: refractive error; RC: anterior corneal curvature radius; Q: asphericity; PCA: anterior chamber depth; EC: lens thickness; PCV: vitreous chamber depth; LA: Axial length. The distribution by age and sex is shown for the five refractive groups.

for successive analysis, dividing the sample into two subgroups: those with AL under 24 mm (n=65) and those with AL equal or above 24 mm (n= 44).

In figure 3 the relationship between ACD and AL is shown for both subgroups separately. In this graph the loss of correlation can be seen between both parameters in eyes of a larger size (LA ≥ 24 mm), where an increase of the AL without a significant increase of ACD was observed.

Figure 4 shows the relationship between X-ray and AL, where the limit established (AL the same as 24 mm) corresponds with an X-ray error of -2.00 D. Therefore, in refractive terms, greater values of -2.00 D can apply to moderate and high and lower values than -2.00 D to eyes with refractive conditions. The

descriptive statistics for both groups are shown in table 3. Larger eyes present greater values in the biometric measurements, as well as more prolate corneas and flatter central keratometric readings.

In table 4 the correlation between the distinct ocular parameters is presented. The sample is divided in two subgroups according to the AL, as was described in table III. It was observed that, with respect to table 2 (global sample), the correlation between the parameters increases in both subgroups. A significant statistical relationship between the ACD and the CT was found with the AL in the sub group with LA < 24 mm. On the contrary, this relationship was not found for eyes with AL > 24 mm. A similar relationship was observed between the RC and

Table II. Result of multidimensional statistical analysis applied to all the sample (n=109) indicating the correlation coefficient «r» and the level of statistical signification «p» for all the biometric topographic variables

Ocular parameters	RC	Q	ACD	EC	VCD	AL	Rx
RC		p = 0.025	p = 0.767	p = 0.836	p < 0.001	p < 0.001	p = 0.726
Q	r = 0.214		p = 0.853	p = 0.535	p = 0.003*	p = 0.007	p = 0.075
ACD	r = 0.029	r = 0.018		p < 0.001	p = 0.015	p < 0.001	p = 0.338
EC	r = 0.020	r = 0.060	r = 0.409		p = 0.435	p = 0.848	p = 0.026
VCD	r = 0.372	r = 0.287	r = 0.233	r = 0.076		p < 0.001	p < 0.001
AL	r = 0.354	r = 0.258	r = 0.394	r = 0.019	r = 0.969		p < 0.001
Rx	r = 0.034	r = 0.171	r = 0.093	r = 0.214	r = 0.742	r = 0.750	

The statistical significance is represented above the shaded cells. Below these the relationship is represented. The values in bold type identify those statistically significant relationships according to the established criteria

The relationship between ACD and Q is only statistically significant once the level of significance is established in p=0.0024.

Rx: refractive error, RC: anterior corneal curvature radius, Q: asphericity, ACD: anterior chamber depth, EC: lens thickness, VCD: vitreous chamber depth, AL: axial length.

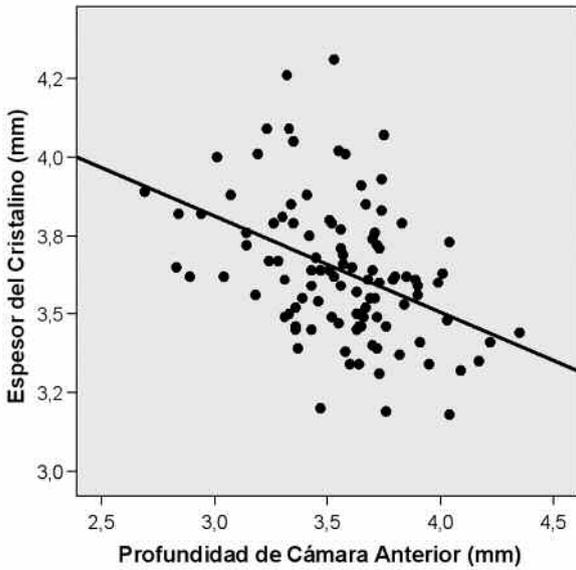


Fig. 1: Linear regression between the anterior chamber depth (ACD) and lens thickness (CT).

the CT with the VCD. The relationship between ACD and CT also resulted significant for both sub groups. Nevertheless, a similar behavior was observed between AL and VCD. In contrast, the relationship between VCD and AL with refractive error is statistically significant for eyes with AL ≥ 24 mm and not for eyes with AL < 24 mm.

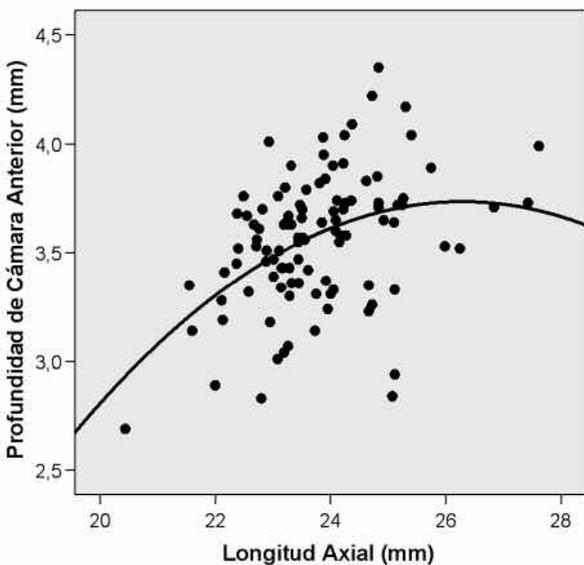


Fig. 2: Square regression graph model between the axial length (AL) and the anterior chamber depth (ACD).

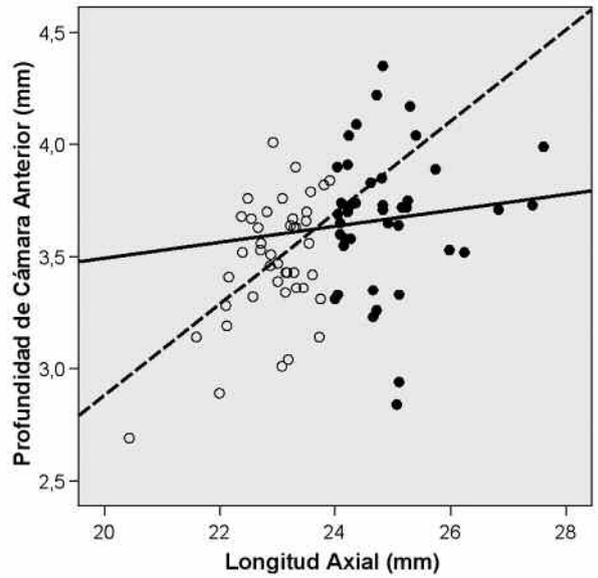


Fig. 3: Linear regression showing the association between the anterior chamber depth (ACD) and the axial length (AL) for eyes with less AL (< 24 mm – Black squares and continuous line) and eyes with greater AL (≥ 24 mm – white squares and discontinuous line).

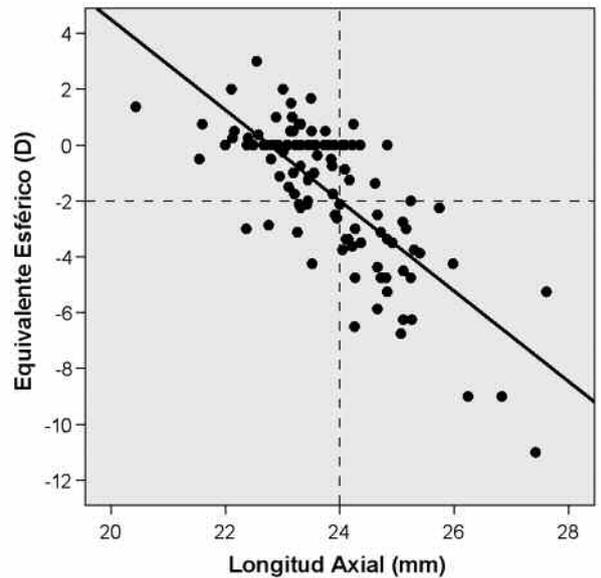


Fig. 4: Representation of the correlation between the refractive error value (spherical equivalence (X-ray) and the axial length (AL). The reference lines divide the sample in eyes with AL under or over 24 mm and/or X-ray over or under -2.00 dioptre. It has been calculated that 75% (34/44) of the eyes with LA ≥ 24 mm have a myopia greater than -2.00 D and that 86% (56/65) of the eyes with LA < 24 mm are in the remaining groups (myopia under -2.00, emmetropia o hypermetropia).

Tabla III. Descriptive statistics of the ocular parameters investigated in this study for eyes with longer axial length (≥24mm) and shorter axial length (<24 mm)

Ocular parameters	LA < 24 mm (n=65)			LA ≥ 24 mm (n=44)			Total	
	Mean	SD	Range	Mean	SD	Range	Mean	SD
RC	7.79	0.19	[7.36 a 8.21]	7.91	0.27	[7.33 a 8.43]	7.84	0.23
Q	-0.21	0.08	[-0.03 a -0.41]	-0.26	0.07	[-0.14 a -0.42]	-0.23	0.08
PCA	3.48	0.27	[2.69 a 4.03]	3.67	0.31	[2.84 a 4.35]	3.56	0.30
EC	3.62	0.18	[3.19 a 4.26]	3.67	0.27	[3.18 a 4.31]	3.64	0.23
PCV	15.94	0.65	[13.85 a 17.16]	17.55	0.85	[16.44 a 20.09]	16.59	1.07
LA	23.05	0.65	[20.43 a 23.95]	24.89	0.86	[24.27 a 27.61]	23.79	1.16

For each group the refractive error (Rx), anterior corneal curvature radius (RC), asphericity (Q), anterior chamber depth (PCA), lens thickness (EC), vitreous chamber depth (PCV) and axial length (LA) is shown.

Lastly, a statistically significant correlation was found between Q and VCD, which implies that eyes with greater VCD tend to more prolate corneas (fig. 5). As regards RC, a statistically significant relationship with VCD was observed (figure 6), in such a way that eyes with greater posterior growth present a flatter central corneal curvature, but this relationship between RC and X-ray was not observed.

The Rx presented a statistically significant correlation with the AL and the VCD in the global sample (table 2) and in the subgroup of LA ≥ 24 mm (table IV).

DISCUSSION

In recent years there has been a great interest in accurately understanding the dimensions of the human eye.

As well as studying the posterior elongation of the ocular globe, it would be extremely useful to understand what parameters reflect the anterior growth of the human eye in order to establish if a loss in the balance between both segments is related to the appearance and development of the ametropia. Previous studies suggest that the diameter (or the

Table IV. Results of multidimensional statistical analysis for eyes with longer axial length (≥ 24 mm) and shorter axial length (<24 mm), showing the correlation coefficient «r» and the level of statistical significance «p» between the studied parameters

Ocular parameters	RC	Q	PCA	EC	PCV	LA	Rx
RC		r = 0.226 p = 0.141	r = 0.027 p = 0.863	r = 0.130 p = 0.399	r = 0.236 p = 0.123	r = 0.202 p = 0.189	r = 0.303 p = 0.045
Q	r = 0.091 p = 0.472		r = 0.103 p = 0.508	r = 0.276 p = 0.069	r = 0.088 p = 0.569	r = 0.036 p = 0.817	r = 0.103 p = 0.507
PCA	r = 0.128 p = 0.310	r = 0.217 p = 0.083		r = 0.513 p < 0.001	r = 0.101 p = 0.514	r = 0.098 p = 0.527	r = 0.276 p = 0.069
EC	r = 0.161 p = 0.201	r = 0.051 p = 0.684	r = 0.426 p < 0.001		r = 0.036 p = 0.815	r = 0.099 p = 0.523	r = 0.300 p = 0.048
PCV	r = 0.363 p = 0.003*	r = 0.088 p = 0.485	r = 0.141 p = 0.261	r = 0.496 p < 0.001		r = 0.942 p < 0.001	r = 0.662 p < 0.001
LA	r = 0.357 p = 0.004	r = 0.012 p = 0.925	r = 0.441 p < 0.001	r = 0.91 p = 0.001	r = 0.922 p < 0.001		r = 0.651 p < 0.001
Rx	r = 0.178 p = 0.157	r = 0.023 p = 0.854	r = 0.057 p = 0.652	r = 0.036 p = 0.778	r = 0.308 p = 0.012	r = 0.324 p = 0.009	

The statistical results for eyes with AL ≥ 24 mm is shown above the shaded cells. Below these those corresponding to eyes with an AL < 24 mm. The values in bold type identify those statistically significant relationships according to the established criteria

The relationship between ACD and RC does not attain statistical significance as the significance level was established at p=0.0024.

Rx: refractive error, RC: anterior corneal curvature radius, Q: asphericity, ACD: anterior chamber depth, EC: lens thickness, VCD: vitreous chamber depth, AL: axial length.

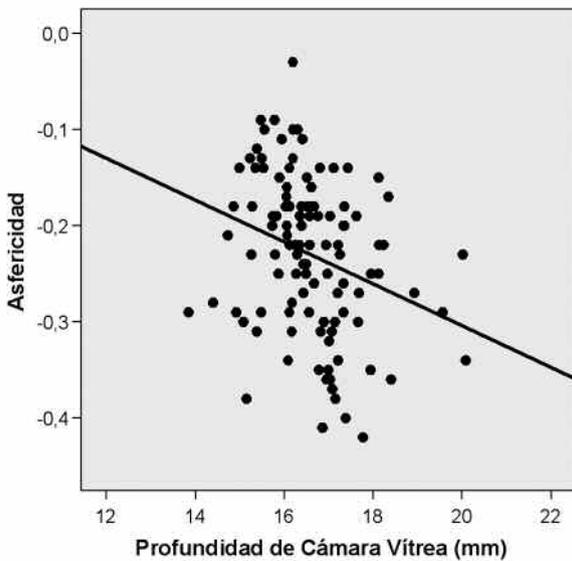


Fig. 5: Linear regression between corneal asphericity (Q) and the vitreous chamber depth (VCD).

area) of the corneal surface is a growth indicator for the anterior segment of the eye (11). Hosny et al (6) described the existing correlation between the ACD and the average corneal diameter, where the ACD could indirectly be considered as the index of transversal and equatorial growth of the anterior segment of the eye.

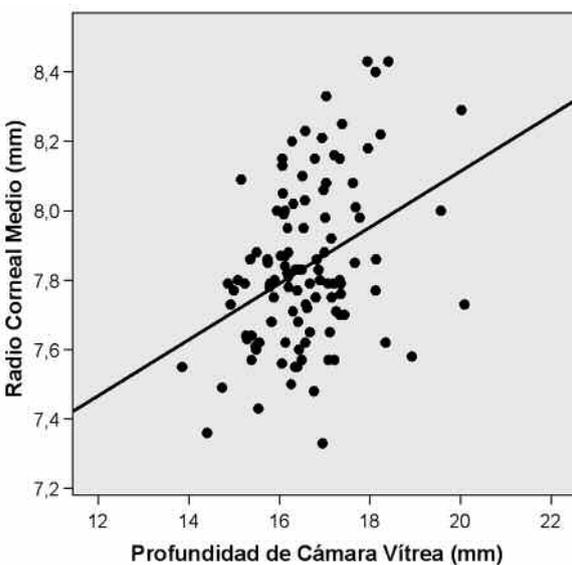


Fig. 6: Linear regression between the average corneal radius (CR) and the vitreous chamber depth (VCD).

The results, similar to those of Hosny et al (6), showed a statistically significant correlation between the ACD and the AL. However, after dividing the sample into two subgroups according to AL, it was observed that for the subgroup with AL < 24 mm it presented a statistically significant correlation between the variables while in the sub group of AL > 24 mm there was no correlation.

The choice of 24 mm as the AL limit was used on the one hand considering it as the commonly accepted AL mean value of the human eye, and on the other hand as it was the mean interval point between 23 and 25 mm, where the inflexion function change is produced (fig. 2). This choice means that each subgroup is formed by a statistically representative number, and it is noticeable that the AL equaling 24 mm corresponds to a refractive error of -2.00 D in the straight regression line between the AL and the refractive error of the sample (fig. 4). This selection is clinically acceptable, given that 75% (34/44) of the eyes with a AL of 24 mm presented a myopia higher than -2.00 D (myopia moderate- high), while 86% (56/65) of the eyes with a AL < 24 mm formed the remaining refractive degrees (myopia < -2.00 D, emetropia and hypermetropia).

The results found in this study also suggest that the anterior chamber depth increases with the AL until a certain value, from which the elongation of the eye would not accompany an increase of the PCA. This finding supports the theory according to which the growth of the eye is a coordinated and harmonic process both in the equatorial and posterior direction, guaranteeing the balanced increase of the anterior and vitreous chambers up to a certain level, which once exceeded loses this balance and the ametropia appears. However, it is important to consider that the interval of AL obtained in this study is relatively small, from 20 to 28 mm, whereas in other papers the AL range extends until 33 mm (6). Therefore, a higher number of elevated myopia cases are necessary to guarantee more conclusive results.

There are studies that show an important role for the lens in the emetropization mechanism but little attention has been given to its relationship with the anterior and vitreous chamber. Garner et al (15), in a transversal study carried out with Tibetan children, found that the balance between the potency reduction of the lens and the vitreous length increase was the main factor that maintained the trend

towards emetropia (15). In another retrospective longitudinal work studying myopia at the beginning of adulthood, the main cause for the development and progression of myopia was found to be vitreous elongation (16).

Garner and Yap (17) demonstrated that ACD decreases with adaptation as a result of swelling (thickening) of the lens. At present and thanks to the accuracy of the measurement techniques of the anterior segment of the eye, as well as the partial coherent interferometer, it has been shown that during the adaptation the anterior lens face is forwarded approximately 200 microns, while the posterior is displaced backwards some 70 microns (18). As a result, and assuming that the other surfaces, cornea and retina, remain invariable, a similar reduction is produced in the depth of the anterior chamber and posterior respectively.

The results found in this study suggest that an increase in the EC is associated to a reduction in the ACD, both in the case refractive errors lower and greater than -2.00 D. A similar result was found on relating PCV with EC in refractive errors less than -2.00 D. However, for myopias greater than -2.00 D no correlation was found. This finding coincides with the theory that elevated myopia is the result of an imbalance in the growth process in the posterior (PCV) and equatorial PCA directions. For this reason the role of the lens in the process of emmetropization would be minimal. In moderate and elevated myopias an increase of EC was observed that brings with it a reduction of the PCA, but not of the PCV, since the excessive growth of the posterior pole disguises the small contribution of the lens.

In this study no correlation was found between corneal asphericity and refractory error, which coincides with the results of previous studies (13). However, posterior investigations suggest that young myopias with more prolated corneas would tend to develop greater levels of juvenile myopia (4). In the present study a statistically significant correlation was found between Q and PCV, in such a way that the eyes with greater AL have higher negative asphericity values.

In conclusion, a detailed statistical analysis on the existing inter-relations between the ocular optical components is presented, separately analyzing the eyes with greater or less AL.

The presence of imbalance between ocular parameters seems to be directly related with the appearance and development of ametropia. We wish to

highlight that in eyes with $AL < 24$ mm a correlation was found between the VCD and RC, as well as between the AL with ACD and EC, while in eyes with $LA \geq 24$ mm these correlations were not found.

According to the studies of Sorby et al. (19) the emmetropization process was considered correct until a maximum refractive error of 4.00 D, since the distinct optical-ocular components maintained a correlation directed to emmetropization, despite some degree of refractive error remaining. In this study this data was updated until a maximum degree of 2.00 D, the closest to emetropia.

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