

Photopolymer Materials for Ophthalmic Additive Manufacturing: Optical Quality, Surface, Ageing and Biocompatibility Requirements

Juan Seguro

3Dresyns by Resyner Technologies S.L.

© 2026 Juan Seguro. All Rights Reserved.

Correspondence: info@3Dresyns.com · www.3Dresyns.com

ER-022 · Engineering Review · Version 1.2 · 2026

Statement of Significance

Ophthalmic suitability cannot be reduced to refractive index. A lens material must combine wavelength-dependent optical quality with surface condition, water and oxygen transport where relevant, mechanical integrity, ageing resistance and a biological evaluation matched to the device class. This review therefore treats ophthalmic VPP as a device-qualification problem rather than as a generic refractive-index engineering exercise.

Keywords: ophthalmic additive manufacturing; optical lens; contact lens; intraocular lens; refractive index; Abbe number; haze; yellowing; oxygen permeability; water uptake; surface; ageing; vat photopolymerisation

Abstract

VPP has been applied to optical lenses, contact-lens structures, Fresnel optics, gradient-index components and proof-of-concept intraocular-lens geometries. The material requirements differ sharply across these device classes. Optical power depends on geometry and refractive index, while image quality additionally depends on transmission, haze, scatter, surface figure and chromatic dispersion. Contact-lens materials introduce hydration, oxygen transport and surface wetting; intraocular and other implanted optical devices add stringent chemical and biological qualification; all optical polymers require ageing studies because post-cure, water, UV and temperature can change yellowing, transmission and mechanics. This review organises ophthalmic material selection around optical quality, transport, surface, ageing and biological qualification. 3Dresyn OL1 MF, OL2IR and refractive-index material families are included as commercial implementation examples only, with no clinical suitability inferred from product positioning. [1–12]

1. Introduction

Directly printed ophthalmic optics are attractive because additive manufacturing can encode freeform surfaces, local geometry and patient-specific optical designs. Yet the threshold for a useful lens is much higher than transparency. Surface waviness, cure-induced index variation, residual layer texture and internal scatter can degrade optical quality even when total transmission appears high. The required evidence also depends on whether the printed element is a spectacle-type optical prototype, a contact lens, an intraocular concept or a research optical insert.

Recent work demonstrates multiple routes: precision spin-coating assisted 3D printing of optical lenses, continuous VPP for lens fabrication, multimaterial contact lenses, functional hydrogel printing on commercial lenses, Fresnel ocular structures and proof-of-concept clear foldable intraocular-lens designs. These studies support feasibility while also showing why optical geometry, material chemistry, surface and biological context must be qualified together. [1–9]

2. Device class determines the evidence chain

Domain	Measured output	Primary dependency	Claim boundary
External optical lens	Optical power, transmission, haze, surface figure.	RI, dispersion, geometry, polish/post-process.	No ocular-contact claim.
Contact lens	Optics plus hydration, oxygen/water transport and surface.	Hydrogel chemistry, thickness, water state, surface wetting.	No clinical wear claim from optical quality alone.
Intraocular-lens concept	Optics, foldability/mechanics, chemical/biological evaluation.	Final cured chemistry, extractables, geometry and implantation context.	Proof-of-concept geometry is not implant qualification.
Functional ocular element	Optics plus drug/sensor/filter function.	Multimaterial interface and functional additive.	Function must not compromise optical/biological requirements.
Gradient/freeform optic	Wavefront or spatial optical response.	Voxel exposure, spatial RI or geometry control.	Nominal RI does not establish wavefront quality.

Table 1. Engineering distinctions that must be preserved.

3. Optical quality extends beyond refractive index

Refractive index is necessary for optical design but does not describe chromatic dispersion, haze, bulk scatter, birefringence, surface roughness or wavefront error. Abbe number or wavelength-resolved index is needed when chromatic performance matters. Total transmission should be distinguished from internal transmission because Fresnel reflection and surface quality can dominate thin lenses. VPP optical papers should therefore report both material optics and manufactured surface/figure metrics. [1,2,7,8]

Metric	What it captures	Critical conditions	What it does not establish
Refractive index	Refraction and optical-power design.	Wavelength, temperature, cure/water state.	Low haze or good surface figure.
Abbe / dispersion	Chromatic change in RI.	Defined wavelength method.	Transmission or biological suitability.
Transmission	Fraction of incident light transmitted.	Thickness, wavelength, surface state.	Image quality if scatter/figure error is high.
Haze/scatter	Diffuse optical loss.	Thickness and instrument geometry.	Correct lens power.
Surface roughness/figure	Manufactured optical interface.	Measurement scale and aperture.	Bulk optical homogeneity.
Wavefront / MTF	System-level imaging quality.	Aperture, wavelength and optical setup.	Biological compatibility.

Table 2. Optical metrics for ophthalmic VPP.

4. Water and oxygen transport

Contact-lens and hydrogel systems introduce transport requirements absent from dry external optics. Water uptake changes dimensions, refractive index and modulus, while oxygen transport depends on chemistry, hydration and thickness. Oxygen permeability and transmissibility should not be used interchangeably: transmissibility includes the lens thickness. A dry-resin RI or tensile value therefore cannot be transferred automatically to the equilibrated hydrated lens state. [3–5,9,10]

5. Surface chemistry and tear-film interface

Surface wetting, roughness, extractables and fouling influence comfort and optical stability in ocular-contact research. Printing and post-cure can create a surface composition different from the bulk. Surface treatment may improve wettability but can age or delaminate. Consequently, contact-angle or roughness measurements should be repeated after relevant aqueous conditioning and cleaning rather than reported only on fresh dry coupons. [3–5,9,10]

6. Ageing and optical stability

Stress	Potential change	Measurement	Interpretation
UV/light exposure	Yellowing, photobleaching, chain damage.	Spectral transmission, colour/yellowness, mechanics.	Supports only defined dose/spectrum.
Water/saline storage	Swelling, extraction, RI/modulus shift.	Mass/dimensions, RI, transmission, mechanics.	Dry data cannot substitute.
Thermal cycling	Stress, dimensional drift, interface changes.	Optical power/figure plus mechanics.	No lifetime extrapolation without model.
Cleaning/disinfection	Surface extraction or coating loss.	Surface chemistry/wetting/roughness plus optics.	Fresh surface behaviour may not persist.
Post-cure evolution	Conversion and yellowing changes.	Conversion, optics and mechanical state versus cure.	One cure protocol is not universal.

Table 3. Ophthalmic ageing pathways.

7. Biological and chemical qualification

For ocular-contact or implanted devices, material selection must be embedded in a risk-based biological evaluation of the final printed and post-processed article. The relevant endpoints depend on contact type and duration, and chemical characterisation/extractables may be needed to understand exposure. A resin description, monomer-free designation or transparent appearance cannot be converted into clinical suitability, medical-device status or long-term ocular compatibility. [10–12]

8. Minimum reporting framework

Block	Minimum information	Reason	Claim limit
Device class	External lens, contact-lens research, IOL concept, functional optic.	Defines qualification burden.	Do not generalise across device classes.
Optical state	RI wavelength, transmission/haze, thickness, surface/figure.	Separates material and manufactured optics.	Transparency alone is insufficient.
Hydration/transport	Water state and oxygen/water metric where relevant.	Defines contact-lens state.	No Dk/t inference from dry polymer.
Post-process	Wash, post-cure, polishing/coating.	Controls optical and chemical surface.	Different post-cures are different states.
Ageing	Light, water, thermal and cleaning history.	Tests retained optical quality.	Fresh performance is not lifetime.
Biological evidence	Final-part chemical/biological evaluation matched to contact.	Contributes to the biological-risk evidence for the defined contact scenario.	No clinical or regulatory claim from TDS alone.

Table 4. Minimum reporting set for ophthalmic VPP studies.

3Dresyns implementation examples

The 3Dresyns ophthalmic and optical portfolio provides implementation examples for material selection, but none of the product names substitutes for device-level ophthalmic qualification.

- 3Dresyn OL1 MF is positioned as a monomer-free resin for direct printing of ophthalmic lenses, with optical clarity and controlled refractive-index positioning. Final lens power, haze, surface quality and biological suitability depend on the actual printed/post-processed device. [M1]
- 3Dresyn OL2IR is positioned as an ophthalmic-lens resin with high-impact-resistance intent. Product positioning does not establish shatter performance, optical quality or clinical suitability for every lens geometry. [M2]
- 3Dresyns low-, medium- and high-refractive-index material families illustrate RI-based optical selection. RI should remain tied to wavelength and final cure state and cannot be treated as a complete ophthalmic specification. [M3]

These examples show commercial implementation of optical-material selection only. Contact-lens, intraocular or other ocular-device claims require application-specific optical, transport, chemical and biological validation.

9. Conclusions

- Ophthalmic material qualification extends well beyond refractive index.
- Transmission, haze/scatter, surface figure and wavelength-dependent dispersion determine manufactured optical quality.
- Contact-lens research additionally requires hydration and oxygen/water transport in the equilibrated state.
- Surface chemistry and wetting should be evaluated after relevant conditioning and cleaning.
- Optical ageing should be measured after defined light, water and thermal histories.
- Biological and chemical evaluation must match final device contact and processing.
- Commercial ophthalmic resin positioning is an implementation starting point, not evidence of clinical suitability.

Limitations

This review addresses materials and qualification logic, not clinical efficacy. No commercial product is assessed as a finished medical device, and no RI, oxygen-permeability or impact range is generalised beyond its documented test state.

Author contributions

Juan Seguro: conceptualisation, literature synthesis, engineering framework, writing and critical review.

Competing interests

The author is affiliated with 3Dresyns by Resyner Technologies S.L. Commercial 3Dresyns materials are identified only as implementation examples supported by controlled product documentation. They are not treated as independent peer-reviewed evidence and no proprietary formulation composition is disclosed.

Data availability

No new experimental dataset was generated for this review. Scientific statements are attributed to the cited literature and standards; commercial examples are separated from the independent evidence base.

Company information

Legal company name: 3Dresyns by Resyner Technologies S.L. Registered tax address: General Etxague 15B, 20003 Donostia / San Sebastián, Gipuzkoa, Spain VAT number: ESB24827511 Contact email: info@3Dresyns.com Company website: www.3Dresyns.com

References

- [1] Y. Shan, J. Hua, H. Mao et al., 3D Printing of Optical Lenses Assisted by Precision Spin Coating, *Advanced Functional Materials* 34(44) (2024) 2407165. DOI: 10.1002/adfm.202407165.
- [2] H. Xu, S. Chen, R. Hu, M. Hu, et al., Continuous Vat Photopolymerization for Optical Lens Fabrication, *Small* 19 (2023) 2300517. DOI: 10.1002/smll.202300517.
- [3] M. Hisham, A.E. Salih, H. Butt, 3D Printing of Multimaterial Contact Lenses, *ACS Biomaterials Science & Engineering* 9 (2023) 4381-4391. DOI: 10.1021/acsbomaterials.3c00175.
- [4] M. Hisham, H. Butt, Vat photopolymerization printing of functionalized hydrogels on commercial contact lenses, *Scientific Reports* 14 (2024) 13860. DOI: 10.1038/s41598-024-63846-7.
- [5] S. Hittini, A.E. Salih, F. Alam, A. Shanti, S. Lee, et al., Fabrication of 3D-Printed Contact Lenses and Their Potential as Color Blindness Ocular Aids, *Macromolecular Materials and Engineering* 308 (2023) 2200601. DOI: 10.1002/mame.202200601.
- [6] V. Hidalgo-Alvarez, N.D. Falcon, J. Eldred, M. Wormstone, A. Saeed, Stereolithographic Rapid Prototyping of Clear, Foldable, Non-Refractive Intraocular Lens Designs: A Proof-of-Concept Study, *Current Eye Research* 49(8) (2024) 843–852. DOI: 10.1080/02713683.2024.2344164.
- [7] M. Ali, M. Hisham, R.K. Abu Al-Rub, H. Butt, Vat photopolymerization of multifunctional Fresnel lenses for ocular management, *Frontiers in Bioengineering and Biotechnology* 12 (2024) 1464129. DOI: 10.3389/fbioe.2024.1464129.
- [8] J. Tu, J.D. Engelhardt, M.H. Barkow, J.C. Cruz Robles, J.F. Stanzione, R.V. Chimenti, G.R. Palmese, Additive Manufacturing of Polymeric Gradient Index Optics via Grayscale Digital Light Processing Vat Photopolymerization Technology, *ACS Applied Optical Materials* 3(6) (2025) 1197–1207. DOI: 10.1021/acsaom.5c00143.
- [9] H. Butt, M.A. Uddin, M. Hisham, V.S. Volkov, Conformal metamaterial inspired contact lenses-designing, 3D printing and characterization for ocular applications, *Light: Advanced Manufacturing* 7 (2026) 39. DOI: 10.37188/lam.2026.039.
- [10] ISO 18369 series, Ophthalmic optics - Contact lenses.
- [11] ISO 11979 series, Ophthalmic implants - Intraocular lenses, cited only as device-qualification context.
- [12] ISO 10993-1:2025, Biological evaluation of medical devices — Part 1: Requirements and general principles for the evaluation of biological safety within a risk management process. International Organization for Standardization.

Manufacturer documentation

- [M1] 3Dresyns, 3Dresyn OL1 MF, manufacturer product documentation, accessed 20 August 2026. <https://www.3dresyns.com/products/3dresyn-ol1-mf-monomer-free-for-printing-ophthalmic-lenses>
- [M2] 3Dresyns, 3Dresyn OL2IR, manufacturer product documentation, accessed 20 August 2026. <https://www.3dresyns.com/products/3dresyn-ol2ir-for-printing-ophthalmic-lenses-with-ultra-high-impact-resistance>
- [M3] 3Dresyns, refractive-index resin families, manufacturer collection and selection documentation, accessed 20 August 2026. <https://www.3dresyns.com/collections/3d-resins-by-refractive-index>

Copyright

© 2026 Juan Segurola. All Rights Reserved.