Characterization of Novel PDMS-Based Drug Encapsulation Strategies for Controlled Release Applications Using Choline-Geranic Acid Ionic Liquid

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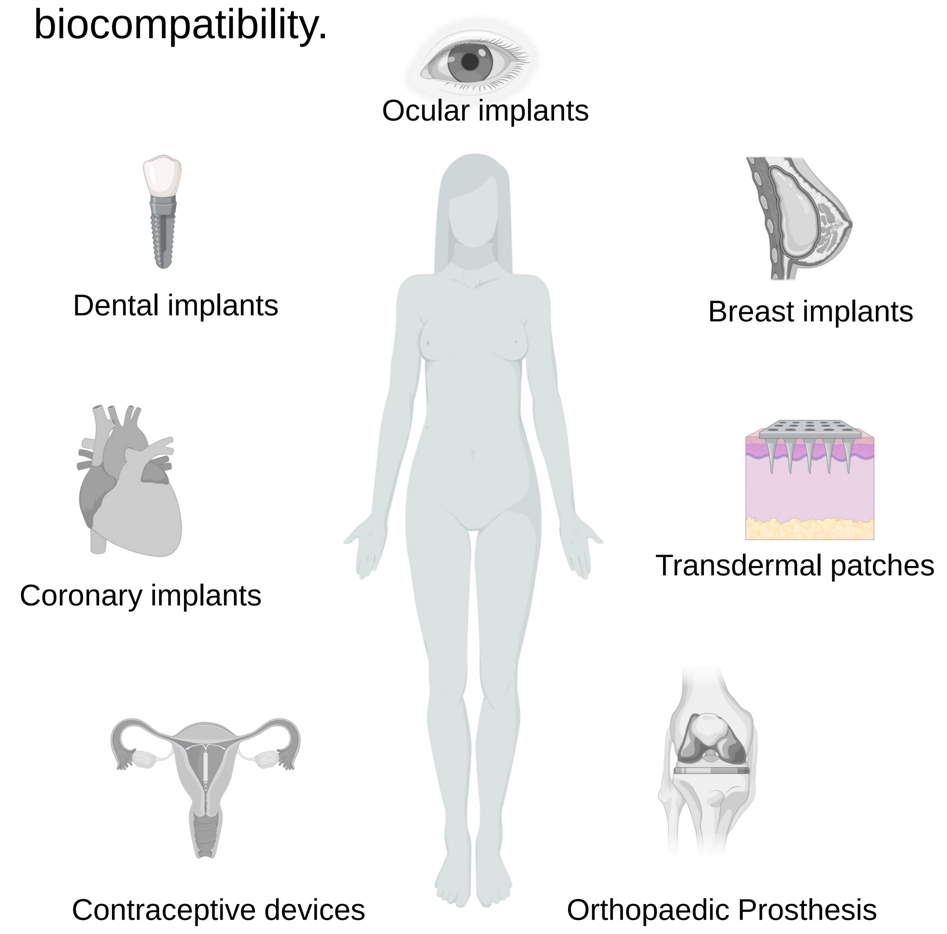
Introduction

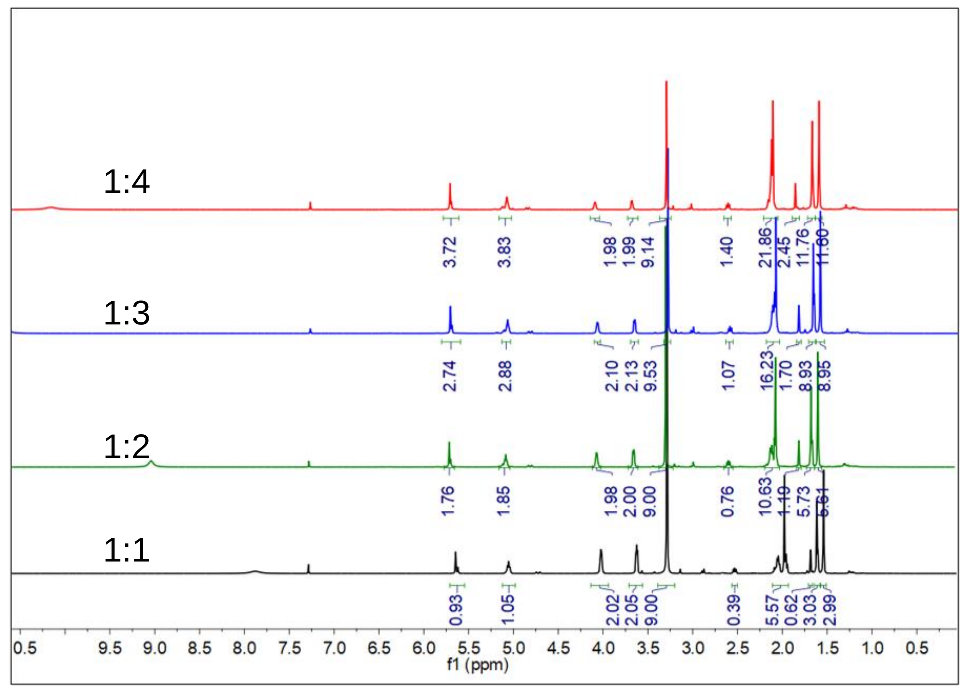
Polydimethylsiloxane (**PDMS**) is an elastomer commonly used in biomedical implants due to its favorable mechanical properties and biocompatibility.



- Combining PDMS with a drug delivery platform enhances its biomedical utility by providing both structural function and therapeutic benefit
- We developed a novel formulation combining PDMS with ionic liquids that enables high loading of the model drug Rhodamine B and supports sustained, high-level release over time.

Ionic Liquids

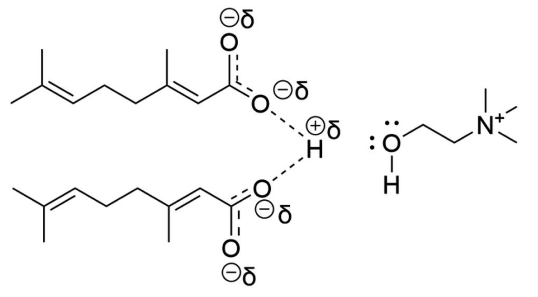
[1]H NMR Spectrum of Ionic liquid

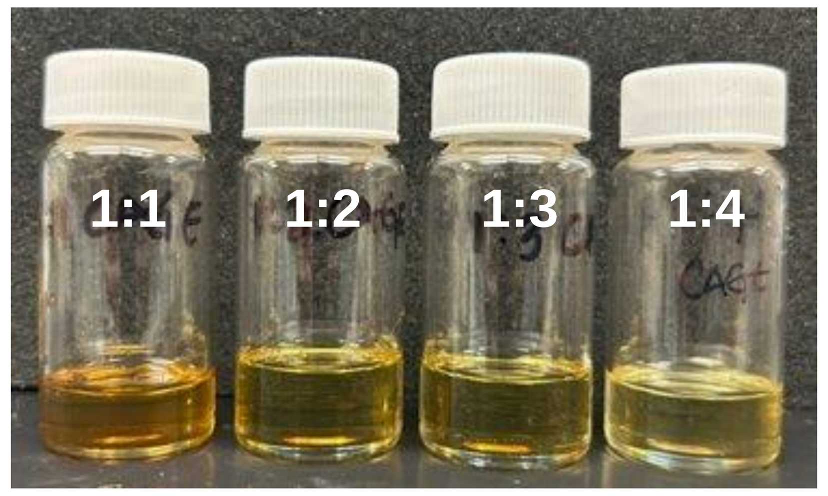


[1]H-NMR spectroscopy of CAGE Ionic liquids made up of four different molar ratios of cation, Choline, and anion, Geranic Acid, molecules.

Ionic liquids (ILs) are salts in a liquid state, typically composed of organic cations and either organic or inorganic anions.

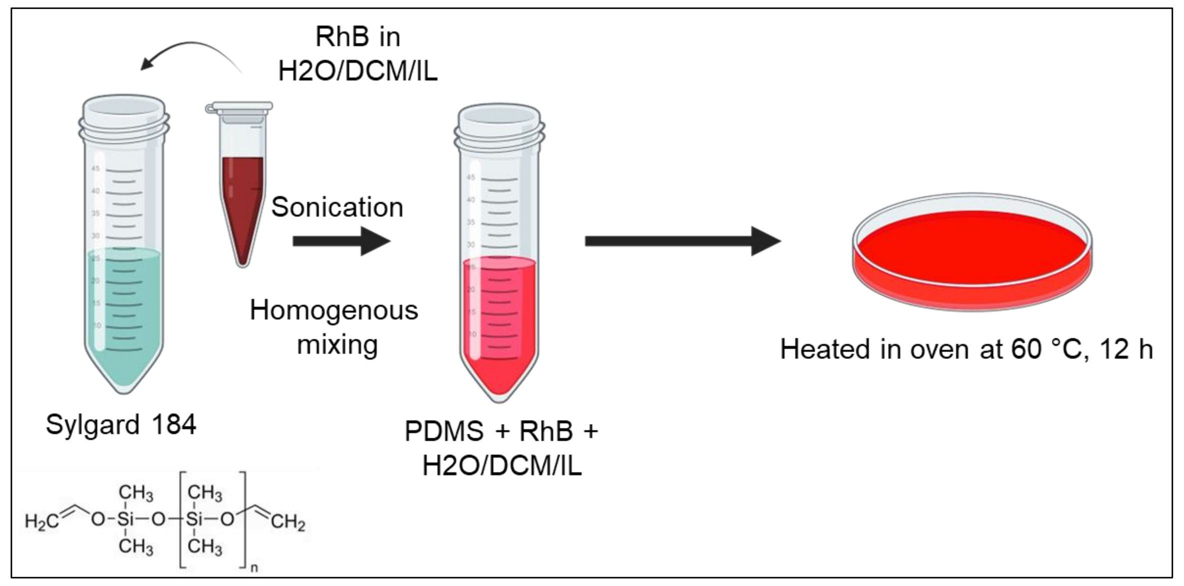
Key Characteristics:
1. Amphiphilic Nature
2. Enhanced Permeability
3. High Solubility
4. Overall Tunability





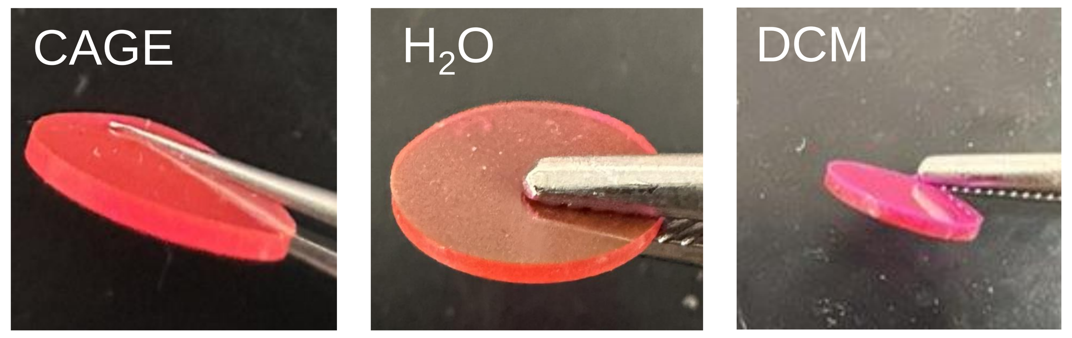
Methods

Fabrication of RhB-loaded PDMS devices

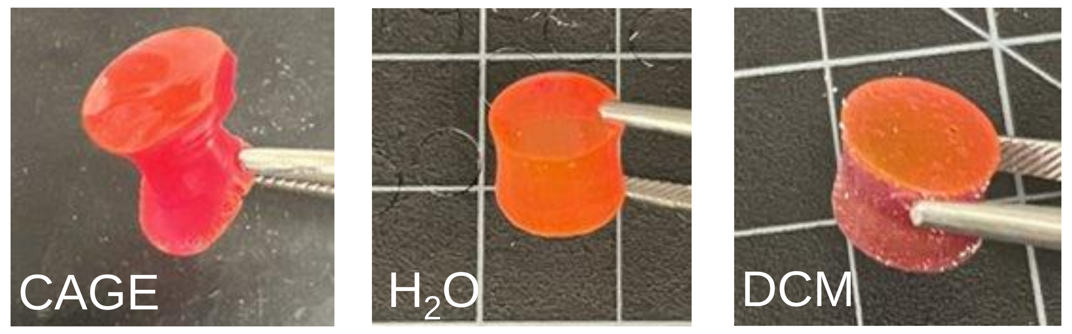


PDMS films were prepared by mixing Sylgard 184 base with curing agent at a 10:1 ratio.

Drug delivery as films

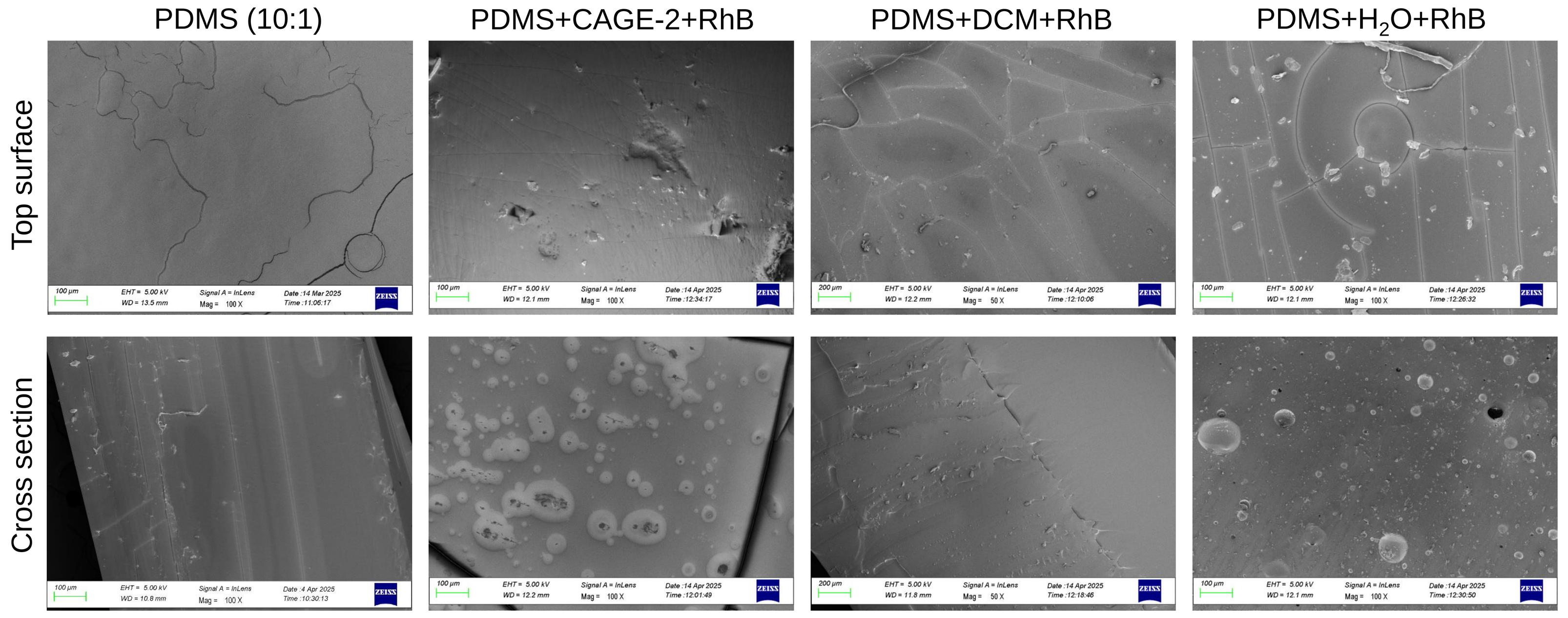


Drug delivery as implants



Results

SEM Imaging



Loading Quantities

Average weight and RhB Loading into films

Thin film (1 mm x 10 mm)	Wt of the film (mg)	RhB loaded (µg)	RhB (µg/mg)
PDMS+DCM+RhB	98.6	90.4	0.9
PDMS+H2O+RhB	81.6	69.6	0.9
PDMS+IL-2+RhB	89.1	225.3	2.5

Average weight and RhB Loading into Implants

Thick film (7 mm x 10 mm)	Wt of the film (mg)	RhB loaded (µg)	RhB (µg/mg)
PDMS+DCM+RhB	538.4	335.6	0.6
PDMS+H2O+RhB	550.4	335.7	0.6
PDMS+IL-2+RhB	615.8	1093.0	1.8

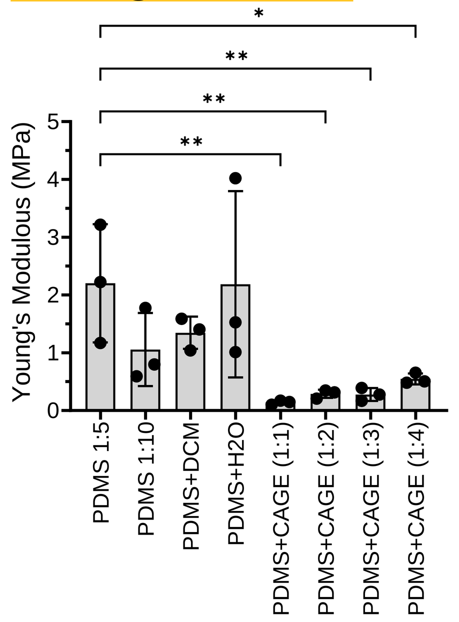
Korsmeyer–Peppas Model

Film Type	Release Constant (k)	Release Exponent (n)
DCM	0.07230	0.36730
H2O	0.08070	0.47322
CAGE (1:1)	0.33747	0.36234
CAGE (1:2)	0.37259	0.29446
CAGE (1:3)	0.40952	0.28033
CAGE (1:4)	0.43352	0.26854

Film Type	Release Constant (k)	Release Exponent (n)
DCM	0.01769	0.51708
H2O	0.01708	0.58465
CAGE (1:2)	0.19946	0.40080

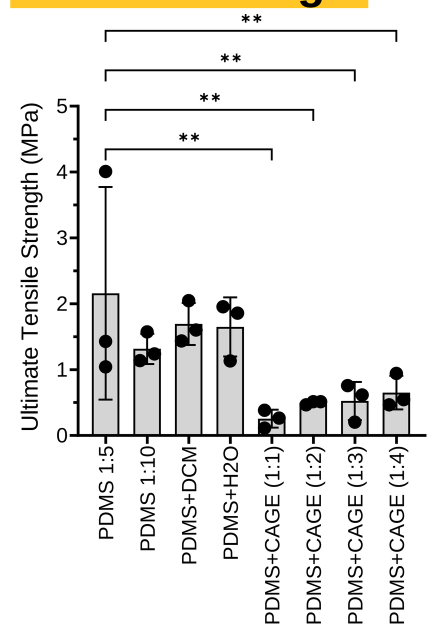
Mechanical Testing

Young Modulus



- CAGE incorporation significantly reduced stiffness (~0.3–0.5 MPa), compared to 1:5 PDMS (~2.4 MPa).
- Lower modulus supports flexibility for coating applications.

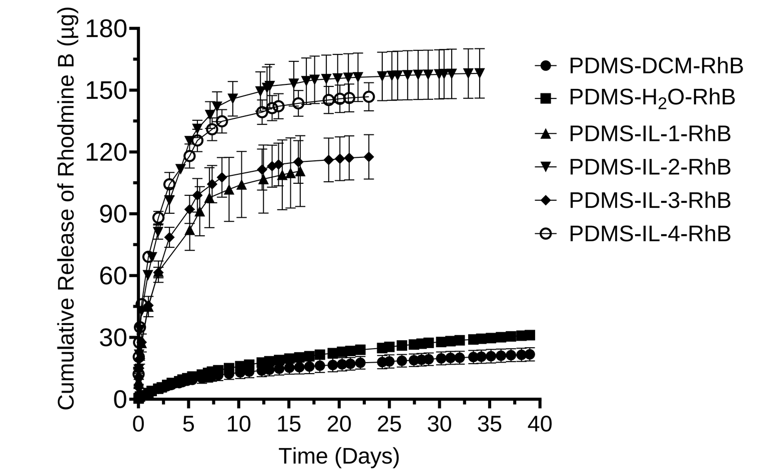
Tensile Strength

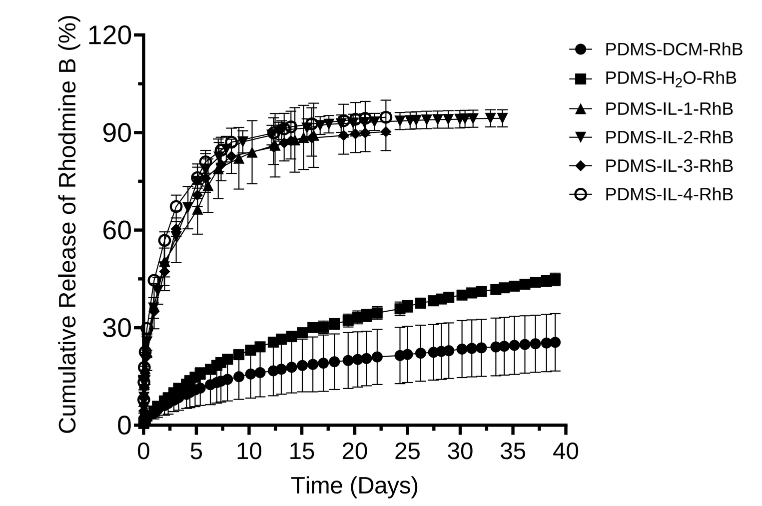


- CAGE films had reduced tensile strength (< 2 MPa) relative to 1:5 PDMS (> 4 MPa).
- Mechanical properties remain suitable for non-load-bearing uses.

RhB Release from devices

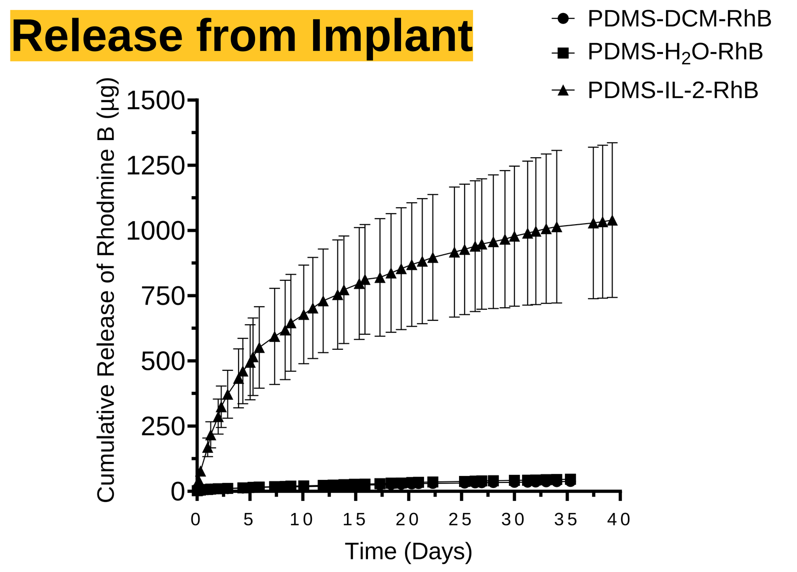
Release from Film

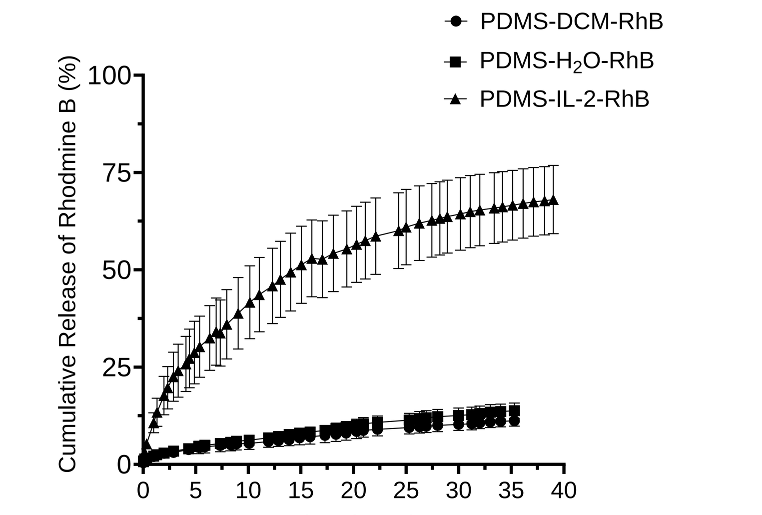




- CAGE films released up to ~150 µg RhB, ~3× more than DCM or water.
- IL-1 to IL-3 reached >90% release; DCM and water stayed below 50%.
- k increased with CAGE ratio (up to 0.43), showing enhanced release rates.
- n decreased with CAGE ratio (down to 0.27), indicating Fickian diffusion.

Release from Implant





- CAGE films released up to ~1500 µg RhB; DCM and water stayed <350 µg.
- IL-2 released ~75% of loaded RhB; others remained <25%.
- k for IL-2 was 0.20 — nearly 10× higher than DCM or water films.
- n for IL-2 was 0.40, suggesting predominantly Fickian transport.

Conclusions / Future Directions

- CAGE-enhanced PDMS films enabled tunable drug loading and sustained release, offering a promising platform for localized delivery in implant coatings and reconstructions.
- Future directions include applying this strategy toward mitigating foreign body response (FBR) using small molecule therapeutics in long-term implants.

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REFERENCES

[1] Marmo, A.C., Grunlan, M.A., Biomedical Silicones: Leveraging Additive Strategies to Propel Modern Utility. *ACS Macro Lett.* https://doi.org/10.1021/acsmacrolett.2c00701. (2023)
[2] Miranda et al. Properties and Applications of PDMS for Biomedical Engineering: A Review. *Journal of Controlled Release* https://pmc.ncbi.nlm.nih.gov/articles/PMC8788510/ (2021)
[3] Padmanabhan et al. Allometrically Scaling tissue forces drive pathological foreign-body responses to implants via Rac2-activated myeloid cell. *Nat. Biomed. Eng.* https://www.nature.com/articles/s41551-023-01091-5 (2023)

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