

Biological-Evaluation Planning for Photopolymer Devices: Material State, Contact Category, Endpoints and Evidence Integration

A risk-based architecture from finished-device definition to residual-risk decision

Juan Segurola

3Dresyns by Resyner Technologies S.L.

© 2026 Juan Segurola. All Rights Reserved.

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

ER-251 · Engineering Review · Version 0.4 · 23 September 2026

Abstract

Biological evaluation of a photopolymer device is not a material label or a fixed panel of tests. It is a risk-management process applied to the final, clinically relevant device state. For vat-photopolymerised devices, resin identity alone is insufficient because printing, washing, drying, post-curing, support removal, finishing, cleaning, sterilisation, ageing and packaging can alter conversion, accessible surface, residues, extractables and degradation behaviour. Contact type, duration, frequency and exposed population then determine which biological hazards and endpoints require evidence. This review defines an evidence architecture that begins with intended use and a frozen material-process-device configuration. It links body-contact categorisation, chemical and physical characterisation, prior knowledge, toxicological assessment and targeted biological testing through explicit gap analysis. Evidence is weighted by relevance to the final device, methodological adequacy and uncertainty; a favourable result cannot compensate for an unrepresented material state or contact scenario. The output is a traceable biological-evaluation plan with decision rules, change triggers and residual-risk statements. The framework does not prescribe a universal test matrix or claim that one resin, process or endpoint establishes device safety. Keywords: biological evaluation; photopolymer device; biocompatibility; material state; body contact; endpoints; risk management; evidence integration

1. Significance and scope

ISO 10993-1:2025 places biological safety within risk management and requires evaluation of the device as used, not merely of constituent materials [1]. ISO 14971:2019 supplies the broader process for hazard identification, risk estimation, control and evaluation of residual risk [2]. This is especially important for photopolymers because the finished network contains a process-dependent distribution of reacted species, residual constituents and surface states.

1.1 Corpus boundary

ER-251 owns biological-evaluation planning, contact categorisation, endpoint selection and evidence integration. ER-175 retains washing-system engineering; ER-181 retains post-cure engineering; ER-206 retains micro-computed-tomography metrology; ER-251 does not replace those process controls. ER-252 owns cytotoxicity-test artefacts; ER-253 owns analytical evaluation thresholds; ER-254 owns constituent toxicological risk assessment; ER-255 to ER-259 own application-specific skin, mucosal, blood, bone-interface and antimicrobial questions; and ER-260 owns digital traceability of patient-specific devices. ER-251 defines how their outputs enter one device-level plan without taking over their methods.

2. Freeze the evaluated device configuration

Define resin formulation or controlled material designation, printer and wavelength, build orientation, layer schedule, wash chemistry and history, drying, post-cure spectrum, dose and temperature, support-removal method, finishing, cleaning, sterilisation, packaging and shelf-age state. Identify every patient-contacting component, adhesive, coating, colorant and processing aid. The test article should represent the worst credible finished-device state for the hazard under study. A polished specimen may be unsuitable for a device whose internal channels remain as printed; an unsterilised coupon may be unsuitable when sterilisation changes extractables or degradation.

3. Describe intended use before selecting tests

Record clinical function, anatomical site, direct and indirect contact, contact duration and repetition, maximum exposed area, fluid path, temperature, mechanical loading, reuse, cleaning and vulnerable populations. Include reasonably foreseeable misuse when it changes exposure. Contact classification is an input to risk analysis, not an automatic endpoint list. Devices in the same broad category can differ in geometry, surface area, flow, wear and local concentration.

4. Construct the biological hazard inventory

Consider chemical constituents and residues, particles, degradation products, surface-mediated effects, mechanical irritation, thermal effects and microbiological consequences. For photopolymers, the inventory should address residual monomers and oligomers, photoinitiator-related species, inhibitors, pigments, fillers, wash residues, post-cure products and substances introduced by finishing or sterilisation.

ISO 10993-18:2020, together with Amendment 1:2022 on determination of the uncertainty factor, describes a stepwise chemical-characterisation framework spanning materials, manufacturing-introduced substances, extractables and leachables [3,8]. Chemical evidence is essential but does not by itself represent every biological interaction.

5. Map hazards to endpoints

For each credible hazard, state the biological effect, exposure route, relevant tissue, time scale and proposed evidence. Endpoints can include cytotoxicity, sensitisation, irritation, systemic toxicity, genotoxicity, implantation response, haemocompatibility, pyrogenicity, degradation and other application-specific effects. The mapping must explain inclusion and exclusion. Absence of a test is justified only by adequate prior evidence, lack of relevant exposure, a controlled risk or another scientifically stronger line of evidence.

6. Quantify evidence coverage

A planning score may be used to expose gaps, but it is not a safety index: $C_{plan} = \sum w_k c_k$ where C_{plan} is the planning-coverage indicator, w_k is the declared importance weight for hazard-endpoint pair k , and c_k is the evidence-completeness fraction for that pair. A high aggregate cannot close a critical zero-coverage hazard; every non-compensatory item remains separately visible.

7. Build an evidence hierarchy

Give greatest weight to evidence on the final device made by the qualified process and tested under relevant exposure. Next come equivalent devices with justified compositional and process equivalence, followed by constituent data, mechanistic evidence and literature on related materials. Supplier statements and generic descriptors are inputs, not conclusions. The United States Food and Drug Administration guidance of 8 September 2023 similarly emphasises risk-based assessment, chemical information and representative test-article preparation [5]. Regulatory applicability and recognised editions must be checked for the target jurisdiction at the time of submission.

8. Integrate chemical and biological evidence

Chemical characterisation identifies and estimates exposure to constituents; biological tests observe responses in defined systems. ISO 10993-17:2023, together with Amendment 1:2025, addresses toxicological risk assessment of device constituents [4,9]. Neither line should be read in isolation. A cytotoxic response can trigger analytical investigation, process correction or both. Conversely, a non-cytotoxic extract does not eliminate sensitisation, genotoxicity, haemocompatibility or long-term degradation concerns.

9. Treat process state as a biological variable

Brooks and Yadavalli showed that post-print wash and cure sequence materially changed cell response for several printed resins [6]. Turkalj, Pully, Li, Sun, Ghosh, Čokić, Vanoirbeek, Van Meerbeek and Van Landuyt linked post-processing to degree of conversion and monomer elution in printed dental composites [7]. These studies establish process sensitivity, not universal safe settings. Record exposure dose, solvent condition, agitation, drying and elapsed time as controlled variables. A process deviation is potentially a biological-evaluation change, even if nominal resin identity is unchanged.

10. Define equivalence rigorously

Equivalence requires comparison of composition, supplier controls, geometry, surface state, manufacturing, post-processing, sterilisation, packaging, ageing and use exposure. A shared trade name or polymer family is insufficient. Document uncertainty and negative evidence. If a constituent is undisclosed or a processing residue is not characterised, the gap cannot be converted into equivalence by assumption.

11. Select test articles by hazard

The most conservative article can differ by endpoint. Maximum surface area, minimum cure, most difficult-to-wash channel, highest pigment loading, greatest wear or longest ageing may represent different hazards. Define the selection rationale before testing. Include production variability and clinically relevant finishing. Coupon manufacture should not remove the very surface or geometry that creates the exposure.

12. Use non-compensatory gates

Gate	Required evidence	Blocking failure
Intended use	Contact site, duration, frequency and population	Choosing tests from product name
Material state	Final process, sterilisation and ageing state	Testing raw resin or ideal coupons only
Chemistry	Constituents, residues, extractables and degradation hypotheses	Treating formulation as fully known
Endpoint map	Hazard-to-endpoint rationale	Applying an unexplained checklist
Test article	Worst credible relevant configuration	Selecting the easiest geometry
Integration	Concordance, discordance and uncertainty	Declaring safety from one favourable assay
Change control	Biological impact assessment for each change	Carrying evidence across unverified changes

Failure at one gate requires resolution or an explicit residual-risk decision; it cannot be averaged away.

13. Analyse discordant evidence

When chemistry, in vitro response, animal evidence or clinical experience disagree, first test comparability of material state and exposure. Examine extraction severity, dose expression, assay interference, cell model, detection limits, ageing and batch variation. Discordance is information about the model boundary. It should lead to a focused hypothesis and discriminating study, not to selective acceptance of the most favourable result.

14. Express residual risk explicitly

A qualitative residual-risk ledger can be represented as $R_{res} = \sum p_j s_j$ where R_{res} is a prioritisation indicator, p_j is the estimated probability or exposure plausibility for harm scenario j , and s_j is its declared severity weight. The expression supports ranking only; clinical acceptability requires justified criteria, uncertainty and benefit-risk context.

15. Predefine decision rules

State acceptance criteria, control validity, retest rules and escalation paths before generating results. Define what constitutes a process correction, additional chemistry, targeted biological testing, toxicological review or clinical risk-control update. Avoid post hoc movement of thresholds or exclusion of unfavourable specimens without a documented assignable cause.

16. Control changes over the lifecycle

Assess changes to formulation, supplier, pigment, printer, optical source, layer schedule, cleaning, post-cure, support removal, surface finishing, sterilisation, packaging, shelf life, geometry, contact claim and manufacturing site. Evaluate both the changed component and downstream effects. The decision can be no action, analytical bridging, focused testing or full reassessment, but the rationale must be recorded.

17. Maintain traceability

Link every conclusion to device configuration, risk item, evidence object, protocol, raw data, analysis version and approval. Preserve negative and superseded evidence. A report without configuration identity cannot support later change assessment. ER-260 owns the complete digital thread for patient-specific devices; ER-251 requires only the biological-evaluation links needed to reproduce decisions.

18. Minimum reporting set

Report intended use; contact category and duration; patient population; full material-process-device state; manufacturing and sterilisation; constituent and surface information; hazard inventory; endpoint rationale; literature search; prior evidence; test-article selection; methods and controls; results; uncertainty; discordance analysis; risk controls; residual-risk conclusion; limitations; change triggers; and traceable identifiers.

19. Knowledge boundary

The standards and guidance define current planning principles [1-5]. Experimental studies demonstrate that post-processing can alter cytotoxicity, conversion and monomer release [6,7]. They do not establish that a named resin, a generic post-cure or one negative assay is safe for every geometry, contact category, duration or population.

20. Limitations

References [1-5] were verified from official primary records; references [6] and [7] were examined at full-text or detailed primary-record depth. Standards and regulatory recognition can change. This review does not provide legal advice, prescribe a jurisdiction-independent test matrix or disclose proprietary formulations, processing windows or acceptance limits.

21. Conclusions

Biological evaluation of a photopolymer device begins with the final device state and intended contact, then integrates chemistry, prior knowledge, toxicology and targeted biological evidence. The defensible plan is explicit about gaps, uncertainty, decision rules and change triggers. Safety is a device-specific residual-risk conclusion, not a property conferred by resin name, printing technology or one passing test.

References

1. International Organization for Standardization. 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. Geneva: ISO; 2025. <https://www.iso.org/standard/10993-1>
2. International Organization for Standardization. ISO 14971:2019 Medical devices - Application of risk management to medical devices. Geneva: ISO; 2019. <https://www.iso.org/standard/72704.html>
3. International Organization for Standardization. ISO 10993-18:2020 Biological evaluation of medical devices - Part 18: Chemical characterization of medical device materials within a risk management process. Geneva: ISO; 2020. <https://www.iso.org/standard/64750.html>
4. International Organization for Standardization. ISO 10993-17:2023 Biological evaluation of medical devices - Part 17: Toxicological risk assessment of medical device constituents. Geneva: ISO; 2023. <https://www.iso.org/standard/75323.html>
5. United States Food and Drug Administration. Use of International Standard ISO 10993-1, Biological evaluation of medical devices - Part 1: Evaluation and testing within a risk management process: Guidance for Industry and Food and Drug Administration Staff. 8 September 2023. <https://www.fda.gov/regulatory-information/search-fda-guidance-documents/use-international-standard-is-o-10993-1-biological-evaluation-medical-devices-part-1-evaluation-and>
6. Brooks AK, Yadavalli VK. Post-print processing to minimize cytotoxicity of 3D-printed photopolymer resins for biomedical applications. *Journal of Applied Polymer Science*. 2025;142:e56545. <https://doi.org/10.1002/app.56545>
7. Turkalj M, Pully D, Li Q, Sun W, Ghosh M, Čokić SM, Vanoirbeek J, Van Meerbeek B, Van Landuyt KL. Monomer elution and cytotoxicity of 3D-printed resin-based composites. *Dental Materials*. 2025;41(9):1140-1150. <https://doi.org/10.1016/j.dental.2025.06.016>
8. International Organization for Standardization. ISO 10993-18:2020/Amd 1:2022 Biological evaluation of medical devices - Part 18 - Amendment 1: Determination of the uncertainty factor. Geneva: ISO; 2022. <https://www.iso.org/standard/82241.html>
9. International Organization for Standardization. ISO 10993-17:2023/Amd 1:2025 Biological evaluation of medical devices - Part 17 - Amendment 1. Geneva: ISO; 2025. <https://www.iso.org/standard/88201.html>

Copyright

© 2026 Juan Seguro. All Rights Reserved.