

# Dynamic Changes in Implantable Collamer Lens Vault and Anterior Chamber Angle Under Varying Lighting Conditions

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**Purpose:** To evaluate the effect of lighting conditions on Implantable Collamer Lens (ICL) vault and anterior chamber angle measurements using the MS-39, and to determine whether vault variability correlates with average vault or ICL power.

**Methods:** A retrospective analysis was performed on 100 eyes from 53 patients who underwent EVO or EVO Toric ICL implantation. Postoperative anterior segment imaging was conducted using the MS-39 device under scotopic, mesopic, and photopic lighting. Vault and anterior chamber angles were measured, with angle values derived from the mean of the nasal and temporal readings along the 180° axis. A Friedman and ANOVA test assessed changes in measurements across lighting conditions. Pearson and Spearman correlation was used to evaluate relationships between vault variability, mean vault, and ICL power.

**Results:** Mean vault significantly decreased under photopic conditions ( $393.8 \pm 165.6 \mu\text{m}$ ) compared to mesopic ( $486.7 \pm 185.5 \mu\text{m}$ ) and scotopic ( $495.6 \pm 187.7 \mu\text{m}$ ) states ( $p < 0.0001$ ). Angle measurements increased significantly under brighter lighting ( $p < 0.0001$ ). Vault variability positively correlated with mean vault ( $\rho = 0.395$ ,  $p < 0.0001$ ), while ICL power showed a weak negative correlation ( $\rho = -0.224$ ,  $p = 0.025$ ).

**Conclusion:** ICL vault and anterior chamber angle measurements vary meaningfully with lighting conditions. Eyes with higher vaults exhibit greater variability, while lower vaults demonstrated less variability across lighting conditions. ICL power may have a small but weak influence on vault dynamics. These findings may help refine ICL sizing strategies and postoperative assessment protocols.

**Keywords:** refractive surgery, vision correction, phakic IOLs, vault, sizing

## Introduction

Implantable Collamer Lens (ICL) vault, the distance between the posterior surface of the ICL and the anterior capsule of the crystalline lens, is a critical postoperative outcome measure. It plays a key role in ensuring adequate aqueous humor flow while avoiding mechanical contact with intraocular structures. Inadequate vault can be associated with cataract formation, whereas excessive vault can increase the risk of angle closure and elevated intraocular pressure.<sup>1,2</sup>

The ideal vault varies based on individual anterior segment anatomy, including white-to-white (WTW) and sulcus-to-sulcus measurements.<sup>3,4</sup> Recent advances in anterior segment imaging, such as swept-source optical coherence tomography (OCT) and Scheimpflug imaging, and ultrasound biomicroscopy (UBM) allow for more precise pre- and postoperative assessments. Accurate prediction of postoperative vault has become increasingly important as ICL indications expand to include lower myopic powers and expanded age ranges in the United States.<sup>5,6</sup>

However, vault is not a static metric. Dynamic changes in iris configuration and pupil size can alter the spatial relationship between the ICL and the natural lens.<sup>7</sup> Physiologic changes such as accommodation, age-related lens thickening, and environmental factors like lighting can influence the anterior segment's structure and thereby the ICL's position.<sup>8,9</sup> Prior studies have suggested that lighting conditions can cause variability in vault due to iris behavior and



shifting of the ICL.<sup>10,11</sup> Despite these insights, few studies have comprehensively quantified the effect of scotopic, mesopic, and photopic lighting on vault and angle measurements. Moreover, the clinical implications of these variations remain underexplored. This also implies that if vault is both broadly tolerated and inherently dynamic, then striving to predict an exact postoperative vault may be less valuable than previously assumed and fixating on achieving specific numbers postoperatively may not be necessary.

This study evaluates postoperative ICL vault and anterior chamber angle measurements under varying lighting conditions using the MS-39 anterior segment analyzer. The primary aim is to determine whether lighting conditions significantly affect vault and angle measurements, and whether vault variability is associated with mean vault or ICL power. We hypothesize that vault and angle measurements vary across lighting conditions and that higher vaults demonstrate greater variability.

## Materials and Methods

### Study Design

This study was a single-center retrospective chart review of consecutive patients who underwent EVO or EVO Toric Implantable Collamer Lens (ICL) implantation at Parkhurst NuVision (San Antonio, Texas, USA) between January 6, 2025 and October 19, 2025.

Data were collected from 100 eyes of 53 consecutive patients with complete postoperative imaging using the CSO MS-39 anterior segment analyzer (CSO, Florence, Italy). Vault measurements were obtained under three standardized lighting conditions simulated by the device: scotopic, mesopic, and photopic. The average anterior chamber angle was calculated as the mean of nasal and temporal angle measurements along the 180-degree meridian. For each lighting condition, sufficient time was allowed for the pupil to reach a steady physiologic state prior to image acquisition.

All patients were evaluated at a single postoperative time point between 1 and 2 months following surgery.

Demographic variables recorded included age, eye laterality, ICL size, and ICL power.

### Ethics Statement

This study adhered to the tenets of the Declaration of Helsinki. The study protocol was reviewed by Salus Institutional Review Board (Austin, Texas, USA). The IRB determined this study to be exempt under 45 CFR 46.104(d)(4) (Salus Number: 26075; Date of Determination: February 10, 2026). In addition, a waiver of HIPAA Authorization was approved under 45 CFR 164.512(i)(2). Given the retrospective design and use of existing clinical data, the requirement for informed consent was waived by the IRB. No prospective interventions were performed for research purposes.

### Surgical Protocol

The ICL procedures were planned and performed in the typical manner. Younger patients were generally targeted for a spherical equivalent outcome of +0.25 D, moving closer to plano by age 50. For those older than 40–45, blended vision was offered and frequently implemented, adjusting the non-dominant eye closer to  $-1.00$  D after assessing tolerance prior to surgery. The manufacturer's nomogram, Stella, was used for these calculations. In eyes where ACD measurement was below the FDA indication of 3.0 mm or greater, clinical judgement was used to assess safety and a "one eye at a time" approach was employed in lieu of same day immediately sequential bilateral surgery as appropriate, especially for patients with ACDs  $<2.8$  mm. The lowest internal ACD we have personally performed safe EVO ICL surgery on is 2.34 mm. The EVO+ lens was the primary choice, and the EVO lens was chosen when necessary, when the EVO+ was not available due to lens power. The ICLs were implanted through a 3.0 mm incision. The majority of the cases were bilateral, same-day except when it was decided to perform the cases one eye at a time due to ambiguity in sizing or ACD  $<2.8$ . Each bilateral procedure was immediately sequential with separate sets of sterile instruments and medications from separate lot numbers between cases. A brief exam was performed 1 hour after surgery to check IOP and wound closure. For additional consideration of lens size selection, a combination of techniques were used including the Parkhurst Nomogram and ICLGuru on the Sonomed Escalon (Escalon Medical, Wayne, PA, USA). During this study, we also implemented ICL Fit (ICLFit.com), our novel, in-house AI nomogram utilizing the Pentacam AXL (Oculus

Optikgeräte GmbH, Wetzlar, Germany). For additional information on the surgical techniques the authors use, please consult the video library we put together for ICL surgery at: <https://refractivefoundations.com/icls/>.

## Statistical Analysis

Statistical analysis included descriptive statistics for vault and angle measurements under each lighting condition. Friedman and ANOVA test was used to assess whether vault and angle measurements differed significantly between lighting conditions, accounting for repeated measurements across lighting conditions within eyes. Correlations were calculated between vault variability (defined as the range across lighting conditions) and both average vault and ICL power using correlation coefficients. Data visualization was performed using boxplots and scatter plots with linear regression overlays. All statistical analyses were conducted using RStudio with Dplyr and TidyR libraries (R Foundation for Statistical Computing, Vienna, Austria). Vault variability was defined as the range of vault measurements obtained across scotopic, mesopic, and photopic lighting conditions for each eye.

## Results

The cohort included 100 eyes (mean age  $34.6 \pm 7.1$  years), with the majority receiving toric lenses and sizes ranging from 12.6 mm to 13.2 mm (Table 1). The distribution of left and right eyes was balanced, and all surgeries were performed by experienced refractive surgeons using standard protocols.

Mean vault measurements across lighting conditions were as follows:

- Scotopic:  $495.6 \pm 187.7 \mu\text{m}$
- Mesopic:  $486.7 \pm 185.5 \mu\text{m}$
- Photopic:  $393.8 \pm 165.6 \mu\text{m}$

Mean anterior chamber angles are as follows:

- Scotopic:  $27.2 \pm 5.2^\circ$
- Mesopic:  $27.0 \pm 5.1^\circ$
- Photopic:  $29.7 \pm 6.3^\circ$

The Friedman test showed statistically significant differences in both vault ( $p < 0.00001$ ) and angle ( $p < 0.00001$ ) across lighting conditions (Figures 1 and 2). Vaults decreased under brighter lighting, while angles widened. The mean difference in vault between scotopic and photopic conditions was  $101.8 \pm 74.5 \mu\text{m}$ . Mean difference in vault between mesopic and photopic conditions was  $92.9 \pm 65.8 \mu\text{m}$ .

A moderate positive correlation ( $\rho = 0.395$ ,  $p = 0.000048$ ) was found between average vault and vault variability, indicating that higher vaults are subject to greater changes across lighting conditions (Figure 3). However, there was

**Table 1** Baseline Patient Demographic Data

Total Number of Eyes	100
Total Number of Patients	53
Mean Age $\pm$ SD (years)	$34.6 \pm 7.1$
Gender (Male/Female)	46/24
Toric ICLs (Yes/No)	42/58
ICL Size Distribution	12.1: 8 12.6: 49 13.2: 43

**Abbreviations:** SD, standard deviation; ICL, implantable Collamer lens.

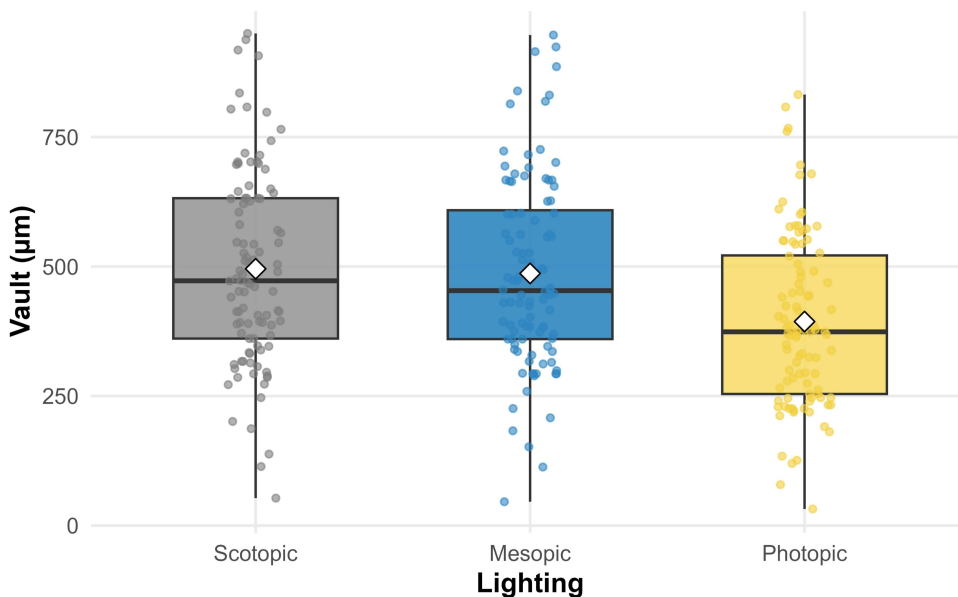


Figure 1 ICL Vault by Lighting Conditions.

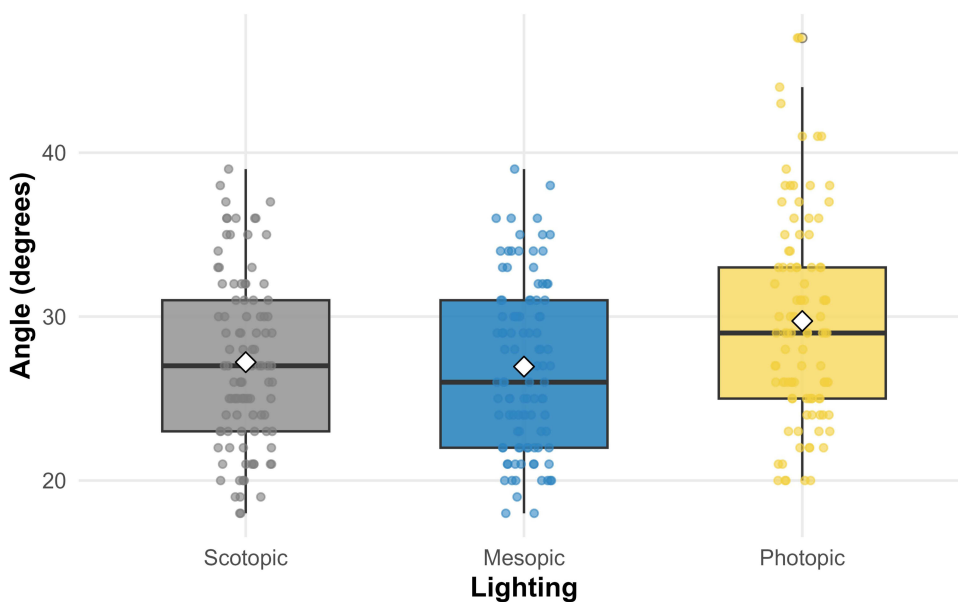


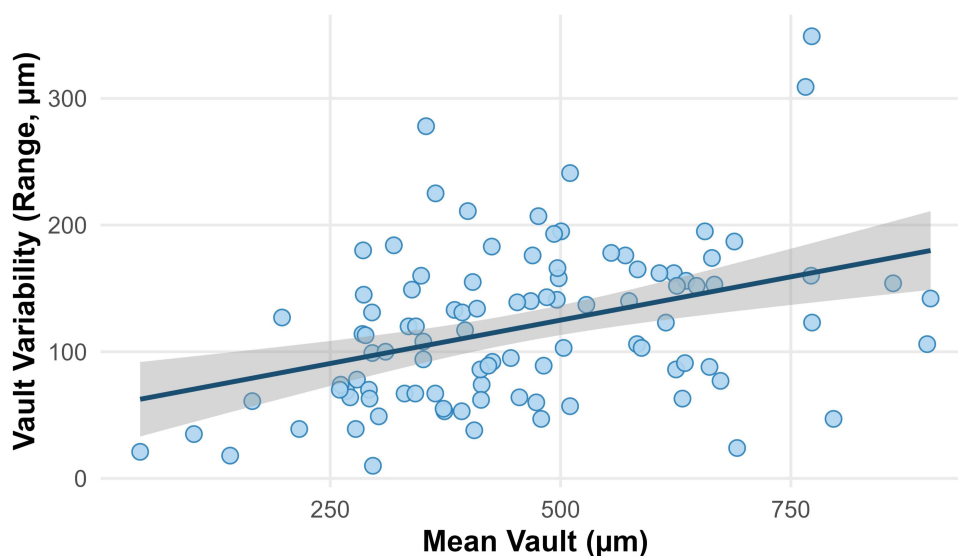
Figure 2 Anterior Chamber Angle by Lighting Conditions.

a weak negative correlation between ICL power and vault variability ( $\rho = -0.224, p = 0.02535$ ) (Figure 4). Visual inspection of scatter plots confirmed these trends, with variability clustering more widely at higher vault means.

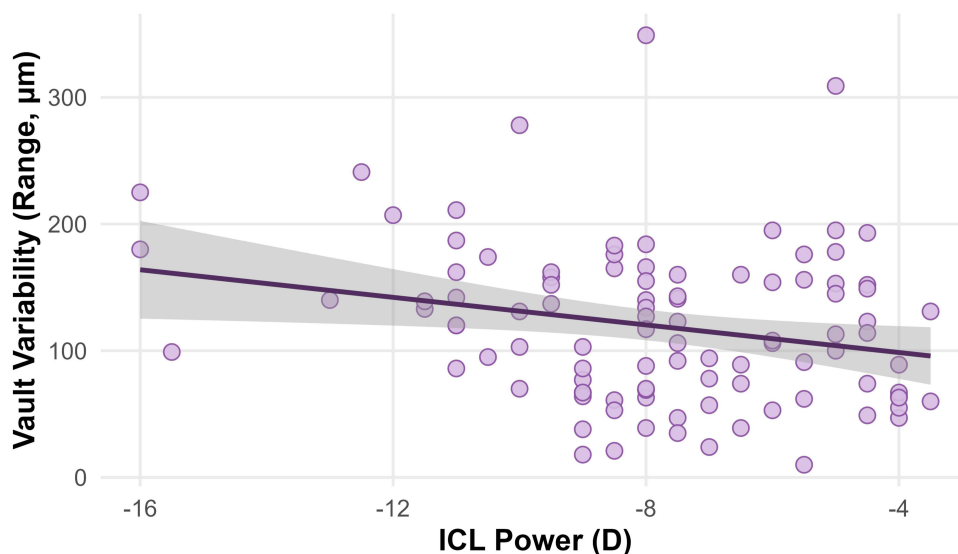
Lastly, age was not significantly related to mean vault ( $\rho = -0.111, p = 0.2704$ ) or vault variability ( $\rho = 0.041, p = 0.6846$ ).

## Discussion

This study suggests that ICL vault is not static and varies significantly under different lighting conditions. Notably, eyes with higher mean vaults exhibited greater variability, while those with lower vaults demonstrated less variability across lighting conditions in this dataset. Angle measurements also increased significantly under photopic conditions, consistent with known behavior of the iris-lens diaphragm in response to light. A weak negative association between ICL dioptric



**Figure 3** Vault Variability vs Mean Vault.



**Figure 4** Vault Variability vs ICL Power.

power and vault variability suggests that optical power may have a small influence on ICL mobility or anterior segment dynamics. These findings align with prior literature indicating that ICL sizing and haptic positioning, not power, are the primary determinants of vault.<sup>12,13</sup>

Study limitations include the limited sample size and reliance on a single imaging modality. The retrospective nature of the study may also introduce selection bias, although patients were drawn from a consecutive series of EVO ICL cases. Furthermore, all patients were measured at a single postoperative timepoint, precluding longitudinal analysis. Important determinants of vault such as sulcus anatomy, crystalline lens rise, anterior chamber depth, and sizing parameters were not modeled and may contribute to vault behavior. These factors may be valuable to examine in future studies using advanced imaging such as UBM. Both eyes from some patients were included, which may introduce inter-eye correlation. However, each eye represents an independent surgical unit in the context of ICL implantation, with individualized sizing decisions based on eye-specific anatomy, and bilateral eyes do not necessarily receive the same lens size or exhibit the same postoperative vault characteristics. Importantly, the primary analyses in this study evaluate

within-eye changes across lighting conditions rather than between-eye comparisons. As such, the central findings are driven by repeated physiologic measurements within the same eye, which mitigates the impact of inter-eye dependence. The consistency of observed trends across the dataset further supports the robustness of these findings. While variability measures such as range may partially scale with the overall magnitude of vault, the observed relationship was consistent across the dataset and is unlikely to be fully explained by this effect alone.

Given the observed variability in vault measurements across differing physiologic conditions, vault should be considered a dynamic parameter rather than a fixed postoperative value. If vault fluctuates in response to factors such as lighting and pupillary state, then efforts to predict or target a single precise postoperative vault measurement may be of limited clinical relevance. Instead, a successful ICL outcome may be more appropriately conceptualized as a physiologic range within which measurements remain stable across varying physiologic conditions or a composite assessment of ICL fit that accounts for multiple parameters beyond a single measurement. Framing vault as a spectrum rather than a point estimate better reflects its intrinsic variability and may help refine both preoperative sizing strategies and postoperative assessment paradigms. This perspective also allows for the possibility of alternative methods of characterizing ideal ICL fit and optimal phakic IOL outcome beyond absolute micrometer values. For example, vault could be expressed relative to individual anterior segment anatomy, such as a percentage of anterior chamber depth, thereby accounting for inter-eye variability in ocular dimensions. Conceptualizing vault proportionally rather than absolutely may provide a more physiologically meaningful framework for evaluating safety and optimizing sizing strategies and these are areas we are actively interested in and investigating.

Vault and anterior chamber angle measurements vary meaningfully with lighting conditions. Higher vaults tend to exhibit greater variability, which may have implications for long-term vault behavior and sizing algorithms. Future studies with larger samples and longitudinal follow-up are warranted to refine our understanding of vault dynamics post-ICL implantation. Incorporating dynamic vault analysis into routine clinical evaluation may help identify patients at risk for future complications and improve sizing nomograms.

## Conclusion

In summary, we have found that ICL vault is a dynamic, physiologic parameter that varies with lighting conditions, with higher vaults demonstrating greater variability while lower vaults demonstrate less variability across lighting conditions in this dataset. These findings support conceptualizing vault as a physiologic range rather than a fixed target value and suggest that future sizing strategies may benefit from proportional or anatomy-based approaches based on “fit” rather than reliance on absolute micrometer measurements.

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## Disclosure

Matthew Hirabayashi MD, Taj Nasser MD, and Greg Parkhurst MD are consultants for STAAR Surgical.

The authors report no conflicts of interest in this work.

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