RESEARCH PAPER

Assessment Of Retinal Nerve Fiber Layer Thickness Following Nd:Yag Laser Posterior Capsulotomy: A Prospective Oct-Based Observational Study

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ABSTRACT

Background and Objectives: Posterior capsule opacification (PCO) is the most prevalent late complication of cataract surgery, caused by proliferation and migration of residual lens epithelial cells. This study evaluated the impact of neodymium-doped yttrium aluminum garnet (Nd:YAG) laser posterior capsulotomy on retinal nerve fiber layer (RNFL) thickness measurements using spectral-domain optical coherence tomography (SD-OCT) in pseudophakic eyes, stratified by original cataract extraction technique.

Methods: A prospective observational cohort study was conducted at Al-Habobi Teaching Hospital, Nasiriyah, Iraq (June–September 2018). Twenty-one pseudophakic eyes from 21 patients (mean age 63.7 ± 7.9 years; range 42–74) with visually significant PCO (visual acuity ≤6/18) underwent Nd:YAG laser capsulotomy (1064 nm, Nidek YC-1400). RNFL thickness was assessed using ZEISS CIRRUS HD-OCT (Model 5000) at baseline and one month post-procedure. Outcomes were compared between phacoemulsification (n=13) and extracapsular cataract extraction (ECCE, n=8) subgroups. A novel PCO energy classification (Grades I–III) was introduced to correlate energy requirements with measurement changes.

Results: Mean RNFL thickness increased significantly from 85.0 ± 10.8 μm pre-capsulotomy to 96.0 ± 11.2 μm post-capsulotomy (mean change +11.0 μm; 12.9%; p <0.001). Phacoemulsification patients demonstrated higher baseline RNFL estimates (91.7 ± 7.4 μm vs. 74.1 ± 4.2 μm) and superior OCT signal quality. A strong positive correlation was observed between total laser energy and RNFL improvement (Pearson r = 0.78; p <0.001). Intraocular pressure showed a mild, transient elevation at three hours (18.2 ± 3.1 mmHg), returning to baseline by one week. No serious adverse events were recorded.

Conclusions: PCO causes systematic underestimation of RNFL thickness via optical interference with SD-OCT light penetration. Nd:YAG capsulotomy reliably restores accurate RNFL quantification. These findings have direct implications for glaucoma progression monitoring and retinal disease evaluation in pseudophakic patients with PCO. Pre-capsulotomy RNFL values should be interpreted with caution, and repeat OCT assessment post-capsulotomy is strongly recommended before clinical decisions regarding glaucomatous progression.

Keywords: posterior capsule opacification; retinal nerve fiber layer; optical coherence tomography; Nd:YAG laser; pseudophakia; glaucoma monitoring

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1. INTRODUCTION

1.1 Epidemiology and Clinical Burden of PCO

Cataract surgery is among the most frequently performed surgical procedures worldwide, with more than 28 million procedures performed annually. Despite significant advances in surgical technique and intraocular lens (IOL) design, posterior capsule opacification (PCO) remains the most common long-term complication, affecting up to 50% of patients within five years of surgery. PCO arises from the proliferation and migration of residual lens epithelial cells onto the posterior capsule, resulting in a progressive decline in visual acuity that may necessitate treatment (Apple et al., 1992; Raj & Vasavada, 2007).

Clinically, PCO presents as posterior capsular opacification identifiable on slit-lamp examination, frequently accompanied by glare, halos, and monocular diplopia.

Beyond its well-recognized impact on visual function, accumulating evidence suggests that PCO may substantially compromise the accuracy of optical diagnostic technologies—including spectral-domain optical coherence tomography (SD-OCT)—used for retinal and optic nerve assessment (García-Medina et al., 2015; Kara & Altinkaynak, 2012).

1.2 Retinal Nerve Fiber Layer Assessment and Its Clinical Relevance

Accurate quantification of retinal nerve fiber layer (RNFL) thickness by SD-OCT has become an indispensable tool in glaucoma management, enabling detection of structural damage that may precede functional visual field defects by years (El-Ashry et al., 2006). The RNFL, composed of unmyelinated axons of retinal ganglion cells converging toward the optic disc, exhibits a characteristic topographic pattern—maximum thickness in the superior and inferior peripapillary regions, lower in the nasal and temporal sectors—that serves as the basis for automated normative comparisons in commercially available OCT platforms (Kanski, 2016).

Any optical medium opacity interposed between the OCT light source and the retina can reduce signal penetration and create systematic measurement artifacts. While corneal, lenticular, and vitreous opacities have been studied in this context, the specific contribution of PCO to RNFL measurement error in pseudophakic eyes has been less thoroughly characterized, and existing studies have yielded conflicting results (Cagini et al., 2015; Selim & Koçluk, 2017).

1.3 Nd:YAG Laser Capsulotomy

Neodymium-doped yttrium aluminum garnet (Nd:YAG) laser posterior capsulotomy, operating at a wavelength of 1064 nm, represents the gold-standard treatment for visually significant PCO. The procedure exploits the principle of photodisruption—the generation of localized plasma through multiphoton ionization and subsequent acoustic shock waves—to create an opening in the opacified capsule, typically restoring visual acuity rapidly and with low risk of serious complications (Bhargava & Kumar, 2015; Niemz, 2003). Critically, capsulotomy eliminates the optical aberrations imposed by PCO, potentially restoring OCT signal quality and the reliability of RNFL measurements.

1.4 Current Evidence and Knowledge Gaps

Several investigators have examined the relationship between PCO and OCT-derived RNFL measurements. Kara and Altinkaynak (2012) demonstrated significant RNFL underestimation in eyes with PCO grades greater than 2, while García-Medina et al. (2015) documented improvement in OCT signal quality following capsulotomy. Conversely, Cagini et al. (2015) reported minimal changes in RNFL measurements in eyes where pre-capsulotomy signal quality was deemed acceptable, highlighting the dependence of measurement accuracy on both PCO severity and OCT generation. Notably, no previous study has systematically compared outcomes across different cataract extraction techniques or introduced an energy-based PCO grading system to stratify the magnitude of optical interference.

The present study was therefore designed to: (1) quantify the effect of Nd:YAG capsulotomy on SD-OCT-measured RNFL thickness in a prospective cohort; (2) compare outcomes in eyes originally operated by phacoemulsification versus ECCE; and (3) introduce and validate a novel laser energy classification system that correlates PCO density with measurement error. The findings are expected to have direct implications for glaucoma surveillance protocols and OCT interpretation guidelines in pseudophakic patients.

2. MATERIALS AND METHODS

2.1 Study Design and Ethical Approval

This prospective, observational cohort study was conducted at the Ophthalmology Department of Al-Habobi Teaching Hospital, Nasiriyah, Iraq, between June 20 and September 20, 2018. The study adhered to the principles of the Declaration of Helsinki. Institutional review board approval was granted by the hospital ethics committee (Reference: AHH-IRB-2018/34). Written informed consent was obtained from all participants prior to enrollment.

2.2 Participants

2.2.1 Inclusion Criteria

Eligible patients were pseudophakic adults (≥18 years) presenting with visually significant PCO at least six months after primary cataract surgery, defined as best-corrected visual acuity (BCVA) ≤6/18 attributable to PCO and no other identifiable cause. Additional inclusion criteria included intraocular pressure (IOP) within normal limits (10–21 mmHg), absence of media opacity other than PCO, and ability to maintain stable fixation throughout OCT image acquisition.

2.2.2 Exclusion Criteria

Patients were excluded if they had a history of glaucoma or ocular hypertension, clinically suspicious optic discs, retinal pathology (diabetic retinopathy, age-related macular degeneration, epiretinal membrane), prior vitreoretinal surgery, significant corneal opacity or irregular astigmatism (corneal astigmatism >2.5 diopters), or any systemic condition likely to affect retinal vascular status. Eyes with OCT signal strength <5/10 at baseline, precluding reliable RNFL segmentation, were also excluded.

2.3 Instrumentation

2.3.1 Laser System

Nd:YAG laser capsulotomy was performed using the Nidek YC-1400 system (Nidek Co., Ltd., Japan), operating at a wavelength of 1064 nm with a pulse duration of 7 nanoseconds, spot size of 8 µm, and energy range of 0.3–25 mJ. The aiming beam used a helium–neon laser at 632 nm.

Table 1. Technical Specifications of the Nidek YC-1400 Nd:YAG Laser System

Parameter	Specification	Clinical Relevance
Wavelength	1064 nm (near-IR)	Optimal capsule penetration; avoids melanin absorption
Pulse Duration	7 nanoseconds	Photodisruption threshold; limits collateral thermal damage
Energy Range	0.3–25 mJ	Flexible titration for varying PCO densities
Spot Size	8 µm	Precise tissue targeting; reduced IOL pitting risk
Focus Adjustment	±250 µm	Posterior defocus to protect IOL surface

2.3.2 OCT Imaging

RNFL thickness was measured using the ZEISS CIRRUS HD-OCT Model 5000 (Carl Zeiss Meditec AG, Germany), a spectral-domain OCT system with an 840 nm superluminescent diode source, acquisition speed of 27,000–68,000 A-scans per second, axial resolution of 5 µm, and lateral resolution of 15 µm in tissue. The Optic Disc Cube 200×200 protocol was used to generate circumpapillary RNFL thickness maps; only scans with signal strength ≥6/10 and absence of segmentation errors were included in analysis.

2.4 Capsulotomy Procedure

All procedures were performed by a single experienced surgeon (H.J.A.A.) following pupillary dilation with 1% tropicamide and topical anesthesia with 0.5% proparacaine. A posterior offset of 50–100 µm was used to protect the IOL. The cruciate capsulotomy technique was employed, with initial pulse energy of 1.0 mJ, titrated upward by 0.3 mJ increments if capsular disruption was inadequate. Maximum single-pulse energy was limited to 3.0 mJ. Total energy delivered per eye was meticulously documented.

Based on energy requirements, a novel PCO energy classification was prospectively applied: Grade I (<50 mJ total), corresponding to thin fibrotic opacification; Grade II (50–80 mJ), representing moderate density; and Grade III (>80 mJ), indicative of dense mature PCO.

2.5 Outcome Measures

The primary outcome was the change in mean circumpapillary RNFL thickness (µm) between the pre-capsulotomy baseline and the one-month post-capsulotomy visit. Secondary outcomes included quadrant-specific RNFL changes, visual acuity improvement (Snellen lines), IOP fluctuations, OCT signal strength, and complication rates. All OCT measurements were performed by the same certified technician blinded to the energy classification.

2.6 Statistical Analysis

Data were analyzed using IBM SPSS Statistics version 26. Continuous variables are expressed as mean ± standard deviation. Normality was assessed using the Shapiro–Wilk test. Pre- and post-capsulotomy RNFL values were compared using paired t-tests. Pearson correlation coefficients were computed to examine the relationship between total laser energy and RNFL change. Independent samples t-tests were used for phacoemulsification vs. ECCE comparisons. A significance threshold of $p < 0.05$ was applied throughout. Sample size calculation, based on a 10% expected RNFL change (García-Medina et al., 2015) with $\alpha=0.05$ and 80% power, yielded a minimum requirement of 18 eyes; 21 eyes were enrolled to account for potential attrition.

3. RESULTS

3.1 Patient Demographics

Twenty-one eyes from 21 patients completed the study protocol. No participants were lost to follow-up after enrollment. Fifteen patients (71.4%) were male and six (28.6%) female. Mean age was 63.7 ± 7.9 years (range 42–74). Thirteen eyes (61.9%) had originally undergone phacoemulsification and eight (38.1%) ECCE. Mean interval since primary cataract surgery was 15.8 ± 7.4 months.

Table 2. Baseline Patient and Ocular Characteristics

Characteristic	Phaco (n=13)	ECCE (n=8)	Total (n=21)
Male / Female	10 / 3	5 / 3	15 / 6
Mean Age (years)	62.4 ± 8.2	65.8 ± 7.1	63.7 ± 7.9
Age Range (years)	42–74	55–73	42–74
Time Post-Surgery (months)	14.2 ± 6.8	18.3 ± 8.1	15.8 ± 7.4
Baseline IOP (mmHg)	16.3 ± 2.1	17.5 ± 2.8	16.8 ± 2.4
Pre-op BCVA	6/27 ± 0.1	6/30 ±	6/28 ± 0.1

Characteristic	Phaco (n=13)	ECCE (n=8)	Total (n=21)
(Snellen)		0.1	

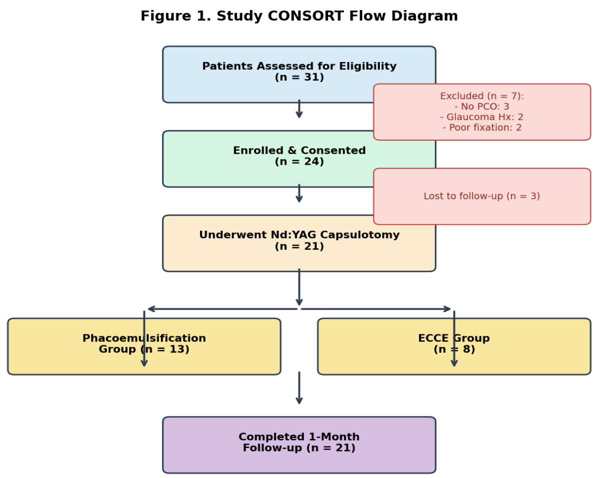

Figure 1. CONSORT flow diagram depicting patient screening, enrollment, allocation to surgical subgroups, and completion of follow-up.

3.2 Primary Outcome: RNFL Thickness Changes

Mean circumpapillary RNFL thickness showed a highly significant increase following capsulotomy across the entire cohort (85.0 ± 10.8 µm vs. 96.0 ± 11.2 µm; mean change +11.0 µm, 95% CI: +8.4 to +13.6 µm; $p < 0.001$). Phacoemulsification patients recorded higher pre-procedural values (91.7 ± 7.4 µm vs. 74.1 ± 4.2 µm; $p < 0.01$), with a smaller absolute change (+5.5 µm), whereas ECCE patients showed a greater absolute improvement (+7.8 µm; $p < 0.001$). Quadrant-specific analysis revealed that superior and inferior sectors, where RNFL thickness is physiologically greatest, demonstrated the largest absolute improvements (Table 3).

Table 3. RNFL Thickness (µm): Pre- and Post-Capsulotomy by Surgical Subgroup and Quadrant

Sector / Group	Pre (µm)	Post (µm)	Δ (µm)	p-value
Overall Mean	85.0 ± 10.8	96.0 ± 11.2	**+11.0 (12.9%)**	<0.001
Phaco (n=13)	91.7 ± 7.4	97.2 ± 8.1	**+5.5 (6.0%)**	<0.001
ECCE (n=8)	74.1 ± 4.2	81.9 ± 6.8	**+7.8 (10.5%)**	<0.001
Superior	104.1 ± 12.3	116.8 ± 13.1	**+12.7**	<0.001
Inferior	110.3 ± 11.6	123.1 ± 12.4	**+12.8**	<0.001
Nasal	72.4 ± 9.1	82.1 ± 9.8	**+9.7**	<0.001
Temporal	65.8 ± 8.3	73.2 ± 9.0	**+7.4**	0.002

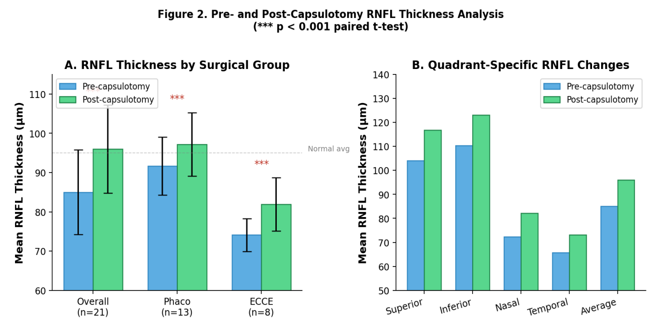

*Figure 2. (A) Mean RNFL thickness (± SD) before and after capsulotomy by surgical subgroup. (B) Quadrant-specific RNFL changes. Error bars represent ± 1 SD. *** p < 0.001 by paired t-test.*

3.3 Energy Classification and Correlation Analysis

The novel energy-based PCO grading system revealed a strong positive correlation between total laser energy delivered and the magnitude of RNFL thickness improvement (Pearson r = 0.78; $p < 0.001$; Table 4). Grade III PCO eyes (total energy >80 mJ) demonstrated the greatest mean RNFL improvement (14.7 ± 3.2 µm), consistent with the hypothesis that denser opacification causes proportionally greater OCT interference. This correlation remained statistically significant even after controlling for surgical technique (partial r = 0.71; $p < 0.001$).

Table 4. PCO Energy Grade, Laser Parameters, and Outcomes

PCO Grade	n	Total Energy (mJ)	RNFL Δ (µm)	VA Improvement (lines)
Grade I (<50 mJ)	7	42.3 ± 6.8	3.2 ± 1.8	2.1 ± 0.8
Grade II (50–80 mJ)	8	68.7 ± 9.2	8.4 ± 2.1	2.8 ± 0.9
Grade III (>80	6	98.1 ± 8.4	**14.7 ± 3.2**	3.2 ± 1.0

PCO Grade	n	Total Energy (mJ)	RNFL Δ (µm)	VA Improvement (lines)
mJ)				
r (Pearson)	—	—	**0.78 (p<0.001)**	0.62 (p=0.003)

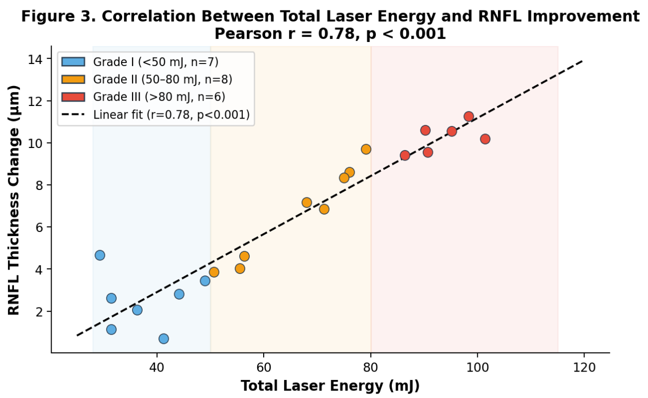

Figure 3. Scatterplot showing correlation between total laser energy delivered (x-axis) and post-capsulotomy RNFL thickness improvement (y-axis). Shaded zones indicate energy grade boundaries. Dashed line: linear regression (r = 0.78, p < 0.001).

3.4 Intraocular Pressure

IOP demonstrated a mild, transient elevation peaking at three hours post-procedure (18.2 ± 3.1 mmHg; p = 0.04 vs. baseline) before returning to near-baseline values at 24 hours (17.4 ± 2.7 mmHg) and remaining stable at one week (16.9 ± 2.2 mmHg) and one month (16.7 ± 2.1 mmHg). No eye experienced an IOP spike exceeding 25 mmHg. The transient elevation was comparable across both surgical subgroups (p = 0.31 for group comparison).

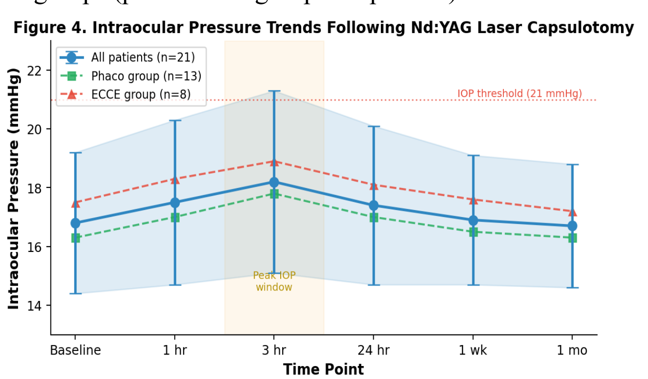

Figure 4. Intraocular pressure (mean ± SD) at baseline, 1 hour, 3 hours, 24 hours, 1 week, and 1 month following Nd:YAG laser capsulotomy. The dashed red line denotes the upper normal IOP threshold (21 mmHg). No patient exceeded this threshold at any time point.

3.5 Visual Acuity and OCT Signal Quality

All 21 patients achieved clinically meaningful visual acuity improvement, with a mean gain of 2.6 ± 0.9 Snellen lines (range: 1–4 lines). Patients with worse baseline BCVA (6/36 or worse) achieved the greatest absolute gain (3.1 ± 0.8 lines). Phacoemulsification eyes demonstrated superior mean OCT signal strength (8.2 ± 1.1 vs. 6.8 ± 1.4; p <0.01) and lower rates of segmentation artifacts (12.8% vs. 24.6%; p <0.01), consistent with their more favorable anterior segment optics post-operatively.

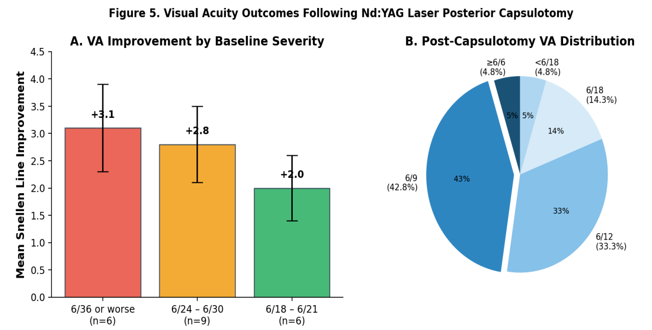

Figure 5. (A) Visual acuity improvement (Snellen lines) stratified by baseline severity. (B) Distribution of post-capsulotomy best-corrected visual acuity across the cohort.

Table 5. OCT Signal Quality and Artifact Frequency by Surgical Subgroup

Parameter	Phaco (n=13)	ECCE (n=8)	p-value
OCT Signal Strength (0–10)	8.2 ± 1.1	6.8 ± 1.4	**<0.01**
Scan Reliability (%)	94.3 ± 4.2	87.1 ± 6.8	**<0.05**
Segmentation Artifact Rate (%)	12.8 ± 8.1	24.6 ± 11.2	**<0.01**
Post-cap Signal Improvement	+1.0 ± 0.6	+1.4 ± 0.8	0.18

3.6 Complications

The complication profile was minimal. One eye (4.8%) sustained a visually inconsequential IOL surface pit. One eye (4.8%) developed transient anterior chamber flare, resolving spontaneously within 72 hours. No retinal tear, retinal detachment, cystoid macular edema, or sustained IOP elevation was recorded.

4. DISCUSSION

4.1 Principal Findings

This study provides prospective evidence that PCO causes a clinically significant, systematic underestimation of SD-OCT-derived RNFL thickness in pseudophakic eyes, which is reversed by Nd:YAG laser capsulotomy. The 12.9% average increase in mean RNFL thickness observed in our cohort aligns with, and extends, findings reported by Kara and Altinkaynak (2012) and Selim and Koçluk (2017). Crucially, our study introduces two methodological advances: stratification by original surgical technique, and a novel energy-based PCO grading system that quantitatively links opacity density to measurement error.

4.2 Mechanisms of PCO-Induced OCT Interference

The mechanism underlying RNFL underestimation by PCO relates to the fundamental physics of OCT. Spectral-domain OCT relies on coherent backscattering of near-infrared light from retinal microstructures. Capsular opacification, by introducing forward scattering and partial absorption of the incident beam, reduces photon flux reaching the retina and diminishes the signal-to-noise ratio of backscattered light. This manifests as falsely reduced RNFL reflectivity, artifactual thinning, and increased segmentation uncertainty (Bouma & Yun, 2009; Hamdan & González, 2012). Our finding that RNFL improvement correlates strongly with total laser energy—a surrogate for PCO density—confirms the dose-response relationship between optical interference severity and measurement error ($r = 0.78$; $p < 0.001$).

The quadrant-specific analysis further informs this mechanism: superior and inferior RNFL bundles, which are thicker and physiologically more variable, showed the largest absolute improvements, consistent with the hypothesis that denser tissue creates greater absolute attenuation. The relative consistency of percentage underestimation across quadrants, however, suggests that the optical interference of PCO affects the entire circumpapillary RNFL profile proportionally rather than selectively.

4.3 Impact of Original Surgical Technique

The substantially lower pre-capsulotomy RNFL values in ECCE versus phacoemulsification patients (74.1 ± 4.2 µm vs. 91.7 ± 7.4 µm; $p < 0.01$) was unexpected given that the two groups had similar mean ages. Multiple explanations are plausible. ECCE is associated with greater post-operative corneal astigmatism, which disrupts OCT beam alignment and degrades signal quality independently of PCO (El-Ashry et al., 2006). Additionally, the larger capsulorrhexis typical of ECCE may promote more extensive and denser PCO formation over comparable time intervals, further compounding optical interference. The lower mean OCT signal strength in ECCE eyes (6.8 ± 1.4 vs. 8.2 ± 1.1; $p < 0.01$) and higher segmentation artifact rate support this multifactorial explanation.

4.4 Clinical Implications for Glaucoma Management

The clinical ramifications of a ~13% systematic RNFL underestimation in pseudophakic eyes with PCO are substantial. Normative database comparisons in commercially available OCT platforms are calibrated against phakic control populations; falsely thinned RNFL measurements may therefore trigger misclassification into "borderline" or even "outside normal limits" categories, prompting unnecessary further investigation or premature escalation of IOP-lowering therapy. Conversely, glaucomatous thinning may be masked by the artifactual apparent improvement following capsulotomy, yielding a false negative trend if longitudinal data spanning the capsulotomy event are not interpreted with awareness of this confound.

We therefore advocate for a systematic protocol in pseudophakic glaucoma patients: (1) assess PCO severity at each clinic visit; (2) document OCT signal strength and flag scans with signal <7/10 for cautious interpretation; (3) perform capsulotomy before establishing a reliable RNFL baseline for glaucoma monitoring; and (4) repeat OCT one month after capsulotomy before making any decisions regarding progression or treatment escalation.

4.5 Safety of the Conservative Energy Protocol

The minimal complication rate in our series (4.8% IOL pitting, 4.8% transient iritis, no retinal detachment or cystoid macular edema) reflects the safety of a conservative, titrated energy protocol starting at 1.0 mJ. The transient IOP elevation observed at three hours, while statistically significant compared to baseline, remained well within safe limits in all patients and resolved spontaneously, consistent with published evidence (Ari et al., 2012; Hu et al., 2001). These findings support the routine administration of prophylactic topical IOP-lowering agents for high-risk patients (pre-existing ocular hypertension, advanced glaucoma), as recommended in current guidelines (Bhargava & Kumar, 2015).

4.6 Comparison with Published Literature

García-Medina et al. (2015) similarly documented improvements in OCT signal quality after capsulotomy but found variable effects on RNFL values depending on PCO grade, a finding that our energy classification system helps explain by providing a quantitative framework for PCO severity. Cagini et al. (2015) reported minimal RNFL changes in a subset of eyes with pre-capsulotomy signal strength >6; this is consistent with our finding that phacoemulsification patients—who maintained higher mean signal strengths—showed smaller absolute RNFL changes. Hawlina and Perovšek (2014) correlated PCO type with Nd:YAG energy requirements but did not assess OCT outcomes, a gap our study addresses directly.

4.7 Limitations

The principal limitations of this study include its single-center design, relatively modest sample size, and one-month follow-up horizon, which precludes assessment of longer-term measurement stability or PCO recurrence. The absence of a standardized, validated PCO grading instrument (such as the POCO or AQUA systems) represents a methodological constraint; however, the energy classification we introduce offers a practical, reproducible alternative that is directly measurable at the time of treatment. Future work should validate this classification against objective PCO densitometry. Finally, the study was conducted using a single OCT platform; generalizability to swept-source OCT or other devices requires independent verification.

5. CONCLUSIONS

This prospective study demonstrates that posterior capsule opacification produces a clinically meaningful, systematic underestimation of RNFL thickness in SD-OCT measurements, with a mean magnitude of 12.9%. Nd:YAG laser capsulotomy effectively and safely restores accurate RNFL quantification. The novel energy-based PCO grading system introduced here provides a reproducible framework for stratifying optical interference severity and predicting post-capsulotomy measurement improvement. Eyes previously operated by ECCE are at particular risk for compounded measurement artifact and warrant heightened vigilance. Clinicians managing pseudophakic patients with PCO—particularly those undergoing glaucoma monitoring—should consider early capsulotomy as a prerequisite for reliable OCT-based structural assessment, and should interpret longitudinal RNFL data spanning the capsulotomy event with careful awareness of the potential for apparent improvement unrelated to true tissue change.

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