

Collagen Methacryloyl Photoresins: Collagen Source, Methacrylation, Triple-Helix State, Low-Temperature DLP, Hydration, Enzymatic Degradation and Qualification

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Statement of Significance

Collagen methacryloyl is not one material. Species and tissue source, collagen type, extraction, solubilisation, molecular integrity, derivatisation and purification define the macromer. Temperature, concentration, initiator, optical dose, washing, hydration and triple-helix or fibril evolution define distinct network and article states.

Keywords: collagen; collagen methacryloyl; ColMA; triple helix; fibrillogenesis; DLP; hydration; collagenase; degradation; qualification

Abstract

Primary evidence shows that type-I collagen can be methacrylated while retaining fibrillar self-assembly and enzymatic degradability, but source, extraction, solubilisation, methacrylation and neutralisation remain material-defining. Gaudet and Shreiber reported rapid 365 nm photocrosslinking, a five-fold storage-modulus increase and state-dependent collagenolytic resistance for one collagen methacrylamide route. Han et al. later combined extracted ColMA with PEGDA for DLP printing, creating a hybrid rather than a neat collagen network. This review separates collagen identity, triple-helix/fibril state, derivatisation, formulation, low-temperature handling, optical processing, hydration, mechanics, collagenase degradation and biological evidence, and defines minimum qualification gates.

1. Scope and boundaries

ER-122 owns material-specific identity and qualification of collagen methacryloyl photoresins. It covers animal species and tissue source, collagen type, extraction and solubilisation, molecular integrity, derivatisation, neutralisation, formulation, low-temperature handling, exposure, washing, hydration, triple-helix and fibril state, mechanics and enzymatic degradation.

ER-06 retains biological-response methodology; ER-10 geometric metrology; ER-15 degradation and mechanical evolution; ER-27 conversion; ER-33 washing and drying; ER-67 generic hybrid-network architecture; ER-86 extractables; ER-100 corpus architecture; and ER-121 and ER-123 to ER-126 neighbouring natural-polymer derivative families. [C1,C2,C3,C4,C5,C6,C7,C8,C9,C10,C11,C12,C13].

General AM characteristics, geometric test artefacts and geometrical tolerancing should follow the declared standards [S1,S3,S4].

Collagen type and source are not extraction history. Methacrylation feed is not measured incorporation. ColMA is not GelMA, and neat ColMA is not ColMA/PEGDA. A cold formulation is not proof of retained triple helix. Green, washed and hydrated articles, and in-vitro and in-vivo degradation states, must remain separate.

2. Controlled collagen-photoresin state chain

State	Minimum identity	Failure if omitted
Incoming collagen	Animal species, tissue and extraction lot, isolation, solubilisation, molecular distribution, purity and storage	The word collagen replaces protein identity
Photoactive derivative	methacrylic-anhydride feed and reaction, purification, drying, measured incorporation and calculation basis	Feed or ColMA acronym is treated as chemistry
Vat or bioink	Derivative concentration, water/buffer, initiator, absorber, cells or additives, temperature and age	Formulation and biological state disappear
Article	Exposure and layer strategy, green geometry, wash, hydration, secondary structure, conversion, residuals and mechanics	Green, washed, hydrated and tested objects are conflated

Table 1. Minimum state chain for collagen methacryloyl photocurable networks.

This material and article chain is separate from process and production-site qualification under ISO/ASTM 52920:2023 [S2].

3. Primary evidence and controlled interpretation

3.1 Methacrylamide functionalisation and photocrosslinking

Gaudet and Shreiber modified type-I collagen with methacrylate functionality while retaining spontaneous fibrillar self-assembly and enzymatic biodegradability [1]. Irradiation at 365 nm produced a rapid, approximately five-fold increase in storage modulus in their system. Uncrosslinked and photocrosslinked collagen methacrylamide showed different collagenolytic resistance, demonstrating that degradation attribution requires the exact network and article state.

As a structural comparator, Brinkman et al. reported a twelve-fold increase in shear modulus after crosslinking without loss of collagen triple-helical content [3].

3.2 Concentration, hydration and mechanics are coupled

Collagen source, extraction and solubilisation history influence molecular integrity and fibrillogenesis. Methacrylation feed is not measured incorporation, and measured incorporation is not retained triple-helix content. A release specification therefore requires independent chemical and structural measurements rather than the acronym ColMA alone.

3.3 A ColMA/PEGDA hybrid is not evidence for neat ColMA

Han et al. extracted type-I collagen and developed a ColMA/PEGDA ink for DLP printing [2]. PEGDA changes network chemistry, crosslink density, swelling and degradation; the resulting article is a hybrid network and cannot be used as evidence for neat ColMA. Printer temperature and residence time must also be controlled because collagen conformation and viscosity are temperature-sensitive.

3.4 Low-temperature handling is not proof of retained structure

Low-temperature processing can preserve a formulation before exposure, but it is not evidence that the triple helix, fibrils or biological motifs remain unchanged after derivatisation, irradiation, washing and equilibration. Structural assays must be performed on the relevant incoming, derivative and printed states.

3.5 Enzymatic degradation requires complete method identity

Collagenase or other enzymatic degradation is meaningful only with enzyme identity and activity, buffer, pH, temperature, replenishment, specimen geometry and conditioning reported. Mass loss, dimensions, mechanics and soluble products must remain separate endpoints; one in-vitro curve is not an in-vivo resorption rate.

4. Photochemistry, protein structure and process state

Collagen concentration, molecular integrity, pH, salt, temperature and ageing control viscosity and fibrillogenesis. Derivatisation changes reactive sites; initiator, wavelength, irradiance, exposure, oxygen, layer thickness and optical attenuation control polymerisation. Triple-helix and fibril content must be measured rather than inferred from low-temperature handling.

Hybrid ColMA/PEGDA systems require component-specific controls. Covalent conversion, collagen fibrillogenesis, hydration and enzymatic degradation are distinct coordinates. Network attribution requires neat-component and hybrid controls measured on matched green, washed and equilibrated states.

5. Hydration, degradation and biological boundaries

Evidence block	What it can show	What it cannot establish alone
Hydration/equilibration	Medium- and time-specific mass, dimensions, swelling and mechanics	Conversion, in-use lifetime or degradation mechanism
Secondary structure	Method- and state-specific triple-helix and fibril or other conformational content	Covalent conversion or a verified second network
Enzymatic incubation	Enzyme-, activity-, medium-, temperature-, geometry- and time-specific mass/property evolution	Universal in-vivo resorption
Biological model	Response of the exact construct in the stated cell, tissue or animal model	General safety, clinical efficacy or regulatory approval

Table 2. Evidence blocks that must remain separate for collagen photo-networks.

ISO 10993-12:2021/Amd 1:2025 and ISO 10993-18:2020/Amd 1:2022 anchor sample preparation and chemical characterisation [S5,S6]. ISO 10993-1:2025 frames biological-safety evaluation within risk management [S7], while ISO 22442-1:2020 is relevant when animal-derived starting materials enter a medical-device claim [S8]. None of these standards converts a favourable cell or animal observation into general clinical suitability.

6. Release matrix

Gate	Minimum evidence	Claim withheld
Collagen identity	Species/source, tissue lot, extraction, dissolution, molecular distribution, purity and storage	Generic collagen equivalence

Gate	Minimum evidence	Claim withheld
Functionalisation	Reaction conditions, purification, measured incorporation method/result and storage	methacrylation feed or ColMA acronym as identity
Vat process	Concentration, initiator, wavelength, irradiance, exposure, layer thickness, temperature and ageing	Transferable print settings
Network attribution	Conversion plus independent secondary-structure and physical-state evidence with controls	Unverified dual network
Article state	Green, washed and hydrated x/y/z, mass, residuals and conditioning history	Unqualified dimensions or mechanics
Biological boundary	Exact formulation, construct, dose, wash, model, endpoint and statistics	Universal biocompatibility or clinical suitability

Table 3. Minimum release architecture for collagen methacryloyl photocurable constructs.

7. Failure-mode interpretation

- A nominally identical ColMA becomes much less viscous: verify species, tissue source, extraction and solubilisation, chain degradation, concentration, temperature, storage and freeze-thaw history before changing exposure.
- A higher methacrylation feed does not increase modulus: measure incorporated functionality and conversion; feed, measured methacrylamide incorporation and network density are different quantities.
- The green object is accurate but expands after washing: report x/y/z, mass and medium history after a defined wash and equilibration; do not publish green dimensions as in-use dimensions.
- Mechanical strength rises during incubation: measure water content and secondary structure before assigning further covalent cure or degradation.
- A PEGDA hybrid prints better than neat ColMA: retain hybrid identity, filler state and optical absorption; do not transfer the result to neat collagen resin.
- Cells remain viable after printing: retain the exact collagen route, formulation, light, wash, construct and model; do not infer approval or universal biocompatibility.

8. Minimum workflow and research priorities

- Freeze animal species, tissue source, collagen type, extraction and solubilisation, molecular integrity, purity, bioburden and storage.
- Report methacrylation feed, pH, temperature, time, mixing, purification, dialysis cutoff and duration, drying, measured incorporation and calculation basis.
- Map viscosity, absorbance and working curves over temperature, ageing and the complete build-duration window.
- Measure conversion, gel fraction, residuals and retained collagen on matched green, washed and hydrated states.
- Quantify secondary structure independently from covalent conversion and distinguish physical reinforcement from a verified second network.
- Track mass and x/y/z dimensions through washing, equilibration, drying, rehydration and degradation.
- Report enzyme or medium identity, activity, pH, temperature, replenishment, geometry and time rather than one generic degradation rate.
- Separate model-specific viability, differentiation, adhesion or healing observations from safety, efficacy and regulatory conclusions.

9. Conclusions

Collagen methacryloyl photoresins are controlled collagen, derivative, formulation, network and article states. Source, collagen type, extraction and solubilisation define the incoming polymer; derivatisation and measured incorporation define ColMA; formulation and exposure define the green network; washing, hydration and structural history define the tested article.

Primary evidence supports photoactive type-I collagen, retained fibrillar assembly under defined conditions, tunable mechanics, altered collagenolytic resistance and DLP-printable ColMA/PEGDA hybrids. Each outcome remains bounded to its exact chemistry and article state.

Release requires traceability from tissue source through molecular integrity, derivatisation, formulation, temperature, exposure, wash, hydrated geometry, conversion, triple-helix/fibril state, residuals, mechanics, enzymatic degradation and biological model. ColMA alone is not a specification.

Limitations

This paper is a qualitative engineering review, not a systematic meta-analysis. The cited studies use related but non-identical collagen routes, formulations, printers, exposures, specimens and biological models. Numerical values are retained as study-specific evidence and must not be treated as universal design values.

Author contributions

Juan Seguro: conceptualisation, evidence synthesis, boundary definition, engineering interpretation, manuscript preparation and final author verification.

Competing interests

The author is founder and CEO of 3Dresyns by Resyner Technologies S.L. No comparative product recommendation is made.

Data availability

No new experimental dataset was generated. Scientific statements derive from the cited primary literature and official standards. The review package includes QA and source-boundary controls.

Company information

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