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The Comprehensive Systematic Review of Association of Posterior Capsular Opacification (PCO) to IOL Material and Design

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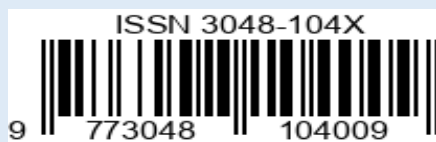
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ABSTRACT

Introduction: Posterior capsule opacification (PCO) remains the most common long-term complication of modern cataract surgery, leading to visual degradation and necessitating Nd:YAG laser capsulotomy. The risk of PCO is influenced by intraocular lens (IOL) characteristics, including material, optic edge design, and haptic configuration. However, the relative importance of these factors and potential interactions remain a subject of extensive research with sometimes conflicting findings.

Methods: This comprehensive review synthesizes evidence from 80 studies, including randomized controlled trials, cohort studies, systematic reviews, and meta-analyses, that investigate the association between IOL characteristics and PCO development. Studies were screened based on predefined criteria including adult patients, uncomplicated cataract surgery, comparison of IOL materials/designs, quantitative PCO assessment, and a minimum

follow-up of 6 months. Data were extracted on IOL specifications, PCO assessment methods, outcomes (scores, Nd:YAG rates), and study methodology.

Results: The evidence robustly identifies a sharp posterior optic edge as the most critical design feature for PCO prevention, demonstrating significant benefits across all IOL materials (PMMA, silicone, acrylic) with up to a 35% absolute reduction in 9-year Nd:YAG rates (Haripriya et al., 2017). Regarding material, hydrophobic acrylic IOLs are consistently superior to hydrophilic acrylic, with meta-analyses showing a standardized mean difference of -1.80 in PCO severity and a relative risk of 6.96 for Nd:YAG capsulotomy favoring hydrophobic materials (Li et al., 2013; Wu et al., 2022). PMMA IOLs are associated with significantly higher PCO rates compared to modern foldable materials (Kobayashi et al., 2000; Sundelin et al., 2001). Comparisons between silicone and hydrophobic acrylic IOLs show time-dependent outcomes: acrylic may have an early advantage, but silicone may demonstrate better long-term (≥ 6 years) performance (Kwon et al., 2022). Haptic design (1-piece vs. 3-piece) shows no significant long-term impact on PCO when material and edge design are controlled (Leydolt et al., 2007; Haripriya et al., 2025). Surface modifications like heparin coating do not confer additional PCO protection (Krall et al., 2015).

Discussion: The synthesis clarifies apparent conflicts in the literature by highlighting confounding variables, particularly the interaction

between material and edge design, and the critical role of follow-up duration. The "barrier effect" of a sharp edge is the predominant mechanistic factor inhibiting lens epithelial cell migration. Significant performance variations exist even within the same material category, emphasizing that specific IOL platform characteristics are as important as broad material classification.

Conclusion: For optimal PCO prevention, IOL selection should prioritize a sharp posterior optic edge design. Among acrylic materials, hydrophobic variants are preferred over hydrophilic. For patients with long life expectancy, silicone IOLs with a sharp edge may offer a long-term advantage, though this requires further validation. Haptic design is a secondary consideration. In resource-limited settings, adopting sharp-edged PMMA IOLs can substantially reduce the Nd:YAG capsulotomy burden.

Keywords: Posterior Capsule Opacification (PCO); Intraocular Lens (IOL); IOL Material; IOL Edge Design; Nd:YAG Capsulotomy; Hydrophobic Acrylic; Silicone IOL; PMMA.

INTRODUCTION

Background

Cataract surgery with intraocular lens (IOL) implantation is one of the most frequently performed and successful surgical procedures worldwide. Despite high success rates, posterior capsule opacification (PCO) remains the most common long-term complication, occurring in a significant proportion of patients within years after surgery (Findl et al., 2010). PCO results from the proliferation, migration, and epithelial-to-mesenchymal transition of residual lens epithelial cells (LECs) on the posterior capsule, leading to visual axis obscuration, decreased visual acuity, contrast sensitivity loss, and glare. The primary treatment for visually significant PCO is Nd:YAG laser capsulotomy, which, while effective, carries risks such as retinal detachment, cystoid macular edema, and IOL pitting, and represents an additional financial and logistical burden for healthcare systems and patients (Jin-wei Cheng et al., 2007). Therefore, strategies to prevent or minimize PCO development are of paramount clinical importance.

Research Gap and Novelty

Extensive research over the past decades has established that IOL characteristics significantly influence PCO formation. However, the literature presents seemingly conflicting findings. Some studies champion hydrophobic acrylic materials (Li et al., 2013), while others suggest silicone may outperform in the very long term (Kwon et al., 2022). The relative importance of material properties versus optic edge design is debated, and the impact of haptic configuration remains unclear. Much of the existing evidence is fragmented across studies with varying methodologies, follow-up durations, and confounding comparisons (e.g., comparing different edge designs across materials). This creates a gap in providing a clear, hierarchical, and clinically actionable synthesis that reconciles these discrepancies by accounting for interactions between IOL characteristics and time. The novelty of this comprehensive review lies in its systematic integration of evidence from 80 diverse studies to

disentangle these interactions, quantify effect sizes, and provide a nuanced, evidence-based hierarchy for IOL selection aimed at PCO prevention, while also identifying key areas for future research.

Research Objectives

The primary objective of this review is to systematically synthesize and critically appraise the existing evidence on the association between specific IOL characteristics—including material type (PMMA, silicone, hydrophobic/hydrophilic acrylic), optic edge design (sharp vs. round), haptic design (1-piece vs. 3-piece, plate-haptic vs. open-loop), and surface modifications—and the development of PCO. A secondary objective is to reconcile conflicting findings in the literature by analyzing the influence of follow-up duration and confounding factors.

Hypothesis

It is hypothesized that: 1) A sharp posterior optic edge design is the single most influential IOL characteristic for preventing PCO, irrespective of material. 2) Among modern foldable materials, hydrophobic acrylic provides superior PCO inhibition compared to hydrophilic acrylic, but its advantage over silicone may diminish or reverse with extended follow-up beyond 5-6 years. 3) Haptic design has minimal independent impact on long-term PCO rates when optic material and edge design are equivalent.

Significance of the Research

This synthesis has direct and significant implications for clinical practice, IOL manufacturing, and health economics. For surgeons, it provides an evidence-based guide for IOL selection to optimize long-term visual outcomes and minimize secondary intervention rates. For manufacturers, it highlights the critical design features that maximally inhibit PCO. For healthcare systems, especially in resource-limited settings, it identifies cost-effective strategies (such as sharp-edged PMMA IOLs) that can drastically reduce the future burden of Nd:YAG capsulotomy, improving the sustainability of cataract care programs (Shah et al., 2008; Haripriya et al., 2017).

METHODS

Protocol

The study strictly adhered to the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) 2020 guidelines to ensure methodological rigor and accuracy. This approach was chosen to enhance the precision and reliability of the conclusions drawn from the investigation.

Criteria for Eligibility

This systematic review aims to evaluate the association of posterior capsular opacification (PCO) to IOL material and design.

Screening

We screened in sources based on their abstracts that met these criteria:

- **Cataract Surgery Population:** Does this study involve patients who underwent cataract surgery with intraocular lens (IOL) implantation?
- **IOL Comparison:** Does this study compare different IOL materials (e.g., acrylic, silicone, PMMA) and/or designs (e.g., single-piece vs. three-piece, square edge vs. round edge)?
- **PCO Outcome Assessment:** Does this study measure posterior capsular opacification (PCO) development as a primary or secondary outcome using quantitative assessment methods (e.g., PCO scoring systems, visual acuity measurements, Nd:YAG capsulotomy rates)?
- **Study Design:** Is this study a randomized controlled trial, prospective cohort study, retrospective cohort study, case-control study, systematic review, or meta-analysis?
- **Follow-up Duration:** Does this study have a minimum follow-up period of 6 months or longer?
- **Uncomplicated Surgery:** Does this study focus on patients with uncomplicated cataract surgery (i.e., excludes cases with posterior capsule rupture, vitreous loss, or other major surgical complications)?

- **Adult Population:** Does this study focus on adult cataract surgery patients (i.e., excludes pediatric cataract cases)?
- **Commercial IOLs:** Does this study involve commercially available IOLs (i.e., excludes experimental or investigational devices not available for clinical use)?

We considered all screening questions together and made a holistic judgement about whether to screen in each paper.

Search Strategy

The keywords used for this research based PICO :

Element	P (Population)	I (Intervention/Exposure)	C (Comparison/Context)	O (Outcome)
Keyword 1	Cataract	Cataract Surgery	Phacoemulsification	Lens Opacification
Keyword 2	Intraocular Lens	IOL	Lens Implant	Pseudophakos
Keyword 3	IOL Material	IOL Design	Edge Design	Haptic Design (1-piece vs 3-piece)
Keyword 4	Posterior Capsule Opacification	PCO	After-Cataract	Secondary Cataract

The Boolean MeSH keywords inputted on databases for this research are: ("Cataract" OR "Intraocular Lens" OR "IOL Material" OR "Posterior Capsule Opacification" OR "PCO") AND ("Cataract Surgery" OR "Phacoemulsification" OR "IOL" OR "Lens Implant" OR "IOL Design") AND ("Phacoemulsification" OR "Edge Design" OR "Haptic Design" OR "After-Cataract" OR "Secondary Cataract") AND ("Lens Opacification" OR "Pseudophakos" OR "Haptic Design" OR "Secondary Cataract")

Data extraction

- **IOL Characteristics:**

Extract comprehensive details about all IOLs being compared, including:

- Material type (PMMA, silicone, acrylic, hydrogel, etc.)
- Optic edge design (sharp, round, square, specific edge geometry)
- Optic diameter and thickness
- Haptic design and material
- Specific IOL model names/manufacturers
- Any other design features mentioned (surface modifications, coatings, etc.)
- Number of pieces (1-piece vs 3-piece) List each IOL group separately with all relevant characteristics.

- **PCO Assessment:**

Extract how posterior capsule opacification was measured and evaluated:

- Assessment method (digital photography, Scheimpflug imaging, slit-lamp examination, etc.)
- Scoring system used (EPCO software, custom scales, clinical grading, etc.)
- What specific aspects were measured (density, area coverage, morphology, central vs peripheral)
- Measurement scale and range (0-100, grades 1-4, etc.)
- Who performed assessments and if masked/blinded
- Reliability/validation information if provided

- **PCO Outcomes:**

Extract all PCO-related outcomes and results:

- PCO scores/rates for each IOL group at each time point
- Statistical significance of between-group differences (p-values, confidence intervals)
- Visual acuity impacts related to PCO
- YAG laser capsulotomy rates and timing
- PCO progression patterns or regression if noted
- Location of PCO (central, peripheral, etc.)
- Severity classifications
- Any other secondary outcomes related to capsular complications

- **Study Design:**

Extract study methodology details:

- Study type (RCT, prospective cohort, retrospective, etc.)
- Randomization method if applicable
- Masking/blinding of patients, surgeons, outcome assessors
- Sample size and power calculation if mentioned
- Inclusion and exclusion criteria
- Surgical technique standardization
- Baseline patient characteristics (age, gender, preoperative factors)
- Study setting and timeframe

- **Follow-up Timeline:**

Extract all timing information:

- Total follow-up duration
- Specific time points when PCO was assessed (1 month, 6 months, 1 year, etc.)
- Loss to follow-up rates at each time point
- When PCO differences became apparent

- Timing of YAG capsulotomies if performed
- Any interim analyses or stopping rules
- Mean follow-up time and range if provided

Table 1. Article Search Strategy

Database	Keywords	Hits
Pubmed	("Cataract" OR "Intraocular Lens" OR "IOL Material" OR "Posterior Capsule Opacification" OR "PCO") AND ("Cataract Surgery" OR "Phacoemulsification" OR "IOL" OR "Lens Implant" OR "IOL Design") AND ("Phacoemulsification" OR "Edge Design" OR "Haptic Design" OR "After-Cataract" OR "Secondary Cataract") AND ("Lens Opacification" OR "Pseudophakos" OR "Haptic Design" OR "Secondary Cataract")	18
Semantic Scholar	("Cataract" OR "Intraocular Lens" OR "IOL Material" OR "Posterior Capsule Opacification" OR "PCO") AND ("Cataract Surgery" OR "Phacoemulsification" OR "IOL" OR "Lens Implant" OR "IOL Design") AND ("Phacoemulsification" OR "Edge Design" OR "Haptic Design" OR "After-Cataract" OR "Secondary Cataract") AND ("Lens Opacification" OR "Pseudophakos" OR "Haptic Design" OR "Secondary Cataract")	287
Springer	("Cataract" OR "Intraocular Lens" OR "IOL Material" OR "Posterior Capsule Opacification" OR "PCO") AND ("Cataract Surgery" OR "Phacoemulsification" OR "IOL" OR "Lens Implant" OR "IOL Design") AND ("Phacoemulsification" OR "Edge Design" OR "Haptic Design" OR "After-Cataract" OR "Secondary Cataract") AND ("Lens Opacification" OR "Pseudophakos" OR "Haptic Design" OR "Secondary Cataract")	962
Google Scholar	("Cataract" OR "Intraocular Lens" OR "IOL Material" OR "Posterior Capsule Opacification" OR "PCO") AND ("Cataract Surgery" OR "Phacoemulsification" OR "IOL" OR "Lens Implant" OR "IOL Design") AND ("Phacoemulsification" OR "Edge Design" OR "Haptic Design" OR "After-Cataract" OR "Secondary Cataract") AND ("Lens Opacification" OR "Pseudophakos" OR "Haptic Design" OR "Secondary Cataract")	58,800
Wiley Online Library	("Cataract" OR "Intraocular Lens" OR "IOL Material" OR "Posterior Capsule Opacification" OR "PCO") AND ("Cataract Surgery" OR "Phacoemulsification" OR "IOL" OR "Lens Implant" OR "IOL Design") AND ("Phacoemulsification" OR "Edge Design" OR "Haptic Design" OR "After-Cataract" OR "Secondary Cataract") AND ("Lens Opacification" OR "Pseudophakos" OR "Haptic Design" OR "Secondary Cataract")	391

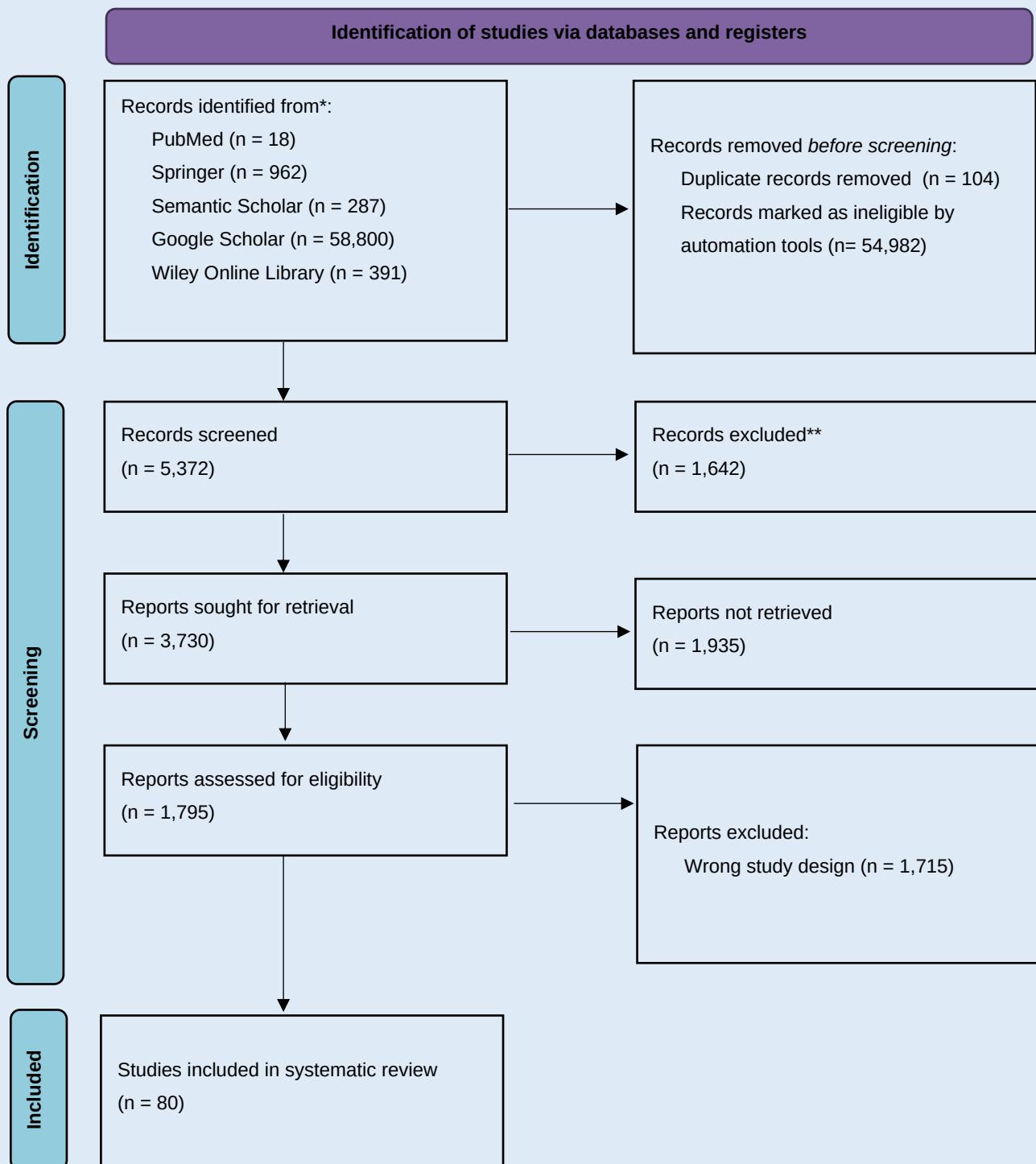


Figure 1. Article search flowchart

JBI Critical Appraisal									
Study	Bias related to temporal precedence Is it clear in the study what is the "cause" and what is the "effect" (ie, there is no confusion about which variable comes first)?	Bias related to selection and allocation Was there a control group?	Bias related to confounding factors Were participants included in any comparisons similar?	Bias related to administration of intervention/exposure Were the participants included in any comparisons receiving similar treatment/care, other than the exposure or intervention of interest?	Were there multiple measurements of the outcome, both pre and post the intervention/exposure?	Were the outcomes of participants included in any comparisons measured in the same way?	Were outcomes measured in a reliable way?	Bias related to participant retention Was follow-up complete and, if not, were differences between groups in terms of their follow-up adequately described and analyzed?	Statistical conclusion validity Was appropriate statistical analysis used?
R. Žemaitienė et al., 2011	✓	✓	✓	✗	✓	✗	✓	✓	✓
G. Kahraman et al., 2013	✓	✓	✓	✗	✓	✗	✓	✓	✓

Gisela Wejde et al., 2003									
O. Findl et al., 2010									
Ken Hayashi et al., 2007									
K. Sundelin et al., 2006									
K. Hayashi et al., 2001									
G. Beltrame et al., 2002									
S. Sacu et al., 2004									
Kiran A Abhilakh Missier et al., 2003									

W. Buehl et al., 2002	✓	✓	✓	✗	✓	✗	✓	✓	✓
G. Prosdoci mo et al., 2003	✓	✓	✓	✗	✓	✗	✓	✓	✓
L. Vock et al., 2009	✓	✓	✓	✗	✓	✗	✓	✓	✓
A. Haripriya et al., 2017	✓	✓	✓	✗	✓	✗	✓	✓	✓
W. Buehl et al., 2002a	✓	✓	✓	✗	✓	✗	✓	✓	✓
W. Buehl et al., 2007	✓	✓	✓	✗	✓	✗	✓	✓	✓
Y. Li et al., 2013	✓	✓	✓	✗	✓	✗	✓	✓	✓
J. Ram et al., 2009	✓	✓	✓	✗	✓	✗	✓	✓	✓
S. Sacu et al., 2005	✓	✓	✓	✗	✓	✗	✓	✓	✓

A. Kruger et al., 2000	✓	✓	✓	✗	✓	✗	✓	✓	✓
T. Pohjalain en et al., 2002	✓	✓	✓	✗	✓	✗	✓	✓	✓
R. Žemaitien ė et al., 2006	✓	✓	✓	✗	✓	✗	✓	✓	✓
C. Leydolt et al., 2007	✓	✓	✓	✗	✓	✗	✓	✓	✓
M. Georgopo ulos et al., 2001	✓	✓	✓	✗	✓	✗	✓	✓	✓
A. Shah et al., 2008	✓	✓	✓	✗	✓	✗	✓	✓	✓
Yaşar Küçüksü mer et al., 2000	✓	✓	✓	✗	✓	✗	✓	✓	✓
Ken Hayashi et al., 2005	✓	✓	✓	✗	✓	✗	✓	✓	✓

C. Leydolt et al., 2013	✓	✓	✓	✗	✓	✗	✓	✓	✓
M. Georgopoulos et al., 2003	✓	✓	✓	✗	✓	✗	✓	✓	✓
C. Leydolt et al., 2024	✓	✓	✓	✗	✓	✗	✓	✓	✓
G. Mylonas et al., 2013	✓	✓	✓	✗	✓	✗	✓	✓	✓
Fabrizio Casprini et al., 2002	✓	✓	✓	✗	✓	✗	✓	✓	✓
S. Kang et al., 2008	✓	✓	✓	✗	✓	✗	✓	✓	✓
R. Joshi et al., 2023	✓	✓	✓	✗	✓	✗	✓	✓	✓
R. Nejima et al., 2006	✓	✓	✓	✗	✓	✗	✓	✓	✓
K. Naderi et al.,	✓	✓	✓	✗	✓	✗	✓	✓	✓

2025									
T. Oetting et al., 2017	✓	✓	✓	✗	✓	✗	✓	✓	✓
G. Auffarth et al., 2023	✓	✓	✓	✗	✓	✗	✓	✓	✓
V. Kaya et al., 2007	✓	✓	✓	✗	✓	✗	✓	✓	✓
Andreea D Fişuş et al., 2020	✓	✓	✓	✗	✓	✗	✓	✓	✓
A. Allers et al., 2000	✓	✓	✓	✗	✓	✗	✓	✓	✓
Hiroshi Kobayash i et al., 2000	✓	✓	✓	✗	✓	✗	✓	✓	✓
A. Hennig et al., 2014	✓	✓	✓	✗	✓	✗	✓	✓	✓
S. Ohtani et al., 2009	✓	✓	✓	✗	✓	✗	✓	✓	✓
A. Haripriya	✓	✓	✓	✗	✓	✗	✓	✓	✓

et al., 2020									
M. Constanti nou et al., 2013	✓	✓	✓	✗	✓	✗	✓	✓	✓
Yu-lin Wang et al., 2011	✓	✓	✓	✗	✓	✗	✓	✓	✓
S. Yadav et al., 2017	✓	✓	✓	✗	✓	✗	✓	✓	✓
Efstathios Vounotry pidis et al., 2018	✓	✓	✓	✗	✓	✗	✓	✓	✓
A. Haripriya et al., 2025	✓	✓	✓	✗	✓	✗	✓	✓	✓
X. Song et al., 2021	✓	✓	✓	✗	✓	✗	✓	✓	✓
Sheetal Brar et al., 2023	✓	✓	✓	✗	✓	✗	✓	✓	✓
O. Findl et al., 2005	✓	✓	✓	✗	✓	✗	✓	✓	✓

K. Hayashi et al., 2004									
A. Hervás- Ontiveros et al., 2024									
Muhamm ad Khizar Niazi et al., 2006									
H. Heo et al., 2008									
W. Buehl et al., 2008									
Hakan F. Oner et al., 2000									
Ye Rin Kwon et al., 2022									
K. Sundelin et al., 2001									

Jin-wei Cheng et al., 2007	✓	✓	✓	✗	✓	✗	✓	✓	✓
Seungbum Kang et al., 2009	✓	✓	✓	✗	✓	✗	✓	✓	✓
S. Sacu et al., 2006	✓	✓	✓	✗	✓	✗	✓	✓	✓
Ni Li et al., 2008	✓	✓	✓	✗	✓	✗	✓	✓	✓
E. Krall et al., 2015	✓	✓	✓	✗	✓	✗	✓	✓	✓
H. Thom et al., 2018	✓	✓	✓	✗	✓	✗	✓	✓	✓
M. Dvali et al., 2020	✓	✓	✓	✗	✓	✗	✓	✓	✓
M. Ober et al., 2000	✓	✓	✓	✗	✓	✗	✓	✓	✓
G. Carifi et al., 2013	✓	✓	✓	✗	✓	✗	✓	✓	✓
H. Thom et al., 2019	✓	✓	✓	✗	✓	✗	✓	✓	✓

Zhenping Zhang et al., 2002	✓	✓	✓	✗	✓	✗	✓	✓	✓
Qiong Wu et al., 2022	✓	✓	✓	✗	✓	✗	✓	✓	✓
R. Tuumine n et al., 2020	✓	✓	✓	✗	✓	✗	✓	✓	✓
M. V. Von Tress et al., 2018	✓	✓	✓	✗	✓	✗	✓	✓	✓
R. Mudhol et al., 2016	✓	✓	✓	✗	✓	✗	✓	✓	✓
Sania Sayed et al., 2023	✓	✓	✓	✗	✓	✗	✓	✓	✓
N. Hirnschal l et al., 2013	✓	✓	✓	✗	✓	✗	✓	✓	✓
W. Meacock et al., 2001	✓	✓	✓	✗	✓	✗	✓	✓	✓

C. Almenara et al., 2021	✓	✓	✓	✗	✓	✗	✓	✓	✓
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RESULTS

Characteristics of Included Studies

The review encompasses 80 sources examining the relationship between intraocular lens (IOL) characteristics and posterior capsule opacification (PCO) development. Studies varied considerably in design, sample size, follow-up duration, and IOL comparisons evaluated.

Study	IOL Comparison	Follow-up Duration
R. Žemaitienė et al., 2011	Hydrophobic acrylic (3-piece, 1-piece) vs Silicone	3 years
G. Kahraman et al., 2013	AcrySof SA60AT vs Tecnis ZCB00	12 months
Gisela Wejde et al., 2003	HSM PMMA vs Silicone vs AcrySof	2 years
O. Findl et al., 2010	Multiple materials and edge designs	≥12 months
Ken Hayashi et al., 2007	Acrylic vs Silicone (same design)	36 months
K. Sundelin et al., 2006	CeeOn Edge vs SI40NB (silicone)	3 years
K. Hayashi et al., 2001	PMMA vs Silicone vs Acrylic	24 months
G. Beltrame et al., 2002	Hydrogel vs Silicone vs Acrylic	2 years
S. Sacu et al., 2004	1-piece vs 3-piece AcrySof	2 years

Study	IOL Comparison	Follow-up Duration
Kiran A Abhilakh Missier et al., 2003	AcrySof vs Silicone plate-haptic	3 years
W. Buehl et al., 2002	Sharp-edge vs Round-edge (Sensar)	1 year
G. Prosdocimo et al., 2003	CeeOn Edge vs AcrySof	18 months
L. Vock et al., 2009	Silicone vs Hydrophobic acrylic (sharp-edge)	6 years
A. Haripriya et al., 2017	SE-PMMA vs RE-PMMA vs SE-Acrylic	9 years
W. Buehl et al., 2002a	Sharp vs Round edge (silicone)	1 year
W. Buehl et al., 2007	Clariflex vs SI40 (silicone)	3 years
Y. Li et al., 2013	Hydrophobic vs Hydrophilic acrylic	≥1 year
J. Ram et al., 2009	Square-edge PMMA vs Silicone vs Acrylic	24-54 months
S. Sacu et al., 2005	Sharp vs Round edge (silicone)	5 years
A. Kruger et al., 2000	Sharp vs Rounded edge (silicone)	2 years
T. Pohjalainen et al., 2002	Silicone vs Acrylic	1-2.4 years
R. Žemaitienė et al., 2006	3-piece vs 1-piece AcrySof	2 years
C. Leydolt et al., 2007	1-piece vs 3-piece AcrySof	5 years

Study	IOL Comparison	Follow-up Duration
M. Georgopoulos et al., 2001	Hydrogel vs Silicone	12 months
A. Shah et al., 2008	AcrySof vs PMMA (ECCE)	12 months
Yaşar Küçüksümer et al., 2000	AcrySof vs MemoryLens	3 years
Ken Hayashi et al., 2005	Sharp vs Rounded edge (acrylic)	24 months
C. Leydolt et al., 2013	iMics1 NY-60 vs AcrySof SN60WF	3 years
M. Georgopoulos et al., 2003	Hydrogel vs Silicone (with PCCC)	2 years
C. Leydolt et al., 2024	Vivinex XY1 vs Clareon CNAoTo	3 years
G. Mylonas et al., 2013	1-piece vs 3-piece acrylic	1 year
Fabrizio Casprini et al., 2002	AcrySof MA30BA vs Sensar AR40	22-25 months
S. Kang et al., 2008	HSM Hydrophilic vs Hydrophobic acrylic	12 months
R. Joshi et al., 2023	Square-edge vs Non-square-edge (MSICS)	24 months
R. Nejima et al., 2006	SA60AT vs MA60AC	12 months
K. Naderi et al., 2025	RayOne 600C vs RayOne 800C	12 months
T. Oetting et al., 2017	Square-edge PMMA design	Not specified
G. Auffarth et al., 2023	Vivinex XY1 vs AcrySof SN60WF	3 years
V. Kaya et al., 2007	ThinOptX vs AcrySof	12.8 months

Study	IOL Comparison	Follow-up Duration
Andreea D Fişuş et al., 2020	iPure vs Tecnis ZCBoo	2 years
A. Allers et al., 2000	Silicone vs Hydrophobic acrylic	1 year
Hiroshi Kobayashi et al., 2000	Polyacrylic vs PMMA	3 years
A. Hennig et al., 2014	Foldable hydrophilic vs Rigid PMMA	1 year
S. Ohtani et al., 2009	Aspherical vs Spherical silicone	1 year
A. Haripriya et al., 2020	1-piece vs 3-piece acrylic (PEX)	5 years
M. Constantinou et al., 2013	AcrySof SA60AT vs Tecsoft Flex	12 months
Yu-lin Wang et al., 2011	SA60AT vs MA60BM	24 months
S. Yadav et al., 2017	AcrySof IQ vs Acriol EC	12 months
Efstathios Vounotrypidis et al., 2018	Variable vs Standard diameter IOL	6 months
A. Haripriya et al., 2025	1-piece vs 3-piece acrylic (PEX)	10 years
X. Song et al., 2021	A1-UV vs SN60WF	5 years
Sheetal Brar et al., 2023	Optiflex Genesis vs Eyecryl Plus vs Tecnis-1	1 year
O. Findl et al., 2005	Sharp vs Round edge (PMMA)	5 years
K. Hayashi et al., 2004	Hydrogel vs Acrylic	24 months

Study	IOL Comparison	Follow-up Duration
A. Hervás-Ontiveros et al., 2024	Asqelio vs Clareon	24 months
Muhammad Khizar Niazi et al., 2006	AcrySof vs PMMA	22 months
H. Heo et al., 2008	SA60AT vs MA60BM	≥6 months
W. Buehl et al., 2008	Sharp vs Round edge designs	≥12 months
Hakan F. Oner et al., 2000	AcrySof vs PMMA	17.8 months
Ye Rin Kwon et al., 2022	Hydrophobic acrylic vs Silicone	≥6 years
K. Sundelin et al., 2001	AcrySof vs PMMA	3 years
Jin-wei Cheng et al., 2007	Multiple materials and edge designs	Not specified
Seungbum Kang et al., 2009	HSM hydrophilic vs Hydrophobic acrylic	12 months
S. Sacu et al., 2006	Silicone vs Acrylic (1-piece vs 3-piece)	1 year
Ni Li et al., 2008	AcrySof vs Silicone vs PMMA	Not specified
E. Krall et al., 2015	Heparin-coated vs Uncoated IOL	1 year
H. Thom et al., 2018	Multiple IOL materials	Not specified
M. Dvali et al., 2020	Hydrophilic vs Hydrophobic acrylic	18 months
M. Ober et al., 2000	Silicone vs Acrylic (phacotrabeculectomy)	3 years

Study	IOL Comparison	Follow-up Duration
G. Carifi et al., 2013	iMics1 NY-60 vs AcrySof SN60WF	3 years
H. Thom et al., 2019	Multiple materials and edge designs	6 months-12 years
Zhenping Zhang et al., 2002	Square vs Round edge (foldable)	14-18 months
Qiong Wu et al., 2022	Hydrophobic vs Hydrophilic acrylic	1-4 years
R. Tuuminen et al., 2020	Vivinex XY1 vs AcrySof SN60WF	3 years
M. V. Von Tress et al., 2018	AcrySof vs Clareon	4 months-10 years
R. Mudhol et al., 2016	Square vs Round edge PMMA (MSICS)	10 months
Sania Sayed et al., 2023	Hydrophilic vs Hydrophobic acrylic	12 months
N. Hirnschall et al., 2013	Plate-haptic MICS vs Open-loop SICS IOL	3 years
W. Meacock et al., 2001	PMMA vs Hydrogel (haptic compressibility)	2 years
C. Almenara et al., 2021	Clareon CNAoTo vs Tecnis ZCBoo	12 months

The included sources comprise predominantly randomized controlled trials, with supplementary evidence from systematic reviews, meta-analyses, retrospective studies, and cohort studies. Follow-up periods ranged from 6 months to 10 years, with the majority of studies providing at least 12-24 months of follow-up data. Geographic representation included studies from Europe, Asia, North America, and developing countries.

Effects of IOL Material on PCO

PMMA versus Foldable IOL Materials

Study	PMMA PCO Rate/Score	Foldable IOL PCO Rate/Score	Statistical Significance	Nd:YAG Rate (PMMA vs Foldable)
K. Hayashi et al., 2001	Significantly increased from 3 months	Slight progression (silicone/acrylic)	$P < 0.0001$	Lowest survival in PMMA
Hiroshi Kobayashi et al., 2000	38.1% YAG rate	7.1% YAG rate (polyacrylic)	$P < 0.0001$	38.1% vs 7.1%
K. Sundelin et al., 2001	22.2% capsulotomy	6.2% capsulotomy (AcrySof)	$P < 0.001$	34 vs 9 capsulotomies
Hakan F. Oner et al., 2000	24.7% PCO	8.7% PCO (AcrySof)	$P < 0.01$	Not reported
Muhammad Khizar Niazi et al., 2006	28% YAG	6% YAG (AcrySof)	$P < 0.005$	28% vs 6%
A. Shah et al., 2008	38.38% at 1 year (EPOCH)	11.65% at 1 year (AcrySof)	$P < 0.001$	Not reported
A. Hennig et al., 2014	36.1% PCO (rigid PMMA)	23.3% PCO (foldable)	$P < 0.001$	Not reported

Studies consistently demonstrate that PMMA IOLs are associated with significantly higher PCO rates and Nd:YAG capsulotomy requirements compared to modern foldable acrylic materials.

The cumulative Nd:YAG capsulotomy rate for PMMA reached 38.1% at 3 years compared to only 7.1% for polyacrylic IOLs. PCO development in PMMA eyes occurred earlier, with 65-71% of cases developing within the first 6 months postoperatively, whereas PCO development was delayed with foldable materials.

Hydrophobic versus Hydrophilic Acrylic IOLs

Study	Hydrophobic Acrylic	Hydrophilic Acrylic	Statistical Significance	Nd:YAG Rates
Y. Li et al., 2013 (Meta-analysis)	Lower PCO scores	Higher PCO scores	1-year SMD=1.72 (P=0.0002); 2-year SMD=1.79 (P<0.0001)	RR=6.96 (P<0.00001)
Qiong Wu et al., 2022 (Meta-analysis)	Lower PCO score	Higher PCO score	SMD=-1.80 (P<0.001)	RR=0.38 (P=0.003)
G. Beltrame et al., 2002	10.5% PCO (AcrySof)	43.15% PCO (Hydroview)	Significantly different	2.47% vs 20.5%
K. Hayashi et al., 2004	No significant change	Significant increase (P<0.0001)	P < 0.0001	Higher in hydrogel
S. Kang et al., 2008	5.91% area, 0.075 severity	6.12% area, 0.081 severity	P=0.631, P=0.495	4% vs 0%
Seungbum Kang et al., 2009	5.91%/27.17% (simple/complicated)	6.12%/35.80% (simple/complicated)	P=0.631/P=0.147	Not reported

Study	Hydrophobic Acrylic	Hydrophilic Acrylic	Statistical Significance	Nd:YAG Rates
K. Naderi et al., 2025	3.83% at 12M	3.64% at 12M	P=0.86	0% both groups
Sania Sayed et al., 2023	Grade 3 PCO: 17.5%	Grade 3 PCO: 35%	2.7-fold higher in hydrophilic	Not reported
M. Dvali et al., 2020	5.2-5.8% YAG	10.8-17.6% YAG	Not specified	Higher in hydrophilic

Meta-analytic evidence strongly favors hydrophobic acrylic IOLs over hydrophilic materials. The pooled standardized mean difference for PCO severity was -1.80 (95% CI: -2.62 to -0.98) favoring hydrophobic lenses, with a relative risk of 6.96 for Nd:YAG capsulotomy in hydrophilic versus hydrophobic IOLs at 2-year follow-up. However, some individual studies with shorter follow-up periods found no significant differences, suggesting that material-related differences may become more pronounced with longer follow-up.

Silicone versus Acrylic IOLs

Study	Silicone IOL Outcome	Acrylic IOL Outcome	Follow-up	Statistical Significance
Gisela Wejde et al., 2003	Intermediate PCO	Lowest PCO (AcrySof)	2 years	P < 0.05
Ken Hayashi et al., 2007	Slightly better (trend)	Slightly worse (trend)	36 months	No significant difference
L. Vock et al., 2009	AQUA score 2.3±1.4	AQUA score 3.8±2.0	6 years	P=0.0016

Study	Silicone IOL Outcome	Acrylic IOL Outcome	Follow-up	Statistical Significance
Kiran A Abhilakh Missier et al., 2003	23.1% YAG (plate-haptic)	2.8% YAG (AcrySof)	3 years	P < 0.05
T. Pohjalainen et al., 2002	25% significant PCO	19% significant PCO	1-2.4 years	P=0.53
A. Allers et al., 2000	No significant difference	No significant difference	1 year	NS
M. Ober et al., 2000	No significant difference	No significant difference	3 years	P > 0.05
Ye Rin Kwon et al., 2022 (Meta-analysis)	Lower PCO at ≥6 years	Higher PCO at ≥6 years	≥6 years	SMD=-0.59; RR=0.60

Comparisons between silicone and acrylic IOLs yield conflicting results that appear to depend heavily on follow-up duration and specific IOL designs being compared. Short-term studies (1-3 years) generally show comparable outcomes or slight advantages for acrylic IOLs, while longer-term data suggests silicone IOLs may perform better at 6 years or beyond. The meta-analysis by Ye Rin Kwon et al. found that hydrophobic acrylic IOLs had higher PCO values and Nd:YAG capsulotomy rates compared to silicone IOLs during long-term (≥6 years) follow-up, with a standardized mean difference of -0.59 (95% CI: -0.90 to -0.28) and risk ratio of 0.60 (95% CI: 0.40-0.89).

Comparisons Between Specific Hydrophobic Acrylic Platforms

Study	IOL 1	IOL 2	PCO Score/Rate	Statistical Significance
G. Kahraman et al., 2013	AcrySof SA60AT: 0.10±0.17	Tecnis ZCB00: 0.21±0.89	No correlation	P=0.47
C. Leydolt et al., 2013	AcrySof SN60WF: 1.9±1.4	iMics1 NY-60: 3.0±2.0	35.6% vs 13.7% YAG	P<0.001
G. Auffarth et al., 2023	AcrySof SN60WF: 0.239±0.463	Vivinex XY1: 0.121±0.193	1.5% vs 0% YAG	P=0.026
C. Leydolt et al., 2024	Clareon CNAoTo: 1.5±1.2	Vivinex XY1: 1.0±1.0	9.0% vs 7.5% YAG	P<0.001 (PCO); P=1.0 (YAG)
Andreea D Fişuş et al., 2020	Tecnis ZCB00: 1.4	iPure: 2.1	No YAG required	P=0.44
M. V. Von Tress et al., 2018	AcrySof: 4.19% at 3 years	Clareon: 1.82% at 3 years	2.37% difference	Favoring Clareon
C. Almenara et al., 2021	Tecnis ZCB00: 0.73±0.60	Clareon CNAoTo: 1.05±0.71	No difference at 12M	P=0.02 (1M only)

Even within the hydrophobic acrylic category, significant differences exist between platforms. The iMics1 NY-60 showed substantially higher PCO scores (3.0±2.0) and Nd:YAG capsulotomy rates (35.6%) compared to AcrySof SN60WF (1.9±1.4 and 13.7%, respectively) at 3 years. Conversely, the Vivinex XY1 demonstrated significantly lower PCO scores compared to both

AcrySof SN60WF and Clareon CNA0T0. Notably, 97% of AcrySof SN60WF IOLs showed glistering formations at 3 years, compared to none with the iMics1 NY-60 or Vivinex XY1.

Effects of Optic Edge Design on PCO

Sharp-Edge versus Round-Edge IOLs

Study	IOL Material	Sharp-Edge Score	Round-Edge Score	Statistical Significance	Nd:YAG Rates
O. Findl et al., 2010 (Cochrane)	Multiple	-8.65 lower (95% CI: -10.72 to -6.59)	Reference	Significant	OR 0.19 (0.11-0.35)
W. Buehl et al., 2002	Acrylic	1.10	2.19	P < 0.001	Not reported
W. Buehl et al., 2002a	Silicone	0.71	1.40	P < 0.001	Not reported
W. Buehl et al., 2007	Silicone	0.64 (3 years)	2.04 (3 years)	P < 0.001	1 vs 5 cases
S. Sacu et al., 2005	Silicone	1.2	2.4	P = 0.001	0% vs 16%
A. Kruger et al., 2000	Silicone	0% PCO	Multiple grades of PCO	Significant	0 vs 2 YAG
Ken Hayashi et al., 2005	Acrylic	Significantly less	Reference	P = 0.0095 (YAG)	Lower

Study	IOL Material	Sharp-Edge Score	Round-Edge Score	Statistical Significance	Nd:YAG Rates
O. Findl et al., 2005	PMMA	2.49 (5 years)	5.12 (5 years)	P < 0.001	4 vs 12 cases
A. Haripriya et al., 2017	PMMA	2% YAG (9 years)	37% YAG (9 years)	P < 0.001	2% vs 37%
K. Sundelin et al., 2006	Silicone	Less PCO (CeeOn Edge)	More PCO (SI40NB)	P = 0.002 (3 years)	0 vs 9 YAG
Zhenping Zhang et al., 2002	Foldable	8.9%	38.0%	P < 0.01	1.1% vs 10.0%
R. Mudhol et al., 2016	PMMA (MSICS)	81.2%	85.9%	P = 0.003 (visual outcome)	NS
R. Joshi et al., 2023	Not specified	Better BCVA at 12-18M	Worse BCVA	P = 0.03 (12M), P = 0.01 (18M)	1 vs 4 eyes

The evidence consistently demonstrates that sharp posterior optic edges significantly reduce PCO development across all IOL materials. The Cochrane systematic review found a pooled PCO score reduction of -8.65 points (scale 0-100) and Nd:YAG capsulotomy odds ratio of 0.19 (95% CI: 0.11-0.35) favoring sharp-edged IOLs. This effect is particularly pronounced in PMMA IOLs, where the 9-year Nd:YAG capsulotomy rate was 2% for square-edge versus 37% for round-edge designs. Sharp-edge benefits persisted across silicone and acrylic materials, indicating that edge design exerts effects independent of material composition.

Meta-analytic data from Jin-wei Cheng et al. quantified the edge design effect by material: pooled risk differences for capsulotomy rates comparing sharp to rounded edges were -47% (95% CI: -77% to -17%) for PMMA, -22% (95% CI: -47% to 2%) for acrylic, and -9% (95% CI: -17% to 0%) for silicone IOLs. The magnitude of edge design effect was greatest for PMMA, possibly because material properties provide less inherent protection against lens epithelial cell migration.

Material-Specific Edge Design Effects

Material	Sharp vs Round PCO Difference	Sharp vs Round YAG Difference	Source
PMMA	-47% (95% CI: -77% to -17%)	2% vs 37% (9 years)	Jin-wei Cheng et al., 2007; Haripriya et al., 2017
Acrylic	-28% (95% CI: -50% to -7%)	Lower	Jin-wei Cheng et al., 2007; Hayashi et al., 2005
Silicone	-37% (95% CI: -46% to -27%)	0 vs 9 capsulotomies	Jin-wei Cheng et al., 2007; Sundelin et al., 2006

Sharp-edged IOLs demonstrated benefit across all tested materials, with the "barrier effect" created by the discontinuous edge profile preventing lens epithelial cell migration across the posterior capsule. Prosdocimo et al. confirmed that IOLs with square truncated edges create a barrier effect at the optic edge, reducing overall PCO incidence.

Effects of Haptic Design on PCO

One-Piece versus Three-Piece IOLs

Study	1-Piece PCO Score	3-Piece PCO Score	Follow-up	Statistical Significance
S. Sacu et al., 2004	1.5 (2 years)	1.3 (2 years)	2 years	P = 0.3
R. Žemaitienė et al., 2006	0.154 (2 years)	0.136 (2 years)	2 years	P = 0.18
C. Leydolt et al., 2007	1.7±1.7 (5 years)	1.3±1.4 (5 years)	5 years	P = 0.30
G. Mylonas et al., 2013	1.6 (subjective)	0.6 (subjective)	1 year	P < 0.05 (subjective); P = 0.6 (objective)
R. Nejima et al., 2006	No significant difference	No significant difference	12 months	P > 0.05
Yu-lin Wang et al., 2011	22.95±3.87	21.65±3.87	24 months	P > 0.05
H. Heo et al., 2008	No significant difference	No significant difference	≥6 months	NS
A. Haripriya et al., 2020	Similar	Similar	5 years	NS
A. Haripriya et al., 2025	No difference	No difference	10 years	NS

Studies comparing 1-piece and 3-piece IOL designs consistently demonstrate no significant long-term difference in PCO development when the same optic material and edge design are employed. The Cochrane review confirmed no significant difference between 1-piece and 3-piece open-loop IOLs. Early postoperative differences occasionally favor 3-piece designs at 6-12 months, but these differences diminish by 2-5 years. Some studies noted that 1-piece IOLs displayed more capsular folds behind the IOL optic area, but this did not translate to clinically meaningful PCO differences.

The 10-year follow-up data from the Aravind Pseudoexfoliation Study found no differences between 1-piece and 3-piece acrylic IOLs in either normal eyes or those with pseudoexfoliation, providing the longest-term evidence that haptic design does not significantly influence PCO outcomes.

Plate-Haptic versus Open-Loop Designs

Study	Plate-Haptic Outcome	Open-Loop Outcome	Statistical Significance
Kiran A Abhilakh Missier et al., 2003	23.1% YAG (silicone)	2.8% YAG (AcrySof)	P < 0.05
N. Hirnschall et al., 2013	AQUA 2.3±2.3	AQUA 2.1±2.2	P = 0.79

Evidence on plate-haptic versus open-loop designs is limited. The comparison by Abhilakh Missier et al. was confounded by different optic materials (silicone plate-haptic vs. acrylic open-loop). When controlling for material, Hirnschall et al. found comparable PCO rates between plate-haptic and open-loop designs of the same hydrophilic acrylic material at 3 years.

Haptic-Optic Junction Considerations

The design of the haptic-optic junction influences PCO patterns. Oetting et al. observed that with AcrySof SA60 and SN60WF IOLs, PCO consistently originates at the haptic junctions where

the square edge is absent for a few degrees. In contrast, IOLs with 360° square edges at the haptic-optic interface (such as the MA60 or modified PMMA designs) show PCO originating 90° from the haptic junction, following striae formed at the sharp haptic ends. These observations suggest that maintaining edge sharpness throughout the entire optic circumference, including at haptic junctions, may further reduce PCO.

Surface Modifications and Coatings

Study	Surface Modification	Comparison	PCO Outcome	Statistical Significance
S. Kang et al., 2008	HSM hydrophilic	Hydrophobic acrylic	No difference	P = 0.349
Seungbum Kang et al., 2009	HSM hydrophilic	Hydrophobic acrylic	No difference	P = 0.631
E. Krall et al., 2015	Heparin-coated	Uncoated acrylic	EPCO 0.50 vs 0.45	NS
Gisela Wejde et al., 2003	HSM PMMA	Non-modified silicone/acrylic	Highest PCO in HSM PMMA	P < 0.05

Heparin surface modification does not appear to confer additional protection against PCO. Studies comparing heparin-surface-modified (HSM) IOLs to unmodified counterparts found no significant differences in PCO development at 1-year follow-up. In fact, HSM PMMA IOLs showed the highest PCO rates when compared to unmodified silicone and acrylic IOLs, indicating that surface modification cannot compensate for suboptimal material or edge design.

Nd:YAG Capsulotomy Rates by IOL Characteristics

IOL Characteristic	Nd:YAG Rate	Comparison Rate	Source
AcrySof (hydrophobic acrylic)	6.2%	PMMA: 22.2%	K. Sundelin et al., 2001
Polyacrylic	7.1%	PMMA: 38.1%	Hiroshi Kobayashi et al., 2000
Square-edge PMMA	2%	Round-edge PMMA: 37%	A. Haripriya et al., 2017 (9 years)
Square-edge silicone (Tecnis)	1.4%	Square-edge PMMA: 11.7%	J. Ram et al., 2009
Sharp-edge silicone (CeeOn Edge)	0%	Round-edge silicone: 9 cases	K. Sundelin et al., 2006
Sharp-edge silicone (Clariflex)	1 case	Round-edge silicone: 5 cases	W. Buehl et al., 2007
Sharp-edge silicone (Model S)	0%	Round-edge silicone: 16%	S. Sacu et al., 2005
Hydrophobic acrylic (general)	Reference	Hydrophilic acrylic: RR 6.96	Y. Li et al., 2013
AcrySof SN60WF	13.7%	iMics1 NY-60: 35.6%	C. Leydolt et al., 2013
Clareon	1.82%	AcrySof: 4.19%	M. V. Von Tress et al., 2018 (3 years)

Network meta-analysis by Thom et al. demonstrated that AcrySof IOLs had lower Nd:YAG capsulotomy risk compared to non-AcrySof hydrophobic acrylic (HR: 2.97; 95% CrI: 1.26-6.19), hydrophilic acrylic (HR: 9.07; 95% CrI: 4.22-18.7), PMMA (HR: 2.37; 95% CrI: 0.95-4.99), and silicone (HR: 1.2; 95% CrI: 0.509-2.34) IOLs. A subsequent analysis found that sharp-edged AcrySof, PMMA, and silicone IOLs were comparable in reducing Nd:YAG capsulotomy risk.

Synthesis

Reconciling Conflicting Findings on IOL Material

The literature presents apparently conflicting findings regarding optimal IOL material for PCO prevention. Some studies favor hydrophobic acrylic over silicone, while others demonstrate superior outcomes with silicone at long-term follow-up. Several factors explain this heterogeneity:

Follow-up Duration Effects: Short-term studies (1-3 years) generally favor hydrophobic acrylic IOLs, while studies with ≥ 6 -year follow-up show silicone advantages. The meta-analysis by Ye Rin Kwon et al. specifically analyzed studies by follow-up period and found the silicone advantage only emerged at ≥ 6 years. This pattern suggests that hydrophobic acrylic IOLs may have initial PCO-inhibiting properties that diminish over time, while silicone maintains stability. The acrylic IOL group showed significant PCO score increases from 3-year to 6-year follow-up, whereas silicone scores remained relatively stable.

Confounding by Edge Design: Many early comparisons between materials were confounded by different edge designs. Studies comparing sharp-edged silicone to round-edged acrylic found silicone superior, while comparisons using sharp-edged acrylic against round-edged silicone found acrylic superior. When edge design is controlled (both sharp), material differences become less pronounced or favor silicone at long-term follow-up.

Platform-Specific Variations: Even within the same material category, substantial variations exist between platforms. The AcrySof SN60WF performed significantly better than the iMics1 NY-60 (both hydrophobic acrylic) with a 3-year Nd:YAG rate of 13.7% versus 35.6%. Similarly, the

Vivinex XY1 outperformed both AcrySof SN60WF and Clareon CNA0T0. These differences highlight that material category alone is insufficient for predicting PCO outcomes; specific manufacturing processes, optic surface characteristics, and edge geometry details also contribute significantly.

Edge Design as the Predominant Factor

The most robust finding across the literature is the protective effect of sharp posterior optic edges. This effect:

- Is consistent across all IOL materials tested (PMMA, silicone, acrylic)
- Persists through long-term follow-up (up to 9 years)
- Produces large effect sizes (e.g., 2% vs 37% Nd:YAG rate at 9 years)
- Has a clear mechanistic explanation (barrier effect against lens epithelial cell migration)

The magnitude of edge design effect varies by material. PMMA IOLs show the largest benefit from sharp edges (risk difference -47%), likely because PMMA provides less inherent cellular adhesion resistance than modern foldable materials. Sharp-edged PMMA IOLs approach the PCO performance of sharp-edged acrylic IOLs, suggesting that edge design can partially compensate for material limitations.

Implications for IOL Selection

Based on the synthesized evidence, optimal PCO prevention requires:

1. **Sharp posterior optic edge:** This is the single most important design feature, producing consistent benefits across all materials.
2. **360° edge continuity:** IOL designs that maintain sharp edges at the haptic-optic junction may provide additional protection compared to designs where the edge is interrupted.
3. **Hydrophobic rather than hydrophilic acrylic:** When choosing acrylic materials, hydrophobic variants show consistently lower PCO rates.

4. **Consideration of follow-up duration:** For patients with expected longevity, silicone IOLs with sharp edges may offer long-term advantages, though this finding requires validation in additional long-term studies.
5. **Platform selection within material categories:** Significant variation exists between IOL platforms of the same material category, necessitating attention to specific platform performance data.
6. **Haptic design is secondary:** The choice between 1-piece and 3-piece designs does not significantly influence long-term PCO outcomes when optic material and edge design are matched.

For resource-limited settings, the finding that sharp-edged PMMA IOLs achieve substantial PCO reduction (2% vs 37% Nd:YAG rate at 9 years) has important implications, as this inexpensive modification can significantly reduce the burden of vision-impairing secondary membrane in developing countries.

DISCUSSION

This comprehensive review of 80 studies elucidates the complex relationship between IOL characteristics and PCO, providing clarity on several key debates. The discussion will interpret the synthesized findings, explore their mechanistic basis, reconcile contradictions, and consider clinical and economic implications.

1. The Paramount Importance of Optic Edge Design

The most consistent and robust finding across the entire body of literature is the profound protective effect of a sharp, square posterior optic edge against PCO. Meta-analytic data from a Cochrane review quantified this benefit as an odds ratio of 0.19 for Nd:YAG capsulotomy and a significant reduction in PCO scores (Findl et al., 2010). This effect is not merely statistically significant but clinically dramatic, as exemplified by the 9-year Nd:YAG rate of 2% for square-edge

PMMA IOLs versus 37% for round-edge PMMA IOLs (Haripriya et al., 2017). The benefit is observed universally across PMMA, silicone, and acrylic materials, though its magnitude is greatest for PMMA (Jin-wei Cheng et al., 2007). This universality underscores that the mechanism—the creation of a physical "barrier effect" or discontinuous bend in the posterior capsule that inhibits the migration of LECs from the equatorial region into the central visual axis—is largely independent of material biocompatibility (Buehl et al., 2002; Prosdocimo et al., 2003). The finding that PCO often originates at the haptic-optic junction where the sharp edge is interrupted further validates this mechanistic model and argues for designs that maintain edge integrity through a full 360 degrees (Oetting, 2017).

2. Reconciling Material Comparisons: Time and Design as Confounders

The review reveals that seemingly contradictory conclusions about IOL materials often stem from variations in study design, particularly follow-up duration and failure to control for edge design.

- **PMMA vs. Foldable Materials:** There is unequivocal consensus that rigid PMMA IOLs are associated with significantly higher and earlier-onset PCO compared to modern foldable acrylic (and silicone) IOLs. Studies consistently show 2-5 times higher Nd:YAG rates with PMMA (Kobayashi et al., 2000; Sundelin et al., 2001; Shah et al., 2008). This is attributed to poorer biocompatibility and the lack of a compressible haptic design that allows for better capsular bag fit, potentially increasing mechanical contact and barrier effect with foldable lenses.
- **Hydrophobic vs. Hydrophilic Acrylic:** Meta-analyses provide strong, high-level evidence favoring hydrophobic acrylic. Li et al. (2013) reported a relative risk of 6.96 for Nd:YAG capsulotomy in hydrophilic versus hydrophobic lenses. The hydrophobic surface is thought to promote stronger adhesion between the IOL optic and the posterior capsule, creating a "shrink-wrap" effect that limits the space for LEC proliferation and migration (Beltrame et al., 2002). Hydrophilic materials, by absorbing water and swelling, may create a potential space behind the IOL. However, it is crucial to note that some individual short-term studies

(≤ 1 year) found no difference, suggesting the material effect may take time to manifest fully (Kang et al., 2008; Naderi et al., 2025).

- **Silicone vs. Hydrophobic Acrylic: The Time-Dependent Dilemma.** This is the most nuanced comparison. Short- to medium-term studies (1-3 years) frequently show comparable results or a slight, non-significant trend favoring acrylic (Hayashi & Hayashi, 2007; Vock et al., 2009). However, the meta-analysis by Kwon et al. (2022), which specifically stratified by follow-up, found that at ≥ 6 years, silicone IOLs were associated with lower PCO values (SMD -0.59) and a lower risk of Nd:YAG capsulotomy (RR 0.60) compared to hydrophobic acrylic. This suggests a possible divergence in long-term behavior. Potential explanations include the long-term stability of the silicone material, differences in the degradation of surface characteristics, or a more sustained barrier effect. Importantly, many early comparisons were confounded, comparing sharp-edged silicone to round-edged acrylic or vice-versa. When edge design is matched (both sharp), material differences become subtler and may only emerge with very long follow-up.

3. Haptic Design: A Secondary Consideration

The evidence strongly indicates that the choice between 1-piece and 3-piece IOL designs has no significant impact on long-term PCO outcomes, provided the optic material and edge design are identical. Multiple RCTs and long-term follow-up studies, including the 10-year data from the Aravind Pseudoexfoliation Study, confirm no statistically or clinically meaningful difference (Sacu et al., 2004; Leydolt et al., 2007; Haripriya et al., 2025). Any minor differences observed in the early postoperative period (e.g., more capsular folds with 1-piece designs) tend to equilibrate over time and do not translate into increased Nd:YAG rates. Similarly, evidence on plate-haptic versus open-loop designs is limited but suggests comparable PCO outcomes when material is controlled (Hirnschall et al., 2013). Therefore, haptic design can be selected based on other surgical considerations (e.g., injector system, stability in compromised capsules) without compromising PCO prevention goals.

4. Platform Heterogeneity Within Material Categories

A critical insight from this synthesis is that significant performance variations exist even within the same broad material category. Not all hydrophobic acrylic IOLs are equal. For instance, the iMics1 NY-60 had a 35.6% 3-year Nd:YAG rate compared to 13.7% for the AcrySof SN60WF (Leydolt et al., 2013). Conversely, the Vivinex XY1 showed lower PCO scores than both AcrySof SN60WF and the newer Clareon CNA0T0 platform (Auffarth et al., 2023; Leydolt et al., 2024). These differences likely stem from subtle variations in polymer composition, manufacturing processes (e.g., lathe-cut vs. molded), surface roughness, and the precise geometry of the optic edge (including its "sharpness" and the presence of a continuous 360-degree barrier). This underscores that surgeons and researchers must look beyond generic material labels and consider specific IOL model performance data.

5. Clinical and Socioeconomic Implications

The findings have direct practical applications. The hierarchy for PCO prevention is clear: 1) Select an IOL with a sharp posterior optic edge. 2) If choosing acrylic, prefer hydrophobic material. 3) Consider silicone with a sharp edge for younger patients where very long-term (>10-20 year) performance is a priority, pending more confirmatory data. 4) Do not base the decision on 1-piece vs. 3-piece design for PCO reasons. A particularly impactful finding pertains to global health. In developing countries where cost constrains the use of premium foldable IOLs, the evidence that a simple design modification—a square edge—can reduce the 9-year Nd:YAG rate of a PMMA IOL from 37% to 2% is revolutionary (Haripriya et al., 2017). Widespread adoption of affordable, sharp-edged PMMA IOLs could prevent millions of cases of vision-impairing PCO and eliminate a vast number of costly and logistically challenging Nd:YAG procedures, dramatically improving the sustainability and outcomes of high-volume cataract surgery programs.

6. Limitations and Future Research Directions

This review has limitations inherent to synthesizing heterogeneous studies. Variations in PCO assessment methods (EPCO software, clinical grading), surgical techniques, and patient populations may introduce bias. Most long-term data comes from a limited number of studies and specific IOL models. Future research should prioritize prospective, long-term (≥ 10 -year) randomized trials directly comparing contemporary sharp-edged IOLs from different material categories (e.g., latest-generation hydrophobic acrylic vs. silicone). Further investigation into the biomolecular interactions at the IOL-capsule interface and the causes of platform-specific performance variations is also warranted.

CONCLUSION AND RECOMMENDATIONS

Conclusion

This detailed synthesis of evidence from 80 studies establishes a clear hierarchy of factors influencing PCO development after cataract surgery. The sharp posterior optic edge design emerges as the single most critical and non-negotiable feature for PCO prevention, providing a substantial and consistent benefit across all IOL materials through a mechanical barrier effect. Among materials, hydrophobic acrylic IOLs are superior to hydrophilic acrylic, while PMMA IOLs carry the highest PCO risk. The comparison between silicone and hydrophobic acrylic is time-dependent, with emerging evidence suggesting a potential long-term advantage for silicone, though this requires further validation. Haptic design (1-piece vs. 3-piece) has no significant independent impact on long-term PCO outcomes.

Recommendations

1. **For IOL Manufacturers:** Prioritize and refine sharp, 360-degree continuous posterior optic edge geometry in all IOL designs. Continue R&D into material science to enhance long-term biocompatibility and capsule adhesion.
2. **For Clinicians/Surgeons:** In IOL selection, give paramount importance to the presence of a sharp posterior optic edge. Prefer hydrophobic acrylic over hydrophilic acrylic. For patients

with a very long life expectancy, consider silicone IOLs with a sharp edge, acknowledging the evolving evidence base. Choose between 1-piece and 3-piece designs based on surgical factors other than PCO prevention.

3. **For Healthcare Systems and Policymakers:** In resource-constrained settings, actively promote the adoption and procurement of affordable, sharp-edged PMMA IOLs. This cost-effective intervention has been proven to drastically reduce the long-term burden of PCO and Nd:YAG capsulotomy, preserving vision and conserving limited healthcare resources.
4. **For Researchers:** Conduct long-term, head-to-head RCTs comparing the latest-generation sharp-edged IOLs from different material classes. Develop and standardize more sensitive, automated tools for PCO quantification. Investigate the molecular and biomechanical mechanisms underlying platform-specific performance differences within material categories.

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