Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

# Effects of Cycloplegia on Pentacam AXL-Based Biometric and Anterior Segment Parameters Across Different Age Groups

**Beyza Yalçın**

beyza-yalcinn@hotmail.com

Istanbul University

**Semih Çakmak**

Istanbul University

**Mustafa Aytekin**

Istanbul University

**Ecem Üstündaş Uzun**

Istanbul University

**Emre Altınkurt**

Istanbul University

**Research Article**

**Keywords:** age, anterior segment parameters, biometry, cycloplegia, Pentacam AXL

**Posted Date:** November 20th, 2026

**DOI:** https://doi.org/10.21203/rs.3.rs-11429234/v1

**License:** This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

**Additional Declarations:** No competing interests reported.

## Abstract

# Background

The aim of this study was to evaluate changes in refractive, corneal topographic, anterior segment, and biometric parameters measured with Pentacam AXL after cycloplegia and to examine their relationship with age.

# Methods

This retrospective cross-sectional study included 300 eyes of 150 subjects aged 5–80 years. Pentacam AXL measurements were obtained before and after cycloplegia induced with 1% cyclopentolate. Pre- and post-cycloplegia values were compared, and age-related associations were assessed.

# Results

After cycloplegia, increases were observed in sphere, spherical equivalent (SE), K1, TCRP1, SimK1, ACD, ACV, pupil diameter, Y coordinate, and chord μ values, whereas decreases were observed in central corneal thickness (CCT), corneal volume, and axial length. In contrast, no significant changes were observed in K2, Kmean, Kmax, TCRP2, SimK2, chord α, or intraocular lens power calculated for emmetropia (IOL-SEQ Emm). Significant correlations were found between age and cycloplegia-induced changes. Age was positively correlated with changes in ACD, ACV, and chord μ displacement vector (DV), and negatively correlated with changes in sphere, SE, CCT, K2, Kmean, and chord α DV.

# Conclusions

Cycloplegia induces significant changes in refractive, anterior segment, biometric, and selected corneal parameters. The observed age-related associations highlight age as an important determinant of the magnitude and direction of the cycloplegic response.

## Background

Cycloplegia is the temporary loss of accommodation due to pharmacological paralysis of the ciliary muscle [1, 2]. Cycloplegia is used not only to enable a detailed fundus examination but also to determine accurate refraction, especially in pediatric patients [3–5]. It also contributes to the prevention of posterior synechiae in uveitis and may affect biometric measurements before phacoemulsification surgery [5, 6].

Evaluating changes in anterior segment and biometric parameters due to cycloplegia is important in ophthalmological diagnosis and treatment planning [7, 8]. Analysis of these changes may contribute to

intraocular lens (IOL) power calculation in phacoemulsification surgery, assessment of keratoconus risk, and correction of refractive errors with glasses, contact lenses, or refractive surgery [9, 10].

The most commonly used drugs to induce cycloplegia in ophthalmology are atropine, cyclopentolate, and tropicamide [11]. Although atropine is considered the gold standard, its use in clinical practice is more limited because of its longer duration of action and more frequent systemic side effects [6, 11]. In contrast, cyclopentolate and tropicamide, which have shorter durations of action, are more commonly used in daily practice [11, 6]. This study was designed to evaluate, using the Pentacam® AXL device, the changes associated with transient paralysis of the ciliary muscle and iris sphincter muscle following cycloplegia induced by 1% cyclopentolate, a synthetic antimuscarinic agent, and to examine the relationship of these changes with age.

## Methods

# Participants

This retrospective cross-sectional study evaluated the eyes of subjects aged 5–80 years. The study was conducted with the approval of the local ethics committee, and all procedures were carried out in accordance with the tenets of the Declaration of Helsinki. Informed consent was obtained from all subjects included in the study.

Subjects with a spherical refractive error of ± 4.00 diopters (D) or less and/or a cylindrical refractive error of 3.00 D or less, and without ocular disease or a history of surgery that could affect corneal topography and anterior segment measurements, were included in the study.

Subjects who used contact lenses; had a spherical refractive error greater than ± 4.00 D and/or a cylindrical refractive error greater than 3.00 D; had corneal topographic abnormalities or suspected keratoconus; had systemic or ocular disease that could affect corneal topographic measurements; had vitreous opacities that could impair image quality; had media opacities such as corneal or lens opacities; or had undergone previous ocular surgery were excluded from the study.

## Measurements

Refractometric measurements were performed in all subjects before the examination using a Nidek ARK-530A autorefractometer (Nidek, Gamagori, Japan). Best-corrected visual acuity (BCVA) was then assessed, and detailed biomicroscopic examinations were performed. Intraocular pressure (IOP) was measured using a Goldmann applanation tonometer. Corneal topography, anterior segment, and biometric measurements were recorded for both eyes using the Pentacam®-AXL device (Oculus, Germany). Subsequently, 1% cyclopentolate hydrochloride (Sikloplejin®, Abdi İbrahim, Istanbul, Türkiye) was instilled into both eyes twice at 5-minute intervals. Measurements were repeated 30 minutes after the second drop, once the absence of the pupillary light reflex had been confirmed. All measurements

were obtained using the same device under low-light (mesopic) conditions and were performed by the same experienced technician. Topographic images were obtained in AXL 3D scan mode, with 25 Scheimpflug images acquired per scan.

Central corneal thickness (CCT, μm), anterior chamber depth (ACD, mm) and volume (ACV, $mm^3$), keratometric values [flat keratometry (K1), steep keratometry (K2), mean keratometry (Kmean), and maximum keratometry (Kmax), D], corneal volume ($mm^3$), corneal densitometry (grayscale units, GSU), pupil diameter (mm), total corneal refractive power values (TCRP1 and TCRP2, D), simulated keratometry values (SimK1 and SimK2, D), pupil center coordinates relative to the corneal vertex (X and Y, mm), chord μ and chord α together with their corresponding axis values (°), sphere (D), cylinder (D), spherical equivalent (SE, D), white-to-white distance (WTW, mm), and axial length (AL, mm) were analyzed. In the device's IOL calculation module, the intraocular lens power calculated for the emmetropic target (IOL-SEQ Emm, D) was recorded after selecting the AcrySof SA60AT lens (Alcon, Fort Worth, TX, USA) according to the Barrett Universal II formula.

The displacement vector (DV) was calculated to assess positional changes in chord μ and chord α. Each measurement was considered a two-dimensional vector with magnitude A (mm) and axis angle Axis (°); the positional components were obtained using the formulas $x = A \times \cos(Axis)$ and $y = A \times \sin(Axis)$. DV was calculated as the Euclidean distance between these components before and after dilation, as follows: $DV = \sqrt{[(A2\cos Axis2 - A1\cos Axis1)^2 + (A2\sin Axis2 - A1\sin Axis1)^2]}$. This value represents the total spatial displacement of the chord center relative to the reference point [12].

# Statistical Analysis

Statistical analyses were performed using NCSS (Number Cruncher Statistical System) 2007 Statistical Software (Utah, USA). Descriptive statistical methods (mean, standard deviation, median, and interquartile range) were used to evaluate the data, and the distribution of variables was assessed using the Shapiro-Wilk normality test. Paired t-tests were used for time comparisons of normally distributed variables, whereas the Wilcoxon signed-rank test was used for time comparisons of non-normally distributed variables. Pearson correlation analysis was used to assess the relationships between variables. Results were evaluated at a significance level of $p < 0.05$.

## Results

The study included 300 eyes of 150 subjects. Of the subjects, 85 were female (56.7%) and 65 were male (43.3%). The mean age of all subjects was 33.71 ± 17.13 years, with a range of 5–80 years. The demographic characteristics of the study group are presented in Table 1.

Table 1
Demographic characteristics of the study population (300 eyes of 150 subjects).

| Variable | n (%) | Age, years (Mean ± SD) | Minimum | Maximum |
|---|---|---|---|---|
| **Female** | 85 (56.7) | 32.82 ± 16.76 | 5 | 80 |
| **Male** | 65 (43.3) | 34.86 ± 17.60 | 6 | 65 |
| **Total** | 150 (100) | 33.71 ± 17.13 | 5 | 80 |

Table 2
Comparison of refractive and corneal topographic parameters before and after cycloplegia (*n = 300 eyes*).

| Parameters | Pre-cycloplegia (*Mean ± SD*) | Post-cycloplegia (*Mean ± SD*) | Difference (*Mean ± SD*) | *p* |
|---|---|---|---|---|
| **Sphere (D)** | -0.26 ± 1.74 | 0.13 ± 1.65 | 0.40 ± 0.30 | < 0.001‡ |
| **Cylinder (D)** | -1.17 ± 0.94 | -1.18 ± 0.94 | -0.01 ± 0.20 | 0.665 |
| **SE (D)** | -0.82 ± 1.90 | -0.43 ± 1.81 | 0.40 ± 0.31 | < 0.001‡ |
| **CCT (µm)** | 549.07 ± 36.58 | 547.82 ± 35.83 | -1.25 ± 8.42 | 0.011* |
| **K1 (D)** | 42.82 ± 1.45 | 42.85 ± 1.46 | 0.03 ± 0.20 | 0.016* |
| **K2 (D)** | 44.16 ± 1.51 | 44.17 ± 1.50 | 0.01 ± 0.22 | 0.252 |
| **Kmean (D)** | 43.49 ± 1.40 | 43.50 ± 1.39 | 0.01 ± 0.25 | 0.649 |
| **Kmax (D)** | 44.72 ± 1.59 | 44.72 ± 1.65 | 0.01 ± 0.39 | 0.785 |
| **CV (mm³)** | 60.79 ± 3.60 | 60.58 ± 3.61 | -0.21 ± 1.16 | 0.002* |
| **CD (GSU)** | 16.33 ± 3.96 | 16.15 ± 3.52 | -0.18 ± 1.58 | 0.056 |
| **TCRP1 (D)** | 42.20 ± 1.51 | 42.26 ± 1.51 | 0.06 ± 0.32 | 0.002* |
| **TCRP2 (D)** | 43.27 ± 1.60 | 43.27 ± 1.61 | -0.10 ± 1.10 | 0.919 |
| **SimK1 (D)** | 42.70 ± 1.54 | 42.74 ± 1.53 | 0.04 ± 1.04 | 0.015* |
| **SimK2 (D)** | 44.00 ± 1.63 | 44.02 ± 1.64 | 0.02 ± 0.27 | 0.389 |

*** p < 0.05, Paired t-test.**

**‡ p < 0.05, Wilcoxon signed-rank test.**

**SE**: Spherical equivalent; **CCT**: Central corneal thickness; **K1**: Flat keratometry; **K2**: Steep keratometry; **Kmean**: Mean keratometry; **Kmax**: Maximum keratometry; **CV**: Corneal volume; **CD**: Corneal densitometry; **TCRP**: Total corneal refractive power; **SimK**: Simulated keratometry.

When the refractive and corneal topographic parameters obtained with Pentacam®-AXL were evaluated, cycloplegia was found to cause statistically significant changes in sphere, SE, CCT, K1, CV, TCRP1, and SimK1 values. After cycloplegia, sphere, SE, K1, TCRP1, and SimK1 values increased, whereas CCT and CV values decreased. In contrast, no significant changes were observed in cylinder, K2, Kmean, Kmax, CD, TCRP2, or SimK2 values (Table 2).

Table 3
Comparison of anterior segment and biometric parameters before and after cycloplegia (*n = 300 eyes*).

| **Parameters** | ***Pre-cycloplegia (Mean ± SD)*** | ***Post-cycloplegia (Mean ± SD)*** | ***Difference (Mean ± SD)*** | ***p*** |
|---|---|---|---|---|
| **ACD (mm)** | 3.02 ± 0.40 | 3.09 ± 0.38 | 0.07 ± 0.06 | < 0.001* |
| **ACV (mm³)** | 180.53 ± 46.01 | 188.78 ± 37.19 | 8.25 ± 21.61 | < 0.001* |
| **Pupil diameter (mm)** | 3.27 ± 0.83 | 6.50 ± 0.98 | 3.20 ± 1.05 | < 0.001* |
| **WTW (mm)** | 11.93 ± 0.39 | 11.92 ± 0.59 | 0.05 ± 1.50 | 0.901 |
| **AL (mm)** | 24.09 ± 1.21 | 24.07 ± 1.20 | -0.02 ± 0.48 | 0.042* |
| **IOL-SEQ Emm (D)** | 19.57 ± 4.16 | 19.64 ± 3.97 | 0.07 ± 1.15 | 0.386 |
| **X (mm)** | -0.02 ± 0.20 | -0.04 ± 0.37 | -0.01 ± 0.33 | 0.280 |
| **Y (mm)** | 0.00 ± 0.14 | 0.04 ± 1.18 | 0.04 ± 0.13 | 0.001‡ |
| **Chord μ (mm)** | 0.21 ± 0.12 | 0.24 ± 0.15 | 0.03 ± 0.13 | 0.001‡ |
| **Axis of μ (°)** | 193.19 ± 104.93 | 199.07 ± 104.47 | 5.88 ± 114.02 | 0.342 |
| **Chord α (mm)** | 0.42 ± 0.13 | 0.45 ± 0.27 | 0.04 ± 0.27 | 0.919 |
| **Axis of α (°)** | 214.25 ± 113.26 | 222.89 ± 107.42 | 6.66 ± 116.52 | 0.449 |

*** p < 0.05, Paired t-test.**

**‡ p < 0.05, Wilcoxon signed-rank test.**

**ACD**: Anterior chamber depth; **ACV**: Anterior chamber volume; **WTW**: White-to-white; **AL**: Axial length; **IOL-SEQ Emm**: Intraocular lens power calculated for emmetropia in the device's IOL calculator using the Barrett Universal II formula after selecting the AcrySof SA60AT lens model (Alcon, Fort Worth, TX, USA); **X**, **Y**: Cartesian coordinates of the pupil center; **μ**: Chord mu; **α**: Chord alpha.

When the anterior segment and biometric parameters obtained with Pentacam®-AXL were evaluated, significant increases were observed in ACD, ACV, pupil diameter, Y coordinate, and chord μ values after cycloplegia, whereas AL showed a significant decrease. In contrast, no significant changes were observed in WTW, IOL-SEQ Emm, X coordinate, axis of μ, chord α, or axis of α values (Table 3).

Table 4
Correlation between age and cycloplegia-induced changes in refractive, corneal topographic, anterior segment, and biometric parameters (*n = 300 eyes*).

| **Parameters** | ***r*** | ***p*** | **Parameters** | ***r*** | ***p*** |
|---|---|---|---|---|---|
| ΔSphere | **−0.252** | **< 0.001*** | ΔSimK2 | −0.099 | 0.095 |
| ΔCylinder | −0.096 | 0.098 | ΔACD | **0.144** | **0.013*** |
| ΔSE | **−0.264** | **< 0.001*** | ΔACV | **0.302** | **< 0.001*** |
| ΔCCT | **−0.132** | **0.022*** | ΔPupil diameter | −0.068 | 0.254 |
| ΔK1 | −0.009 | 0.873 | ΔWTW | 0.089 | 0.239 |
| ΔK2 | **−0.131** | **0.024*** | ΔAL | −0.067 | 0.270 |
| ΔKmean | **−0.142** | **0.014*** | ΔIOL-SEQ Emm (D) | 0.079 | 0.257 |
| ΔKmax | 0.011 | 0.856 | ΔX | −0.050 | 0.398 |
| ΔCorneal volume | −0.048 | 0.409 | ΔY | −0.015 | 0.802 |
| ΔCorneal densitometry | −0.084 | 0.145 | ΔChord μ | 0.079 | 0.184 |
| ΔTCRP1 | 0.038 | 0.522 | ΔAxis of μ | −0.097 | 0.103 |
| ΔTCRP2 | 0.082 | 0.166 | ΔChord α | −0.107 | 0.159 |
| ΔSimK1 | −0.008 | 0.888 | ΔAxis of α | −0.074 | 0.334 |

**Δ, change (post-cycloplegia − pre-cycloplegia); r, correlation coefficient.**

*** p < 0.05, Pearson correlation test.**

When refractive, biometric, and corneal topographic parameters were evaluated, significant correlations were found between age and cycloplegia-induced changes in sphere, SE, CCT, K2, Kmean, ACD, and ACV (Table 4). Age was positively correlated with changes in ACD and ACV, whereas it was negatively correlated with changes in sphere, SE, CCT, K2, and Kmean (all $p < 0.05$). In addition, a statistically significant positive correlation was observed between age and chord μ DV ($r = 0.246$, $p = 0.0001$), whereas a statistically significant negative correlation was found between age and chord α DV ($r=-0.172$, $p = 0.024$). In contrast, no significant relationship was observed between age and changes in the other parameters.

# Discussion

This study evaluated the effects of cycloplegia induced by 1% cyclopentolate on refractive, corneal topographic, anterior segment, and biometric parameters measured with Pentacam®AXL, and examined the relationship of these changes with age. The findings confirmed a hypermetropic shift, characterized by increases in sphere and SE after cycloplegia, while also showing increases in ACD, ACV, and pupil diameter; conversely, limited decreases were observed in CCT, corneal volume, and AL. Most keratometric parameters showed no significant changes, although limited changes were observed in some flat meridian-related measurements. These results suggest that the effect of cycloplegia is not uniform across all parameters and is more pronounced in measurements related to the anterior segment.

When these general findings were evaluated in detail, increases in sphere and SE were observed, consistent with the expected refractive effect of cycloplegia. In addition, increases were observed in K1, TCRP1, SimK1, ACD, ACV, pupil diameter, Y coordinate, and chord μ values, whereas CCT, CV, and AL decreased. The increases in ACD, ACV, pupil diameter, and chord μ values were consistent with previous studies [3, 9, 13, 14]. In the literature, keratometric parameters have mostly been reported to show no significant changes [2, 3]. Arici et al. and Palamar et al. reported that keratometric values were not affected by cycloplegia in Pentacam-based measurements; similarly, Duran and Cevher showed that K1 and K2 values did not change significantly after cycloplegia [3, 6, 9]. In contrast, in our study, increases were found in K1, TCRP1, and SimK1 values, whereas no significant changes were observed in K2, Kmean, Kmax, TCRP2, and SimK2. Our findings suggest that keratometric change is not widespread across all parameters and remains significant but minimal, particularly in keratometric parameters associated with the flat meridian.

In our study, the negative correlation between age and cycloplegia-induced changes in refractive (sphere and SE) and keratometric (K2 and Kmean) parameters may be explained by the age-related decline in accommodative capacity. Because the amplitude of accommodation is generally higher in younger individuals and lower in older individuals, cycloplegia-induced changes in sphere and SE are likely to be more pronounced in younger subjects. The negative correlation between age and changes in K2 and Kmean further suggests that the effect of cycloplegia may be both age-dependent and parameter-specific. The absence of a similar correlation in other keratometric parameters may indicate that this relationship is specific to steep meridian-related parameters or influenced by measurement sensitivity. Tear film stability is known to decrease with age [15]. Considering that the measured CCT value may be affected not only by corneal thickness itself but also by the tear film layer, it is plausible that cyclopentolate hydrochloride–related tear film changes may be less pronounced in older subjects than in younger individuals, resulting in a more limited decrease in CCT. Findings regarding CCT changes after cycloplegia have been heterogeneous in the literature; although most studies have reported no significant change, a limited number of studies have reported a decrease in CCT, consistent with our findings [9, 16]. Palamar et al. suggested that the decrease in CCT after cycloplegia may be related to the reducing effect of 1% cyclopentolate hydrochloride on tear film thickness [9]. Further studies with larger sample sizes are needed to clarify the effect of cyclopentolate hydrochloride on CCT. Some previous studies evaluating changes in CV and AL after cycloplegia did not report significant differences [1, 5].

However, Yuvaci et al. reported a decrease in CV, which is consistent with our findings [17]. In our study, the minimal decrease observed in CV, when considered together with the decrease in CCT, suggests that this finding may be related more to thinning of the tear film layer than to a true change in corneal volume.

However, in our study, cycloplegia-induced changes in chord μ DV, chord α DV, CCT, ACD, ACV, and refractive (sphere and SE) and keratometric (K2 and Kmean) parameters were found to be significantly associated with age. These changes showed positive correlations for chord μ DV, ACD, and ACV, and negative correlations for chord α DV, sphere, SE, CCT, K2, and Kmean. It is known that crystalline lens stiffness increases with age, accommodative response decreases, and the lens assumes a more posterior position after cycloplegia [18–22]. This may explain why the increase in ACD and ACV after cycloplegia observed in our study became more pronounced with increasing age. Previous studies have reported that pupil center decentration caused by pupil dilation after cycloplegia may lead to an increase in chord μ [23, 24]. Neuman et al. also showed that chord μ and chord α exhibit vectorial changes in spatial position [25]. In our study, the relationship between age and the vectorial changes in chord μ and chord α was also evaluated, and cycloplegia-induced chord μ DV was found to be positively correlated with age. This finding may be related to a more pronounced age-related pupil center decentration, but it may also be explained by factors such as posterior displacement of the lens after cycloplegia and repositioning of the optical axis.

This study has several limitations. First, its single-center and cross-sectional design may limit the generalizability of our findings. Second, measurements were obtained only after the application of 1% cyclopentolate and at a single time point, which did not allow evaluation of the effects of different cycloplegic agents or the time course of the cycloplegic response. In addition, the lack of higher-order aberration analysis may have limited a more detailed assessment of cycloplegia-related changes. Finally, because all measurements were obtained using a single device, the generalizability of the findings to other devices may be limited.

# Conclusions

In conclusion, cycloplegia resulted in significant changes not only in refractive parameters but also in anterior segment and some corneal measurements. The age-related correlations observed in our study suggest that the cycloplegic response is not homogeneous across individuals and that age is an important factor influencing its magnitude. Therefore, age should be taken into account when interpreting measurements obtained after cycloplegia.

# Declarations

### Ethics approval and consent to participate

This study was performed in accordance with the principles of the Declaration of Helsinki. Approval was granted by the Clinical Research Ethics Committee of Istanbul University, Istanbul Faculty of Medicine (Decision No. 15, 25 July 2025).

**Informed consent**

was obtained from all subjects included in the study.

**Consent for publication**

Not applicable.

# Competing interests

The authors have no relevant financial or non-financial interests to disclose.

# Funding

The authors declare that no funds, grants, or other support were received during the preparation of this manuscript.

# Author Contribution

All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by BY, SÇ, MA, EÜU, and EA. The first draft of the manuscript was written by BY, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

# Acknowledgements

Not applicable

# Availability of data and materials

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

## References

1. Kirgiz A, Karaman Erdur S, Cakmak S, Dikkaya F, Aydin R. The Effect of Topical Cyclopentolate on Anterior Segment Parameters in Patients with Keratoconus. Turk J Ophthalmol. 2020;50(1):20–5. 10.4274/tjo.galenos.2019.51460.

2. Cheng HC, Hsieh YT. Short-term refractive change and ocular parameter changes after cycloplegia. Optom Vis Sci. 2014;91(9):1113–7. 10.1097/OPX.0000000000000339.
3. Arici C, Turk A, Ceylan OM, Kola M, Hurmeric V. Effects of 1% cyclopentolate hydrochloride on anterior segment parameters obtained with Pentacam in young adults. Arq Bras Oftalmol. 2014;77(4):228–32. 10.5935/0004-2749.20140059.
4. Yuan Y, Zhang Z, Zhu J, He X, Du E, Jiang K, Zheng W, Ke B. (2015) Responses of the Ocular Anterior Segment and Refraction to 0.5% Tropicamide in Chinese School-Aged Children of Myopia, Emmetropia, and Hyperopia. J Ophthalmol 2015:612728. 10.1155/2015/612728
5. Momeni-Moghaddam H, Maddah N, Wolffsohn JS, Etezad-Razavi M, Zarei-Ghanavati S, Akhavan Rezayat A, Moshirfar M. The Effect of Cycloplegia on the Ocular Biometric and Anterior Segment Parameters: A Cross-Sectional Study. Ophthalmol Ther. 2019;8(3):387–95. 10.1007/s40123-019-0187-5.
6. Duran M, Cevher S. Effect of cycloplegic agents (1% cyclopentolate hydrochloride and 1% tropicamide) on anterior segment parameters. Ther Adv Ophthalmol. 2023;15:25158414231180984. 10.1177/25158414231180984.
7. Rabsilber TM, Khoramnia R, Auffarth GU. Anterior chamber measurements using Pentacam rotating Scheimpflug camera. J Cataract Refract Surg. 2006;32(3):456–9. 10.1016/j.jcrs.2005.12.103.
8. Davidova P, Biller M, Ademmer V, Kohnen T. Pupil size measurements with a multifunctional aberrometer/coherence interferometer/tomographer and two infrared-based pupillometers. J Cataract Refract Surg. 2024;50(6):631–6. 10.1097/j.jcrs.0000000000001432.
9. Palamar M, Egrilmez S, Uretmen O, Yagci A, Kose S. Influences of cyclopentolate hydrochloride on anterior segment parameters with Pentacam in children. Acta Ophthalmol. 2011;89(5):e461–465. 10.1111/j.1755-3768.2011.02122.x.
10. Lin FY, Ho RW, Yu HJ, Yang IH, Fang PC, Kuo MT. Impacts and Correlations on Corneal Biomechanics, Corneal Optical Density and Intraocular Pressure after Cataract Surgery. Diagnostics (Basel). 2024;1414. 10.3390/diagnostics14141557.
11. Fraunfelder F, Meyer SM. Systemic reactions to ophthalmic drug preparations. Med Toxicol Advers Drug Exp. 1987;2(4):287–93.
12. Wang R, Long T, Gu X, Ma T. Changes in angle kappa and angle alpha before and after cataract surgery. J Cataract Refract Surg. 2020;46(3):365–71. 10.1097/j.jcrs.0000000000000063.
13. Niyaz L, Can E, Seymen Z, Eraydin B. Comparison of Anterior Segment Parameters Obtained by Dual-Scheimpflug Analyzer Before and After Cycloplegia in Children. J Pediatr Ophthalmol Strabismus. 2016;53(4):234–7. 10.3928/01913913-20160427-02.
14. Guler E, Guragac FB, Tenlik A, Yagci R, Arslanyilmaz Z, Balci M. Influences of topical cyclopentolate on anterior chamber parameters with a dual-Scheimpflug analyzer in healthy children. J Pediatr Ophthalmol Strabismus. 2015;52(1):26–30. 10.3928/01913913-20141111-02.
15. Wolffsohn JS, Arita R, Chalmers R, Djalilian A, Dogru M, Dumbleton K, Gupta PK, Karpecki P, Lazreg S, Pult H, Sullivan BD, Tomlinson A, Tong L, Villani E, Yoon KC, Jones L, Craig JP. TFOS DEWS II

Diagnostic Methodology report. Ocul Surf. 2017;15(3):539–74. 10.1016/j.jtos.2017.05.001.

16. Alghamdi WM, Alrasheed SH, Nair V, Alluwimi MS. Effects of Cyclopentolate Hydrochloride Dosage on Anterior Segment Parameters in Young Adults (Measured with Pentacam). Clin Ophthalmol. 2021;15:891–8. 10.2147/OPTH.S291991.
17. Yuvaci I, Pangal E, Yuvaci S, Bayram N, Atas M, Baskan B, Demircan S, Akal A. (2015) An Evaluation of Effects of Different Mydriatics on Choroidal Thickness by Examining Anterior Chamber Parameters: The Scheimpflug Imaging and Enhanced Depth Imaging-OCT Study. J Ophthalmol 2015:981274. 10.1155/2015/981274
18. Weeber HA, Eckert G, Pechhold W, van der Heijde RG. Stiffness gradient in the crystalline lens. Graefes Arch Clin Exp Ophthalmol. 2007;245(9):1357–66. 10.1007/s00417-007-0537-1.
19. Glasser A, Kaufman PL. The mechanism of accommodation in primates. Ophthalmology. 1999;106(5):863–72. 10.1016/S0161-6420(99)00502-3.
20. Kasthurirangan S, Markwell EL, Atchison DA, Pope JM. MRI study of the changes in crystalline lens shape with accommodation and aging in humans. J Vis. 2011;11(3). 10.1167/11.3.19.
21. Dominguez-Vicent A, Monsalvez-Romin D, Esteve-Taboada JJ, Montes-Mico R, Ferrer-Blasco T. Effect of age in the ciliary muscle during accommodation: Sectorial analysis. J Optom. 2019;12(1):14–21. 10.1016/j.optom.2018.01.001.
22. Toshida K, Okuyama F, Tokoro T, Akizawa Y. [Aging changes in accommodation–comparison of subjective method with objective method]. Nippon Ganka Gakkai zasshi. 1993;97(5):614–8.
23. Umesh Y, Saolapurkar K, Joshi P, Singh D. Measurement of change in angle kappa and its correlation with ocular biometric parameters pre- and post-phacoemulsification. Indian J Ophthalmol. 2023;71(2):535–40. 10.4103/ijo.IJO_1641_22.
24. Shouchane-Blum K, Reitblat O, Dadon J, Bahar I, Sella R. Evaluating Changes in Apparent Chord Mu after Pharmacological Pupil Dilatation. Ophthalmic Res. 2023;66(1):921–7. 10.1159/000530905.
25. Neuman G, Abulafia A, Wasser L, Zadok D. Distribution of angle alpha and angle kappa offsets among adult candidates for cataract surgery. Graefes Arch Clin Exp Ophthalmol. 2025;263(1):157–70. 10.1007/s00417-024-06596-6.