• Clinical Research •

Distinct postoperative anterior segment remodeling in pseudoexfoliation syndrome: a Sirius Scheimpflug analysis

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Abstract

● **AIM:** To investigate postoperative anterior segment remodeling patterns in eyes with pseudoexfoliation syndrome (PXS) using Sirius Scheimpflug imaging and to compare these changes with non-PXS eyes.

● **METHODS:** In this retrospective comparative study, non-PXS cataract patients (Group 1) and PXS patients (Group 2) undergoing uncomplicated phacoemulsification with in-the-bag intraocular lens (IOL) implantation were evaluated. Sirius imaging was performed preoperatively and at 1wk, 1, 3, and 6mo postoperatively. Measured parameters included central corneal thickness (CCT), anterior chamber depth (ACD), anterior chamber angle (ACA), anterior chamber volume (ACV), and corneal volume (CV). Longitudinal and intergroup comparisons were analyzed.

● **RESULTS:** A total of 75 eyes from 75 patients (35 non-PXS, 40 PXS) were included. Mean age was 70.8±1.68y in Group 1 and 73.7±1.09y in Group 2 (P=0.145). Gender distribution (M/F) was 18/17 in Group 1 and 24/16 in Group 2 (P=0.115). Both groups demonstrated postoperative anterior chamber deepening and ACA widening; however, the PXS group showed significantly greater increases in ACA and CV during follow-up (P<0.05). At 1mo, mean ACA was 56.0° in the PXS group versus 51.8° in the non-PXS group (P=0.009), while mean CV was 56.4 mm^3 versus 50.4 mm^3, respectively (P<0.001). Early postoperative increases in CCT were significantly greater in PXS eyes (1wk: P=0.007; 1mo: P=0.008), suggesting transient endothelial stress. No significant intergroup differences were observed in ACD or ACV.

● **CONCLUSION:** Phacoemulsification induces significant anterior segment remodeling following cataract surgery. Eyes with PXS demonstrate more pronounced postoperative changes, particularly regarding ACA widening, transient corneal thickening, and sustained CV increase, possibly related to altered zonular and endothelial biomechanics. Sirius Scheimpflug imaging may provide valuable structural information for postoperative assessment and follow-up in PXS eyes.

● **KEYWORDS:** pseudoexfoliation syndrome; anterior segment remodeling; phacoemulsification; Scheimpflug imaging; corneal volume

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INTRODUCTION

Pseudoexfoliation syndrome (PXS) is a systemic fibrillopathy characterized by progressive accumulation of abnormal microfibrillar extracellular material on various intraocular structures, particularly the anterior lens capsule, pupillary margin, ciliary body, and zonular apparatus[1-2]. In the anterior segment, this deposition may weaken zonular support, disrupt the blood–aqueous barrier, and alter the biomechanical properties of ocular tissues. Recent studies have demonstrated widespread extracellular matrix dysregulation and biomechanical alterations involving multiple anterior segment tissues in PXS, supporting its characterization as a diffuse ocular disorder[2-3].

Histopathological studies have demonstrated the presence of exfoliative material not only on the lens and iris but also within the trabecular meshwork and corneal endothelium, suggesting multifocal anterior segment involvement[4]. Eyes with PXS

are known to present increased surgical challenges during cataract extraction, including zonular instability, insufficient pupillary dilation, and greater endothelial vulnerability[5-7]. Ma *et al*[8] reported significant endothelial alterations in eyes with PXS, while Atalay *et al*[9] demonstrated accompanying retinal microvascular changes, suggesting that ocular involvement in PXS may extend beyond clinically apparent anterior segment manifestations[8-9].

Advanced non-contact imaging modalities such as Scheimpflug tomography and anterior segment optical coherence tomography (AS-OCT) enable highly reproducible quantitative assessment of anterior chamber depth (ACD), anterior chamber angle (ACA), anterior chamber volume (ACV), central corneal thickness (CCT), and corneal volume (CV). These technologies have become increasingly valuable for evaluating postoperative anterior segment remodeling after cataract surgery[10-11]. Several previous studies using AS-OCT and Scheimpflug imaging have demonstrated postoperative increases in ACD and ACA parameters following phacoemulsification, particularly in eyes with PXS[10,12-13]. Persistent alterations in aqueous humor dynamics, iris behavior, and zonular biomechanics may contribute to distinct postoperative remodeling patterns in pseudoexfoliative eyes[7,14].

However, most previous reports have focused primarily on anterior chamber configuration, whereas longitudinal corneal volumetric remodeling and its relationship with other anterior segment parameters remain insufficiently investigated. In particular, information regarding postoperative CV behavior and its association with endothelial stress and biomechanical adaptation in PXS is limited.

Given these gaps in the literature, our study aimed to provide a comprehensive longitudinal comparison of anterior segment remodeling after uncomplicated phacoemulsification in PXS and non-PXS eyes using Sirius Scheimpflug imaging.

PARTICIPANTS AND METHODS

Ethical Approval The study adhered to the principles of the Declaration of Helsinki and was approved by the institutional ethics committee (Approval ID: AESH-EK1-2023-681). Informed consent was obtained from all individual participants included in the study.

Study Design and Participants This retrospective comparative study included patients who presented to the ophthalmology clinic with complaints of decreased vision, were diagnosed with age-related cataract, and underwent uncomplicated phacoemulsification surgery between April 2020 and June 2022.

Participants were divided into two groups: Group 1: Age-related cataract patients without PXS (n=35); Group 2: Cataract patients with clinically diagnosed PXS (n=40).

Pseudoexfoliation diagnosis was based on slit-lamp examination demonstrating characteristic white-gray fibrillar deposits on the pupillary margin, anterior lens capsule, or zonular region. All patients had normal preoperative intraocular pressure (IOP<21 mm Hg) and open ACA confirmed by gonioscopy.

Inclusion and Exclusion Criteria Inclusion criteria: Age≥60y; Nuclear or cortical cataract with best-corrected visual acuity (BCVA) ≤20/40; Absence of ocular pathology other than age-related cataract; Availability of complete preoperative and postoperative imaging data. Exclusion criteria: History of glaucoma, uveitis, corneal dystrophy, ocular trauma, or previous ocular surgery; Zonular dialysis >2 clock hours detected intraoperatively; Intraoperative complications, including posterior capsule rupture or vitreous loss; Persistent postoperative inflammation or corneal edema lasting longer than 1mo; Eyes with significant intraoperative zonular instability requiring capsular tension ring implantation were also excluded from the study.

Surgical Technique All surgeries were performed by the same experienced surgeon using a standard phacoemulsification technique with in-the-bag intraocular lens (IOL) implantation.

After topical anesthesia, a 2.8-mm clear corneal incision and a 1-mm side-port incision were created. A cohesive ophthalmic viscosurgical device (OVD) containing sodium hyaluronate 1% was injected to maintain anterior chamber stability. Continuous curvilinear capsulorhexis (~5.0 mm) was followed by hydrodissection and phacoemulsification using the stop-and-chop technique (CENTURION Vision System, Alcon Laboratories, USA). A foldable hydrophobic acrylic monofocal IOL (AcrySof SN60WF, Alcon Laboratories, USA) was implanted into the capsular bag in all eyes using an injector system. At the conclusion of surgery, all viscoelastic material was carefully aspirated, and 0.1 mL intracameral moxifloxacin was administered.

Postoperative treatment included topical moxifloxacin 0.5% and prednisolone acetate 1%, gradually tapered over 4wk. No significant intraoperative complications occurred in the included eyes.

Anterior Segment Imaging All participants underwent anterior segment imaging using the Sirius Scheimpflug–Placido topography system (CSO, Florence, Italy). This system combines a rotating Scheimpflug camera with Placido-disk corneal topography, enabling highly reproducible three-dimensional evaluation of the cornea and anterior chamber.

Measurements were obtained by the same experienced examiner, who was masked to group allocation, under standardized mesopic lighting conditions. Each scan underwent automatic quality assessment by the device software, and only high-quality scans were included in the analysis (Figure 1). The following parameters were evaluated: CCT (mm), ACD (mm), ACA (degrees), ACV (mm^3), CV (mm^3). Each parameter was

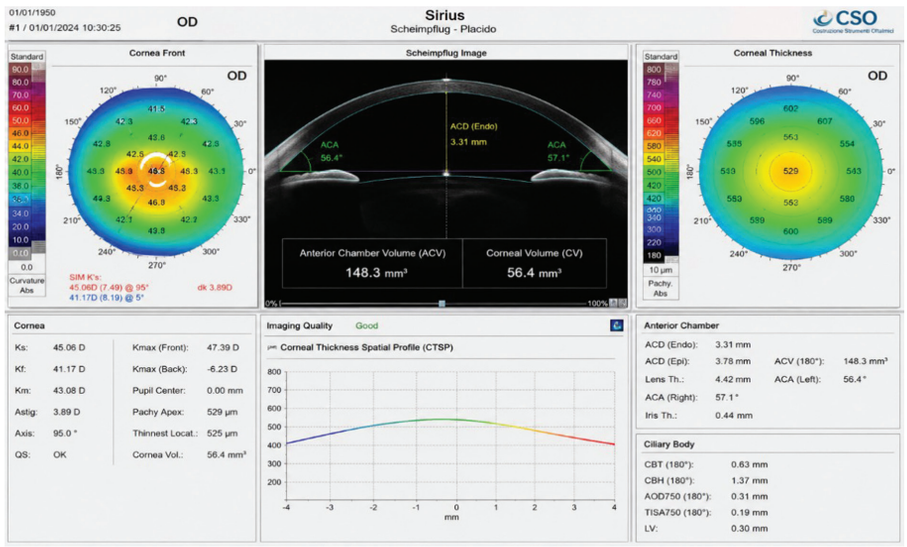


Figure 1 Representative Sirius Scheimpflug–Placido image demonstrating anterior chamber depth (ACD), anterior chamber angle (ACA), anterior chamber volume (ACV), and corneal volume (CV) measurements.

recorded preoperatively and at postoperative 1wk, 1, 3, and 6mo.

Statistical Analysis Statistical analysis was performed using SPSS software (version 26.0; IBM Corp., Armonk, NY, USA). Data were expressed as mean±standard deviation (SD). Normality of data distribution was assessed using the Kolmogorov–Smirnov test. Intergroup comparisons were performed using the independent samples *t*-test, while intragroup longitudinal changes were analyzed using repeated-measures analysis of variance (ANOVA) with Bonferroni post hoc correction. Because of the retrospective design, adjustment analysis for potential unmeasured confounding variables such as endothelial cell density and cataract nucleus grade could not be performed. A *P*-value<0.05 was considered statistically significant.

RESULTS

Demographics A total of 75 eyes from 75 patients (35 non-PXS, 40 PXS) were included. Mean age was 70.8±1.68y in Group 1 and 73.7±1.09y in Group 2 (*P*=0.145). Gender distribution (M/F) was 18/17 in Group 1 and 24/16 in Group 2 (*P*=0.115; Table 1). The two groups were comparable regarding age and baseline anterior segment parameters (all *P*>0.05), except for CV, which was significantly higher in the PXS group (*P*=0.034).

Table 1 Demographic characteristics

Characteristics	Group 1 (*n*=35)	Group 2 (*n*=40)	*P*
Average age (y)	70.8±1.68	73.7±1.09	0.145
Gender (M/F)	18/17	24/16	0.115

Anterior Segment Changes

Central corneal thickness Preoperative CCT was similar between groups (*P*=0.078). A transient increase in CCT was observed in both groups during early postoperative follow-up, but the rise was significantly higher in PXS eyes at 1wk (*P*=0.007) and 1mo (*P*=0.008; Table 2).

By postoperative 3mo, CCT values had largely returned to baseline levels in both groups, suggesting resolution of transient postoperative endothelial stress.

Anterior chamber angle ACA widened progressively after surgery in both groups, reflecting posterior movement of the iris–lens diaphragm. However, the magnitude of widening was significantly greater in PXS eyes at all postoperative time points from 1mo onward (*P*<0.01). At 6mo, mean ACA reached 59.88°±6.52° in PXS versus 53.01°±5.08° in controls (*P*=0.007; Table 2).

Anterior chamber depth and volume ACD increased in both groups after lens removal, with no significant difference between groups (*P*>0.2). Similarly, ACV showed consistent postoperative increases within each group, without intergroup differences (*P*>0.2; Table 2).

Corneal volume CV demonstrated the most distinct postoperative divergence between groups. At baseline, CV was significantly higher in PXS eyes (53.44±8.46 mm^3) compared to non-PXS controls (49.14±6.31 mm^3; *P*=0.034).

Postoperatively, PXS eyes showed persistent and progressive increases in CV at all time points, reaching 59.93±11.68 mm^3 at 6mo (*P*<0.001 *vs* baseline). In contrast, non-PXS eyes demonstrated smaller, transient changes (Table 2).

DISCUSSION

Accurate assessment of anterior segment parameters remains important for cataract surgery planning and postoperative evaluation. Advanced non-contact imaging modalities such as Sirius Scheimpflug–Placido tomography enable reproducible quantitative measurement of ACD, ACA, ACV, and CV,

Table 2 Anterior segment parameters

Parameters	Group 1 (*n*=35)	Group 2 (*n*=40)	*P*
Central corneal thickness (mm)			
Before surgery	0.52±0.04	0.53±0.049	0.078
1wk postsurgery	0.53±0.06	0.57±0.07	0.007
1mo postsurgery	0.54±0.08	0.58±0.06	0.008
3mo postsurgery	0.52±0.05	0.54±0.05	0.312
6mo postsurgery	0.52±0.02	0.53±0.01	0.618
Anterior chamber angle (degrees)			
Before surgery	48.41±9.65	49.40±6.81	0.401
1wk postsurgery	50.61±9.92	51.03±8.22	0.745
1mo postsurgery	51.82±9.38	56.00±6.34	0.009
3mo postsurgery	52.93±9.98	58.85±5.87	0.003
6mo postsurgery	53.01±5.08	59.88±6.52	0.007
Anterior chamber depth (mm)			
Before surgery	2.52±0.32	2.57±0.39	0.285
1wk postsurgery	3.25±0.18	3.23±0.42	0.642
1mo postsurgery	3.28±0.37	3.31±0.58	0.876
3mo postsurgery	3.36±0.49	3.45±0.24	0.378
6mo postsurgery	3.41±0.23	3.46±0.67	0.578
Anterior chamber volume (mm^3)			
Before surgery	126.20±31.8	128.18±40.85	0.516
1wk postsurgery	140.65±34.81	142.22±38.11	0.742
1mo postsurgery	146.47±31.62	148.36±27.59	0.635
3mo postsurgery	152.48±32.42	154.94±25.62	0.246
6mo postsurgery	154.17±41.16	156.18±30.23	0.395
Corneal volume (mm^3)			
Before surgery	49.14±6.31	53.44±8.46	0.034
1wk postsurgery	52.78±10.43	57.07±12.15	0.002
1mo postsurgery	50.43±6.48	56.43±5.67	<0.001
3mo postsurgery	51.38±6.27	56.52±5.41	<0.001
6mo postsurgery	52.54±7.85	59.93±11.68	<0.001

providing valuable structural information in both routine and high-risk cases[10-11].

Previous studies have documented significant alterations in anterior segment parameters following phacoemulsification and IOL implantation. In non-pseudoexfoliation eyes, these changes typically include widening of the ACA, deepening of the anterior chamber, and transient increases in CCT due to endothelial stress[10,12-13]. However, patients with PXS demonstrate a distinct anterior segment response because of zonular weakness, endothelial vulnerability, and altered biomechanical properties[7,15-16]. In the present study, postoperative anterior segment remodeling was significantly more pronounced in PXS eyes, particularly regarding ACA widening and CV changes, suggesting altered biomechanical adaptation after cataract surgery.

One of the most important findings of our study was the sustained postoperative increase in CV in PXS eyes. Although previous studies mainly focused on ACD and ACA changes after cataract surgery, limited data are available regarding longitudinal corneal volumetric remodeling in PXS. At baseline, CV was higher in PXS eyes compared to controls, and postoperative measurements revealed a further progressive increase, suggesting a differential corneal remodeling response. These findings may reflect altered endothelial–stromal interactions and increased susceptibility of the corneal microstructure to surgical stress in PXS eyes.

Recent studies have further highlighted the role of endothelial dysfunction and extracellular matrix abnormalities in persistent corneal structural remodeling in PXS, supporting our observation of sustained postoperative CV changes[1-2,8]. This observation aligns with previous reports indicating that PXS eyes are more susceptible to endothelial stress and demonstrate greater anterior segment structural adaptation postoperatively.

Our findings demonstrated significant early postoperative

increases in CCT in PXS eyes, which likely reflect transient endothelial dysfunction and stress induced by phacoemulsification. Consistent with the findings of Kaljurand *et al*[17] and Erdogdu *et al*[18], PXS eyes exhibited heightened sensitivity to surgical manipulation, which may contribute to temporary corneal edema. Although CCT values gradually returned toward baseline during follow-up, the exaggerated early postoperative increase in PXS eyes highlights the importance of careful endothelial protection during surgery. These findings are also consistent with recent reports describing reduced endothelial reserve and increased corneal susceptibility to surgical stress in pseudoexfoliative eyes[8-9].

Mean ACD increased numerically after surgery in both groups, with no statistically significant between-group differences at any time point. Postoperative ACA values were significantly greater in PXS eyes from 1mo onward. This finding may be attributed to zonular laxity and differences in iris elasticity, which facilitate greater anterior segment expansion following lens removal[7,12-13]. Although the standard principles of phacoemulsification remain unchanged, awareness of exaggerated postoperative anterior segment remodeling in PXS eyes may contribute to individualized perioperative risk assessment, endothelial protection strategies, IOL centration considerations, and postoperative follow-up planning in high-risk patients.

Regarding ACV, our study observed significant postoperative increases in both groups, with a slightly greater trend in PXS eyes. Although preoperative ACV did not differ significantly between groups, the enhanced postoperative expansion observed in PXS eyes may reflect adaptive structural remodeling. Similarly, postoperative CV increases in PXS eyes may be associated with altered endothelial–stromal interactions and greater susceptibility of the cornea to intraoperative stress[8,17]. Emerging evidence suggests that such structural alterations may influence aqueous humor dynamics and functional outflow pathways, potentially contributing to glaucomatous susceptibility in pseudoexfoliative eyes[7,14,18].

Interestingly, despite these pronounced postoperative changes, long-term differences in ACD between PXS and non-PXS eyes remained minimal. This finding is consistent with the results reported by Gunes *et al*[11], suggesting that while PXS may influence short- and medium-term anterior segment remodeling, the final stabilization of ACD over time appears comparable between groups. Recent studies have suggested that corneal and peripheral anterior segment parameters may be more sensitive to pseudoexfoliative tissue alterations than ACD measurements alone[3,8-10].

In contrast, parameters such as CCT, ACA, and CV continued to demonstrate measurable postoperative differences, emphasizing the importance of careful postoperative monitoring in PXS eyes. Preoperative assessment of ACA, ACD, ACV, CV, and CCT remains important for anticipating intraoperative challenges and postoperative outcomes. Techniques aimed at minimizing endothelial stress, including careful phacoemulsification strategies and optimized viscoelastic use, may be particularly beneficial in this high-risk population[19]. Furthermore, detailed anterior segment imaging with Sirius Scheimpflug tomography may provide valuable structural information during postoperative follow-up in patients with PXS.

In conclusion, cataract surgery induces significant anterior segment remodeling in both PXS and non-PXS eyes; however, PXS eyes exhibit more pronounced structural alterations, particularly regarding ACA widening, transient postoperative corneal thickening, and sustained CV increase. These findings suggest that altered zonular and endothelial biomechanics in PXS may influence postoperative anterior segment adaptation.

Parameters such as CV, ACA, and CCT may serve as potential indicators associated with postoperative corneal integrity and glaucomatous risk in PXS eyes. Sirius Scheimpflug imaging may therefore provide valuable support for individualized postoperative assessment and follow-up in this high-risk population. Further prospective longitudinal studies are warranted to validate the clinical relevance and long-term implications of these findings.

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Data Availability Statement: All data produced in the present study are available upon reasonable request to the corresponding author.

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Conflicts of Interest: Telek HH, None; **Balta Ö,** None; **Özdemir YA,** None; **Akkaya S,** None.

REFERENCES

1 Thomas MN, Skopiński P, Roberts H, *et al*. The ocular surface and the anterior segment of the eye in the pseudoexfoliation syndrome: a comprehensive review. *Int J Mol Sci* 2025;26(2):532.

2 Mastronikolis S, Pagkalou M, Plotas P, *et al*. Emerging roles of oxidative stress in the pathogenesis of pseudoexfoliation syndrome. *Exp Ther Med* 2022;24(3):602.

3 Karmiris E, Machairoudia G, Roussou A, *et al*. Corneal and anterior segment parameters in patients with clinically unilateral pseudoexfoliation syndrome. *Med Hypothesis Discov Innov Ophthalmol* 2024;13(2):70-75.

4 Schlötzer-Schrehardt U, Naumann GO. Ocular and systemic pseudoexfoliation syndrome. *Am J Ophthalmol* 2006;141(5):921-937.

5 Nakagawa S, Kanda S, Ishii K. Secondary intrascleral intraocular lens fixation with lens capsule preservation for aphakic eyes in patients with pseudoexfoliation syndrome: a case series. *Cureus* 2024;16(10):e70688.

6 Cakir I, Altan C, Yalcinkaya G, *et al*. Evaluation of post phacoemulsification inflammation in eyes with and without pseudoexfoliation syndrome according to phaco parameters *via* laser flare photometry. *Photodiagnosis Photodyn Ther* 2022;38:102805.

7 Preoteasa LD, Baltă G, Baltă FN. Investigation of risk factors predicting cataract surgery complications in patients with pseudoexfoliation syndrome: a systematic review. *J Clin Med* 2024;13(6):1824.

8 Ma Y, Li Q, Dong Y, *et al*. Unexpected findings: loss of corneal endothelial cells in Uygur patients with exfoliation syndrome. *Int Ophthalmol* 2024;44(1):71.

9 Atalay K, Kocak I, Sayin N, *et al*. Corneal endothelial and retinal microvascular changes in pseudoexfoliation syndrome: insights from specular microscopy and OCT angiography. *BMC Ophthalmol* 2025;25(1):202.

10 Mohammadi M, Johari M, Eslami Y, *et al*. Evaluation of anterior segment parameters in pseudoexfoliation disease using anterior segment optical coherence tomography. *Am J Ophthalmol* 2022;234:199-204.

11 Gunes A, Yigit M, Tok L, *et al*. Evaluation of anterior segment parameters in patients with pseudoexfoliation syndrome using Scheimpflug imaging. *Arq Bras Oftalmol* 2016;79(3):177-179.

12 Elgin U, Şen E, Şimşek T, *et al*. Early postoperative effects of cataract surgery on anterior segment parameters in primary open-angle glaucoma and pseudoexfoliation glaucoma. *Turk J Ophthalmol* 2016;46(3):95-98.

13 Gür Güngör S, Akman A, Asena L, *et al*. Changes in anterior chamber depth after phacoemulsification in pseudoexfoliative eyes and their effect on accuracy of intraocular lens power calculation. *Turk J Ophthalmol* 2016;46(6):255-258.

14 Yüksel N, Yılmaz Tuğan B. Pseudoexfoliation glaucoma: clinical presentation and therapeutic options. *Turk J Ophthalmol* 2023;53(4):247-256.

15 Detorakis ET, Bontzos G, Drakonaki EE, *et al*. Changes in peri-ocular anatomy and physiology in pseudoexfoliation syndrome. *Exp Ther Med* 2021;21(6):650.

16 Hayashi K, Manabe S, Yoshimura K, *et al*. Corneal endothelial damage after cataract surgery in eyes with pseudoexfoliation syndrome. *J Cataract Refract Surg* 2013;39(6):881-887.

17 Kaljurand K, Teesalu P. Exfoliation syndrome as a risk factor for corneal endothelial cell loss in cataract surgery. *Ann Ophthalmol* (*Skokie*) 2007;39(4):327-333.

18 Erdogdu E, Cakır I, Altan C, *et al*. Structural changes in Schlemm's canal and trabecular meshwork after phacoemulsification in patients with pseudoexfoliative glaucoma. *Eur J Ophthalmol* 2026;36(3):662-671.

19 Bilak S, Simsek A, Capkin M, *et al*. Biometric and intraocular pressure change after cataract surgery. *Optom Vis Sci* 2015;92(4):464-470.