

# Consolidating the anatomical relationship between ocular axial length and spherical equivalent refraction

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## SUMMARY

The basis of refractive error is ocular axial length since this will indicate the presence of either a myopic eye or a hyperopic one. Today, ultrasonic biometry can be used to study the anatomical differences between the ocular myopic and the hyperopic globe. Following on from this, we analysed the anatomical relationship between ocular axial length, refraction and the degree of refractive error.

To this end, we measured the ocular axial length with the Compuscan A-B Storz ultrasonic biometer (San Louis, MO, USA) in 100 patients with myopia (n=100; mean age 33.53±8.15; 51.0% women and 49.0% men) and 100 with hyperopia (n=100; mean age 30.90±7.73; 56.0% women and 44.0% men). We established three groups of myopic patients (group M1: -6.50 to -12.00 diopters; group M2: -12.50 to -18.00 diopters; group M3: -18.25 to -24.00 diopters) and two groups of hyperopic patients (group H1: +1.75 to +4.00 diopters; group H2: +4.50 to +9.50 diopters).

Mean ocular axial length was 27.11±1.55 mm in M1, 28.70±1.55 in M2, 29.78±1.10 in M3, 21.66±0.83 in H1 and 21.31±0.92 in H2 (p<0.001). Among the myopic groups (p<0.001) and between the hyperopic groups (p=0.025), differences in mean ocular axial length were significant. Women had an ocular axial length, which was significantly less in the hyperopic groups and in M1 (p=0.020 in H1, p=0.046 in H2 and p=0.027 in M1). In M2 and M3, no significant differences were found (p=0.742 and p=0.104, respectively).

Our study confirms the involvement of ocular axial length in the refractive state and reveals a major difference in the way mean ocular axial length behaves between the sexes as a function of the degree of myopic error presented.

**Key Words:** Ultrasonic biometry – Ocular axial length – Spherical equivalent refraction.

## INTRODUCTION

The in vivo study of the eye has been one of the chief objectives in anatomical exploration in which ultrasonic biometry is a valid method for the study of the ocular globe.

By using ultrasound, information can be obtained on ocular structure since the passage of ultrasonic waves through different tissues is reflected in the generation of distinctive echoes and hence specific information on these tissues can be obtained.

The use of ultrasound in ophthalmology goes back to 1956 (Mundt and Hughes, 1956) and it was Gernet (1965) who proposed the use of ultrasound to measure the ocular axial length.

Clinically speaking, it is necessary to calculate the ocular axial length in order to establish the intraocular lens power (Drexler et al., 1998; Haigis et al., 2000). Nevertheless, ultrasonic biometry can also be used to study the anatomical differences between the myopic and the hyperopic ocular globe.

The ocular globe can be considered a dynamic organ since the refractive state changes with

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age and this is why the prevalence of hyperopia increases in samples of adult Western populations close to old age (Ellingsen et al., 1997) while that of myopia decreases (McCarty et al., 1997). It has further been observed that there is a greater incidence of hyperopia in women (Wu et al., 1999; Dandona et al., 1999).

Ethnic extraction also seems to be related to refractive errors because hyperopia tends to diminish in Afro-Americans as they approach old-age (Wu et al., 1999); this is contrary to the behaviour observed in Western populations (Ellingsen et al., 1997).

It is also generally accepted that the basis of refractive errors is the ocular anatomy itself since a number of studies have reported, a greater ocular axial length in myopic eyes with respect to hyperopic ones (McBrien and Adams, 1997; Osuobeni, 1999; Hosny et al., 2000; Muñoz et al., 2001).

For the above reasons the present study attempts to deepen our understanding of the anatomical relationship between ocular axial length and refractive error. To this end, we calculated the ocular axial length by means of contact ultrasonic biometry in a sample of young adult patients from our immediate environment. We also wished to detect the differences in mean ocular axial length between myopic and hyperopic patients, differences in mean ocular axial length as a function of the degree of refractive error, and differences in mean ocular axial length between women and men.

## MATERIAL AND METHODS

We carried out a prospective study involving Caucasian patients with myopia (cycloplegic spherical equivalent refraction  $>-1.0$  diopters) and hyperopia (cycloplegic spherical equivalent refraction  $>+1.0$  diopters) at the Rahhal Ophthalmology Clinic and the Faculty of Medicine of Valencia (Spain). The work began in October 1998 and written informed consent was obtained from all patients before starting the study.

We developed a three-step procedure. First we selected the patients to be included in the study; second, we formed two groups to be studied (myopics and hyperopics) and, finally, we carried out ultrasonic biometry.

The ultrasonic procedures were performed by the same person (JCI) consistently at the same time for all patients (09:00-10:00 AM).

For selection for inclusion in the study, all patients underwent an ophthalmologic examination that included best corrected visual acuity, cycloplegic refraction (KR.7000-P, Topcon Inc Tokyo, Japan), slit-lamp microscopy (Haag Streit Biomicroscope 900, Bem, Switzerland), central corneal applanation tonometry (Goldmann

Applanation tonometer, Haag Streit, Bern, Switzerland), and dilated fundus examination.

Exclusion criteria included active corneal and ocular disease, previous corneal or ocular surgery (including retinal photocoagulation in highly myopic eyes), systemic disease, contact lens wearers, Goldmann applanation tonometry  $\geq 21$  mmHg, glaucoma, the use of any kind of ophthalmic and systemic drugs (including contraceptives and hormone replacement therapy in the case of women), and incidence of non stable refraction in the course of the previous year.

In the present study, a total of 200 eyes from 200 different patients were examined. Table 1 shows the characteristics of the sample studied.

**Table 1.** Characteristics of the sample studied.

	Myopic eyes = M.	Hyperopic eyes = H.
<b>n</b>	100 (100%)	100 (100%)
<b>Women</b>	49 (49.0%)	56 (56.0%)
<b>Men</b>	51 (51.0%)	44 (44.0%)
<b>Age</b>	33.53 $\pm$ 8.15*	30.90 $\pm$ 7.73*
	r: 19 to 54	r: 19 to 51
<b>SER</b>	-14.804.32*	+5.00 $\pm$ 4.30*
<b>(diopters)</b>	r: -6.50 to -24.00	r: +1.75 to +9.50
<b>BCVA 20/20</b>	5 (5.0%)	73 (73.0%)

\* = mean $\pm$ SD; r = range; SER = Spherical equivalent refraction; BCVA = best corrected visual acuity

We established three groups of myopic patients (groups M1, M2 and M3) and two of hyperopic patients (groups H1 and H2) according to cycloplegic spherical equivalent refraction. Spherical equivalent refraction was calculated as the spherical value plus half of the negative cylinder value. Table 2 shows spherical equivalent refraction and age shown by women and men in each group studied.

Ocular axial length was calculated using the Compuscan A-B Storz (San Louis, MO, USA). This biometer was used to perform 10 consecutive measurements of the ocular axial length, hence obtaining the mean and standard deviation.

In order to carry out the measurements, once the cornea had been anaesthetised (corneal anaesthesia was administered in the form of two drops of oxibuprocaine) the investigator positioned the biometric probe on the ocular surface so as to form an angle of 90°.

In the biometer, the ultrasonic pulse produced in the transducer penetrates the various chambers of the eye. Each time that the pulse passes from one intraocular medium to another the resistance encountered by the ultrasound changes and produces a reflection of the pulse. At that moment, an echo from the ultrasound is retransmitted to the transducer.

A graphic representation of this process appears on the screen of the biometer. The abscissa axis indicates the time required for the

**Table 2.-** Spherical equivalent refraction and age by sex for each group studied.

	Myopic eyes			Hyperopic eyes	
	Group M1	Group M2	Group M3	Group H1	Group H2
<b>n</b>	30 (100%)	45 (100%)	25 (100%)	41 (100%)	59 (100%)
<b>SER* (D)</b>	-9.89±1.51 r: -6.50 to -12.00	-14.80±1.54 r: -12.50 to -18.00	-20.70±1.89 r: -18.25 to -24.00	+3.18±0.66 r: +1.75 to +4.00	+6.14±1.37 r: +4.50 to +9.50
<b>Mean age*</b>	31.30±6.46 r: 19 to 45	33.0±8.00 r: 21 to 49	37.16±9.25 r: 23 to 54	31.44±7.08 r: 19 to 51	30.53±8.19 r: 19 to 50
<b>Women</b>	10 (33.3%)	22 (48.9%)	17 (68.0%)	23 (56.1%)	33 (55.9%)
<b>SER * in Women (D)</b>	-9.28±1.83 r: -6.50 to -12.00	-14.88±1.66 r: -12.50 to -18.00	-20.17±1.57 r: -18.25 to -24.00	+3.13±0.73 r: +1.75 to +4.00	+6.58±1.54 r: +4.50 to +9.50
<b>Mean age* in women</b>	31.30±9.68 r: 19 to 45	30.68±8.12 r: 21 to 47	36.41±8.65 r: 23 to 50	33.74±7.48 r: 19 to 51	31.09±8.67 r: 22 to 50
<b>Men</b>	20 (66.7%)	23 (51.1%)	8 (32.0%)	18 (43.9%)	26 (44.1%)
<b>SER * in men (D)</b>	-10.20±1.26 r: -7.50 to -12.00	-14.73±1.45 r: -12.50 to -18.00	-21.81±2.14 r: -19.00 to -24.00	+3.25±0.58 r: +2.00 to +4.00	+5.84±1.06 r: +4.50 to +8.75
<b>Mean age* in men</b>	31.30±4.39 r: 23 to 42	35.22±7.39 r: 24 to 49	38.751±10.85 r: 23 to 54	28.50±5.42 r: 21 to 40	29.81±7.66 r: 19 to 46

D = diopters; SER = Spherical equivalent refraction; \* = mean±SD; r = range.

propagation of the impulse, while the axis ordinates show the amplitude of the echoes.

The biometer used had a measurement precision of  $\pm 0.06$  mm, depending on the correct positioning of the probe. For this reason, the biometer comes with an automatic alignment system which detects the acceptability or not of the echoes for the ensuing calculations.

Statistics were compiled using the left eyes only. The choice of limiting the study to the left eye instead of the right eye was made in a random fashion because the findings in the left eye are likely to be similar to those in the right eye of the same individual (Murdoch et al., 1998).

The statistical analyses used in the work were the Kolmogorov-Smirnov test, in order to ascertain the normality of variables, after which different parametric and non-parametric tests were applied. The level of significance employed in the analyses was as usual: 5% ( $\alpha=0.05$ ).

The Kruskal Wallis test was used to see whether there were significant differences in mean ocular axial length among the M1, M2, M3, H1 and H2 subgroups.

The Student t-test in H1 and H2 and the one-way Anova test in M1, M2 and M3 were used to see whether there were significant differences in mean ocular axial length as a function of refractive error degree.

Analysis was carried out to determine if there were any statistically significant differences between the mean ocular axial length of women and men by applying the Student t-test for independent samples in M1, M2 and H2 and the Mann-Whitney test in M3 and H1.

## RESULTS

Table 3 shows the anatomical relationship between mean ocular axial length (mm) and mean spherical equivalent refraction (diopters) in myopic and hyperopic eyes. The Kruskal Wallis test confirmed that there were significant differences in mean ocular axial length among the M1, M2, M3, H1 and H2 subgroups ( $p<0.001$ ). Patients with myopia had a mean ocular axial length that was significantly higher than the readings from the hyperopic patients.

In groups M1, M2 and M3 there was a higher mean ocular axial length associated with a higher degree of myopic spherical equivalent refraction, the differences in mean ocular axial length among groups being significant (one-way Anova test;  $p<0.001$ ). In the hyperopic groups a reduction was seen in mean ocular axial length associated with a higher degree of hyperopic spherical equivalent refraction, the differences in mean values between groups H1 and H2 (Student t-test;  $p=0.025$ ) also being significant.

It was found that only in Group M2 did the women have a mean ocular axial length greater than that seen in the men. In the rest of myopic and hyperopic groups, the men had a higher mean ocular axial length.

Here, comparison of the mean values of ocular axial length between women and men afforded contradictory results. Hyperopic eyes showed a uniform tendency, men having a higher mean ocular axial length than women. In group H1

**Table 3.-** Relationship between mean ocular axial length (mm±SD) and mean spherical equivalent refraction (diopters±SD) in myopic and hyperopic eyes\*.

	Myopic eyes			Hyperopic eyes	
	Mse = -14.804.32 D; Moal = 28.491.76 mm			Mse = +5.004.30 D; Moal = 21.46.090 mm	
	Group M3	Group M2	Group M1	Group H1	Group H2
<b>n</b>	25	45	30	41	59
<b>Mse (D)</b>	-20.70±1.89	-14.80±1.54	-9.89±1.51	+3.18±0.66	+6.14±1.37
<b>Moal (mm)</b>	29.78±1.10	28.70±1.55	27.11±1.55	21.66±0.83	21.31±0.92
<b>Mse in Women (D)</b>	-20.17±1.57	-14.88±1.66	-9.28±1.83	+3.13±0.73	+6.58±1.54
<b>Moal in Women (mm)</b>	29.68±0.94	28.78±1.87	26.24±1.05	21.46±0.79	21.12±0.92
<b>Mse in Men (D)</b>	-21.81±2.14	-14.73±1.45	-10.20±1.26	+3.25±0.58	+5.84±1.06
<b>Moal in Men (mm)</b>	29.97±1.44	28.62±1.21	27.54±1.60	21.93±0.83	21.57±0.87

\* = groups set out from greatest to smallest ocular axial length; **Mse** = Mean spherical equivalent refraction (mean diopters±SD); **Moal** = mean ocular axial length (mean mm±SD); **D** = diopters.

(Mann-Whitney test;  $p=0.020$ ) and H2 (Student t-test;  $p=0.046$ ) the differences between women and men were significant. This situation occurred again in the M1 myopic group (Student t-test;  $p=0.027$ ). Nevertheless, for the M2 myopic group (Student t-test;  $p=0.742$ ) as well as Group M3 (Mann-Whitney test;  $p=0.104$ ) no significant differences were observed in the mean ocular axial length between women and men.

## DISCUSSION

Our results report the anatomical relationship between ocular axial length and refractive errors. The results reconfirm the association of ocular axial length with the presence of a greater or lesser degree of refractive error, since we observed a linear decrease in ocular axial length from the highest levels of myopia (group M3) to the lowest one (group M1). By contrast, in hyperopic patients there was a diminished ocular axial length as a function of increasing refractive error.

A number of factors may be responsible for modifying the morphometric results obtained here. One of these is the time-tabling of the measurements. The measurements were carried out between 9 and 10 a.m. exclusively in order to avoid the effects of the relationship between circadian rhythms and ocular elongation rhythms (Nickla et al., 1998).

We also decided to exclude patients affected by any kind of pathology, as ours was an anatomical study specifically focused on healthy people. Thus, people with systematic pathologies were excluded since common pathologies such as diabetes can give rise to refractive errors (Logstrup et al., 1997; Okamoto et al., 2000),

which would modify the composition of the groups under study.

Other common ocular pathologies associated with age are also able to modify ocular morphometric values. In this sense, Connel et al. (1997) demonstrated that elderly patients with cataracts presented an ocular axial length that was greater by approximately 0.30 mm than that presented by healthy adults.

We decided to exclude patients who had previously undergone surgery to the ocular globe since it has been demonstrated that ocular surgery may affect ocular axial length (Leonard, 1975; Naeser et al., 1989; Kalogeropoulos et al., 1994).

In the present study we made use of contact ultrasonic biometry in order to measure ocular axial length. Nonetheless, applanation of the ocular surface may be a cause of error. It has been said (Drexler et al., 1998) that there are differences between contact and non-contact ultrasound axial eye length measurements (approximately 0.14 to 0.36 mm). This is an important issue that anatomists and clinicians must be aware of when analysing the morphometric ocular results obtained with ultrasound technology.

It is a well known fact that when various ocular applanation techniques are applied, the position of the eye (Moses et al., 1982; Nardi et al., 1988) and the patient (Whitacre and Stein, 1993) may give rise to a bad contact surface between the probe and the ocular surface. Here, the automatic alignment system of the biometer enabled us to avoid errors due to this problem.

Anatomically speaking, the eye is a dynamic organ. For this reason, several longitudinal studies have shown changes in mean ocular axial length two years (Lam et al., 1999), three years (Grosvenor and Scott, 1993), or five years after an initial check-up (Lin et al., 1996).

**Table 4.-** Comparison between mean ocular axial length and mean spherical equivalent refraction obtained by Hosny et al. (2000) and the results obtained in our study.

	HYPEROPIC EYES		MYOPIC EYES		
	Group 1 (n=21)	Group 2 (n=44)	Group 5 (n=34)	No similar group to M2	Group 6 (n=28)
<b>Hosny et al. (2000)</b>					
<b>Mse (D)</b>	+5.45±2.43	+3.29±2.53	-8.97±2.92	x	-19.34±3.34
<b>Moal (mm)</b>	19.47±0.47	21.5±0.32	27.7±0.59	x	31.17±1.43
<b>Present study (2001)</b>	Group H2 (n=59)	Group H1 (n=41)	Group M1 (n=30)	Group M2 (n=45)	Group M3 (n=25)
<b>Mse (D)</b>	+6.58±1.54	+3.13±0.73	-9.28±1.83	-14.88±1.66	-20.17±1.57
<b>Moal (mm)</b>	21.31±0.92	21.66±0.83	27.11±1.55	28.70±1.55	29.78±1.10

Mse = mean spherical equivalent refraction (mean diopters±SD); D = diopters; Moal = Mean ocular axial length (mean mm±SD).

Lam et al. (1999), in a study performed in schoolchildren (mean age 11.8±93.04 years), reported an increase in mean ocular axial length of approximately 0.50 mm in a second control carried out two years after. Lin et al. (1996) observed the same evolution in a study conducted over a five-year period (increases of approximately of 0.50 mm in a sample ranging between 18 and 21 years old). Likewise, Grosvenor and Scott (1993) observed a change in mean ocular axial length of +0.16±0.26 mm in emmetropic eyes, +0.18±0.21 mm in youth-onset myopia and +0.20±0.18 mm in early onset myopia three years after the first evaluation.

Furthermore, in myopic patients the age of onset of myopia can lead to an increase in ocular axial length. Fledelius (1995) observed that the appearance of myopia before the age of 17 led to an increased mean ocular axial length (patients with myopia after 18 years of age presented an approximate reduction of 0.90 mm in mean ocular axial length as compared to those that had developed myopia before 17 years of age).

Another factor that should be taken into account is the question of the age of the subjects studied. The mean age of our patients was similar to previous studies. Furthermore, some studies have been carried out on samples with a higher mean age than our patients. The results of studies carried out in elderly European populations (mean age 76.2±10.1 years) afforded a mean ocular axial length of 23.11±1.23 mm; women and men had 22.98±1.31 and 23.33±0.97 mm respectively (Midelfart and Aamo, 1994). Other studies on healthy adult African people (mean age 56.1±10.8 years) reported an eye length of 23.03±1.24 mm (Connell et al., 1997). As can be seen, similar results were obtained in elderly Caucasian and African populations.

The sex of the patient can also influence the appearance of a refractive error, since several studies have found hyperopia to be more prevalent in women (Wu et al., 1999; Dandona et al., 1999). Although the objective of the present study was not to study the prevalence of refractive errors, the greater number of women pre-

sent in both hyperopic groups (56.1% and 55.9% in H1 and H2 respectively) seems to confirm the greater prevalence of hyperopia in women.

These results can be explained by the lesser ocular axial length shown by women in myopic eyes (Fledelius, 1995; Lin et al., 1996; Osuobeni, 1999; Lam et al., 1999), as in hyperopic eyes (Osuobeni, 1999) and in emmetropic eyes (Osuobeni, 1999; Wong et al., 2001).

Study of the differences in mean ocular axial length between women and men allowed us to establish two differentiated groups of patients: hyperopic and myopic patients, with a spherical equivalent refraction <-12.00 diopters and, extreme myopic patients (spherical equivalent refraction >-12.00 diopters). In hyperopic patients and myopic ones with a spherical equivalent refraction <- 12.00 diopters women had an ocular axial length that was significantly lower. In patients with extreme myopia, no significant differences were observed in the mean values of ocular axial length between the sexes.

It was important to ascertain the results for the myopic groups M2 and M3 (spherical equivalent refraction >-12 D) because population-based epidemiological studies have shown that extreme myopes (more than -10.00 D) account for less than 0.5% of the population (McCarty et al., 1997).

Of the work available in the literature, the results of the study by Hosny et al. (2000) bear the greatest similarity to ours (Table 4). In that study, patients with cataracts and with ages slightly higher than in our sample were included (40.35±16.3 years; range = 18 to 78 years). These factors can justify the important differences observed between groups H2 and 1 and between groups M3 and 6 but they should have also affected the two other groups, in which we found no major differences. This leads us to think that the differences may be due to a greater or lesser presence of women and men in each group, although unfortunately, in the study by Hosny et al. (2000) neither the number nor the mean spherical equivalent of women and men for each group analysed were offered.

In sum, the present study confirms the anatomical relationship between ocular axial length and refractive errors; it also provides morphometric results *in vivo*, which allow us to establish anatomical differences between myopic and hyperopic eyes.

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