



Electrically Controlled Local Drug Delivery Beyond Size and Charge Limitations of Iontronic Transport

Sebastian Hecko, PhD

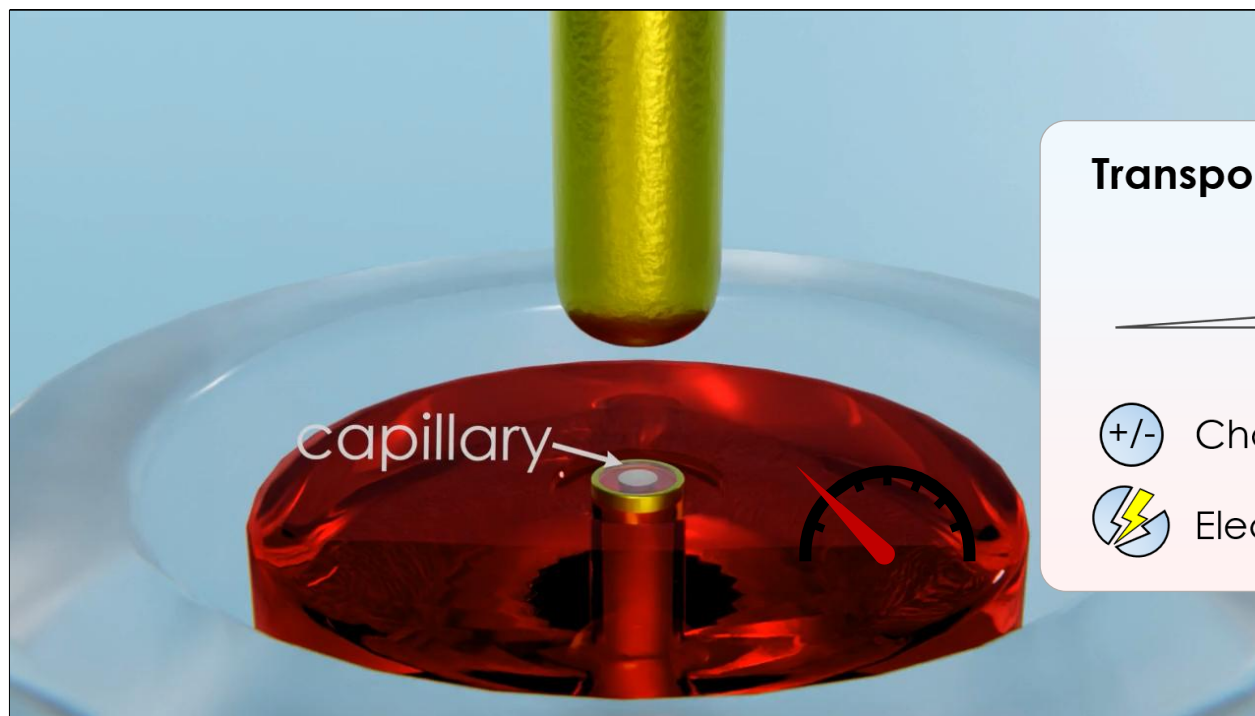
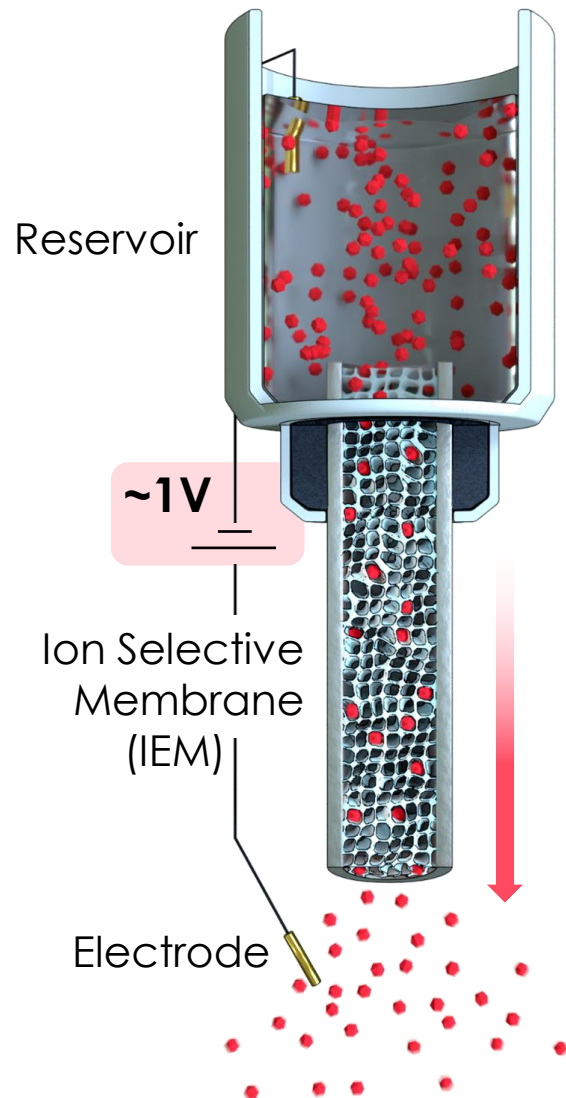


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Ion Pump

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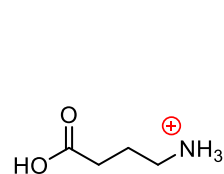


Transport Limits

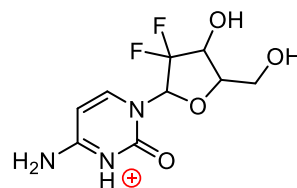
≥ 600 Da
Molecular Weight

+/- Charge $\neq 0$

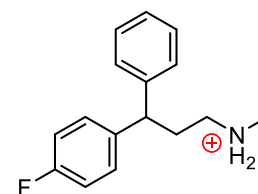
Electrochemically **Unstable**



GABA



Gemcitabine



Fluoxetine

Iontronically Delivered Drugs

Strakosas et al., *Sci. Adv.* **2021**, 7 (5), eabd8738.
Waldherr et al., *Adv Mater Technol.* **2021**, 2001302.
Asefifeyzabadi et al., *Adv. Mater. Technol.* **2025**, 70039.



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Humira (Anti-Tumor Necrosis Factor)  \$19,720 Billion Immunology	Elquis (Anti-Tumor Necrosis Factor)  \$12,149 Billion Immunology	Keytruda (Anti-Tumor Necrosis Factor)  \$11,054 Billion Immunology	Revlimid (Anti-Tumor Necrosis Factor)  \$9,270 Billion Immunology	Imbruvica (Anti-Tumor Necrosis Factor)  \$8,000 Billion Oncology	Opdivo (Anti-Tumor Necrosis Factor)  \$6,010 Billion Immunology	Eylea (Anti-Tumor Necrosis Factor)  \$7,363 Billion Immunology	Avastin (Anti-Tumor Necrosis Factor)  \$7,280 Billion Immunology	Enbrel (Anti-Tumor Necrosis Factor)  \$7,216 Billion Immunology	Xarelto (Anti-Tumor Necrosis Factor)  \$6,811 Billion Immunology	Riluxun (Anti-Tumor Necrosis Factor)  \$6,571 Billion Immunology	Stelara (Anti-Tumor Necrosis Factor)  \$6,014 Billion Immunology	Herceptin (Anti-Tumor Necrosis Factor)  \$4,220 Billion Immunology	Prevnar 13 (Anti-Tumor Necrosis Factor)  \$3,947 Billion Immunology	Remicade (Anti-Tumor Necrosis Factor)  \$3,304 Billion Immunology	Ibrance (Anti-Tumor Necrosis Factor)  \$4,961 Billion Immunology	Biktarvy (Anti-Tumor Necrosis Factor)  \$4,730 Billion Immunology	Tecladra (Anti-Tumor Necrosis Factor)  \$4,431 Billion Immunology	Trulicity (Anti-Tumor Necrosis Factor)  \$4,394 Billion Immunology	Xtandi (Anti-Tumor Necrosis Factor)  \$4,380 Billion Immunology	
Lucanta (Anti-Tumor Necrosis Factor)  \$3,647 Billion Immunology	Soliris (Anti-Tumor Necrosis Factor)  \$3,246 Billion Immunology	Gemvaya (Anti-Tumor Necrosis Factor)  \$3,121 Billion Immunology	Ocrevus (Anti-Tumor Necrosis Factor)  \$3,112 Billion Immunology	Balox (Anti-Tumor Necrosis Factor)  \$3,111 Billion Oncology	Gardasil (Anti-Tumor Necrosis Factor)  \$3,111 Billion Immunology	Perjeta (Anti-Tumor Necrosis Factor)  \$3,111 Billion Immunology	Lyrica (Anti-Tumor Necrosis Factor)  \$3,099 Billion Onc & Anesthesia	Coenlyx (Anti-Tumor Necrosis Factor)  \$3,111 Billion Immunology	Januvia (Anti-Tumor Necrosis Factor)  \$3,492 Billion Immunology	Imvigor (Anti-Tumor Necrosis Factor)  \$3,111 Billion Immunology	Victoza (Anti-Tumor Necrosis Factor)  \$3,111 Billion Immunology	Jardiance (Anti-Tumor Necrosis Factor)  \$3,111 Billion Immunology	Iams (Anti-Tumor Necrosis Factor)  \$3,111 Billion Immunology	Gileya (Anti-Tumor Necrosis Factor)  \$3,111 Billion Onc & Anesthesia	Neulasta (Anti-Tumor Necrosis Factor)  \$3,111 Billion Immunology	Xolair (Anti-Tumor Necrosis Factor)  \$3,111 Billion Immunology	Tagrisso (Anti-Tumor Necrosis Factor)  \$3,111 Billion Immunology	Triumq (Anti-Tumor Necrosis Factor)  \$3,111 Billion Immunology	Enlyvio (Anti-Tumor Necrosis Factor)  \$3,111 Billion Immunology	
Daralex (Anti-Tumor Necrosis Factor)  \$2,999 Billion Immunology	Orencia (Anti-Tumor Necrosis Factor)  \$2,977 Billion Immunology	Mavyel (Anti-Tumor Necrosis Factor)  \$2,999 Billion Immunology	Humalog (Anti-Tumor Necrosis Factor)  \$2,999 Billion Immunology	Truvada (Anti-Tumor Necrosis Factor)  \$2,999 Billion Immunology	Zylgia (Anti-Tumor Necrosis Factor)  \$2,999 Billion Oncology	Symbicort (Anti-Tumor Necrosis Factor)  \$2,999 Billion Immunology	NovoKapid (Anti-Tumor Necrosis Factor)  \$2,999 Billion Immunology	Prolla (Anti-Tumor Necrosis Factor)  \$2,999 Billion Immunology	Sprycel (Anti-Tumor Necrosis Factor)  \$2,999 Billion Immunology	Vyvanse (Anti-Tumor Necrosis Factor)  \$2,999 Billion Onc & Anesthesia	Aclema (Anti-Tumor Necrosis Factor)  \$2,999 Billion Immunology	ProQuad (Anti-Tumor Necrosis Factor)  \$2,999 Billion Immunology	Dupixent (Anti-Tumor Necrosis Factor)  \$2,999 Billion Immunology	Shingrix (Anti-Tumor Necrosis Factor)  \$2,999 Billion Immunology	Spivria (Anti-Tumor Necrosis Factor)  \$2,999 Billion Immunology	Xeljanz (Anti-Tumor Necrosis Factor)  \$2,999 Billion Immunology	Nexium (Anti-Tumor Necrosis Factor)  \$2,999 Billion Immunology	Simponi (Anti-Tumor Necrosis Factor)  \$2,999 Billion Immunology	Pomalyst (Anti-Tumor Necrosis Factor)  \$2,999 Billion Immunology	
Advair (Anti-Tumor Necrosis Factor)  \$2,145 Billion Immunology	Pentacel (Anti-Tumor Necrosis Factor)  \$2,111 Billion Immunology	Alimta (Anti-Tumor Necrosis Factor)  \$2,111 Billion Immunology	Prezista (Anti-Tumor Necrosis Factor)  \$2,111 Billion Immunology	Spinraza (Anti-Tumor Necrosis Factor)  \$2,111 Billion Immunology	Lipitor (Anti-Tumor Necrosis Factor)  \$2,111 Billion Oncology	Twicay (Anti-Tumor Necrosis Factor)  \$2,111 Billion Immunology	Augurio (Anti-Tumor Necrosis Factor)  \$2,111 Billion Immunology	Janumet (Anti-Tumor Necrosis Factor)  \$2,111 Billion Immunology	Epclusa (Anti-Tumor Necrosis Factor)  \$2,111 Billion Immunology	Cimzia (Anti-Tumor Necrosis Factor)  \$2,111 Billion Immunology	Xgeva (Anti-Tumor Necrosis Factor)  \$2,111 Billion Immunology	Tecentiq (Anti-Tumor Necrosis Factor)  \$2,111 Billion Immunology	Tysabri (Anti-Tumor Necrosis Factor)  \$2,111 Billion Immunology	Tasigna (Anti-Tumor Necrosis Factor)  \$2,111 Billion Immunology	Velcade (Anti-Tumor Necrosis Factor)  \$2,111 Billion Oncology	Prograf (Anti-Tumor Necrosis Factor)  \$2,111 Billion Immunology	Lafuda (Anti-Tumor Necrosis Factor)  \$2,111 Billion Immunology	Aranesp (Anti-Tumor Necrosis Factor)  \$2,111 Billion Immunology		
Enbrel (Anti-Tumor Necrosis Factor)  \$1,720 Billion Immunology	Jentadufo (Anti-Tumor Necrosis Factor)  \$1,699 Billion Immunology	Ozempic (Anti-Tumor Necrosis Factor)  \$1,699 Billion Immunology	Pradaxa (Anti-Tumor Necrosis Factor)  \$1,699 Billion Immunology	Avonex (Anti-Tumor Necrosis Factor)  \$1,699 Billion Immunology	Odefsey (Anti-Tumor Necrosis Factor)  \$1,699 Billion Immunology	Xyrem (Anti-Tumor Necrosis Factor)  \$1,699 Billion Onc & Anesthesia	Lynparza (Anti-Tumor Necrosis Factor)  \$1,699 Billion Immunology	Olezia (Anti-Tumor Necrosis Factor)  \$1,699 Billion Immunology	Sandoz (Anti-Tumor Necrosis Factor)  \$1,699 Billion Immunology	Brilinta (Anti-Tumor Necrosis Factor)  \$1,699 Billion Immunology	Crestor (Anti-Tumor Necrosis Factor)  \$1,699 Billion Immunology	Farisga (Anti-Tumor Necrosis Factor)  \$1,699 Billion Immunology	Afinitor (Anti-Tumor Necrosis Factor)  \$1,699 Billion Immunology	Vimpat (Anti-Tumor Necrosis Factor)  \$1,699 Billion Immunology	Copaxone (Anti-Tumor Necrosis Factor)  \$1,699 Billion Immunology	Descovy (Anti-Tumor Necrosis Factor)  \$1,699 Billion Immunology	Yervoy (Anti-Tumor Necrosis Factor)  \$1,699 Billion Immunology	Lovenox (Anti-Tumor Necrosis Factor)  \$1,699 Billion Immunology	Myrbetriq (Anti-Tumor Necrosis Factor)  \$1,699 Billion Immunology	
Imfinzi (Anti-Tumor Necrosis Factor)  \$1,499 Billion Immunology	Pulmicort (Anti-Tumor Necrosis Factor)  \$1,466 Billion Immunology	Plovix (Anti-Tumor Necrosis Factor)  \$1,466 Billion Immunology	Xanax (Anti-Tumor Necrosis Factor)  \$1,466 Billion Immunology	Advate (Anti-Tumor Necrosis Factor)  \$1,466 Billion Immunology	NovoMix (Anti-Tumor Necrosis Factor)  \$1,466 Billion Immunology	Kadcyla (Anti-Tumor Necrosis Factor)  \$1,466 Billion Immunology	Hemlibra (Anti-Tumor Necrosis Factor)  \$1,466 Billion Immunology	Symdeko (Anti-Tumor Necrosis Factor)  \$1,466 Billion Immunology	Promacta (Anti-Tumor Necrosis Factor)  \$1,466 Billion Immunology	Forleo (Anti-Tumor Necrosis Factor)  \$1,466 Billion Immunology	Levemir (Anti-Tumor Necrosis Factor)  \$1,466 Billion Immunology	Tresiba (Anti-Tumor Necrosis Factor)  \$1,466 Billion Immunology	Thixase (Anti-Tumor Necrosis Factor)  \$1,466 Billion Immunology	Taltz (Anti-Tumor Necrosis Factor)  \$1,466 Billion Immunology	Edoxaban (Anti-Tumor Necrosis Factor)  \$1,466 Billion Immunology	Abraxane (Anti-Tumor Necrosis Factor)  \$1,466 Billion Immunology	Human Insulin (Anti-Tumor Necrosis Factor)  \$1,466 Billion Immunology	Tafrolin/Mekrolin (Anti-Tumor Necrosis Factor)  \$1,466 Billion Immunology	Synagis (Anti-Tumor Necrosis Factor)  \$1,466 Billion Immunology	
Mrena (Anti-Tumor Necrosis Factor)  \$1,353 Billion Immunology	Lenvima (Anti-Tumor Necrosis Factor)  \$1,353 Billion Immunology	Opsumit (Anti-Tumor Necrosis Factor)  \$1,327 Billion Immunology	Galvus (Anti-Tumor Necrosis Factor)  \$1,297 Billion Immunology	Humulin (Anti-Tumor Necrosis Factor)  \$1,29 Billion Immunology	Gleevec (Anti-Tumor Necrosis Factor)  \$1,263 Billion Immunology	Duvelim (Anti-Tumor Necrosis Factor)  \$1,244 Billion Immunology	Abily Maltina (Anti-Tumor Necrosis Factor)  \$1,241 Billion Immunology	Simponi (Anti-Tumor Necrosis Factor)  \$1,224 Billion Immunology	Novoseven (Anti-Tumor Necrosis Factor)  \$1,218 Billion Immunology	Beo Elipia (Anti-Tumor Necrosis Factor)  \$1,204 Billion Immunology	Restasis (Anti-Tumor Necrosis Factor)  \$1,189 Billion Immunology	Rexilli (Anti-Tumor Necrosis Factor)  \$1,177 Billion Immunology	Orkambi (Anti-Tumor Necrosis Factor)  \$1,174 Billion Immunology	Ventolin (Anti-Tumor Necrosis Factor)  \$1,163 Billion Immunology	Esbril (Anti-Tumor Necrosis Factor)  \$1,163 Billion Immunology	Stridin (Anti-Tumor Necrosis Factor)  \$1,131 Billion Immunology	Somaline (Anti-Tumor Necrosis Factor)  \$1,124 Billion Immunology	Jakavi (Anti-Tumor Necrosis Factor)  \$1,114 Billion Immunology	Sasagur (Anti-Tumor Necrosis Factor)  \$1,113 Billion Immunology	

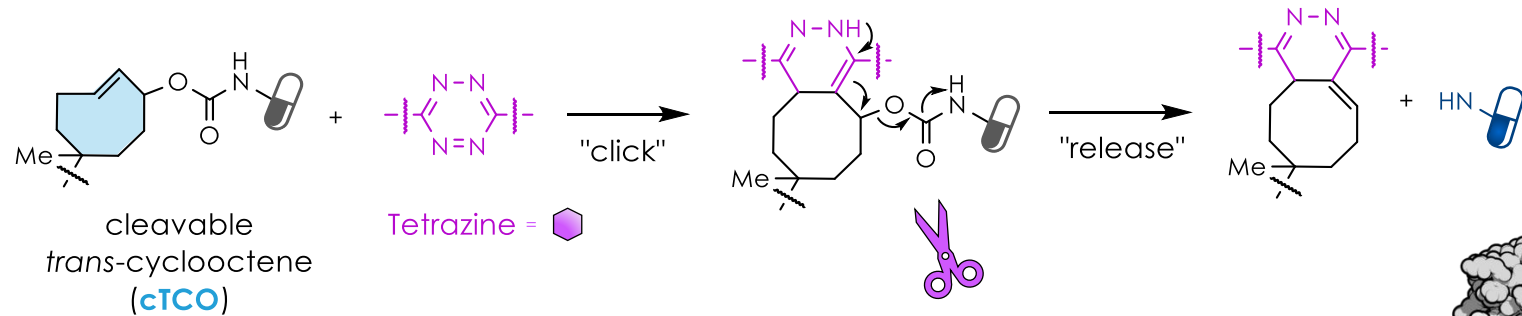
Ion Pump

Click-to-Release (C2R)

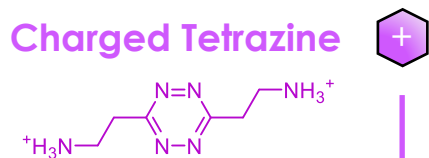
Reservoir

Ion Selective Membrane (IEM)

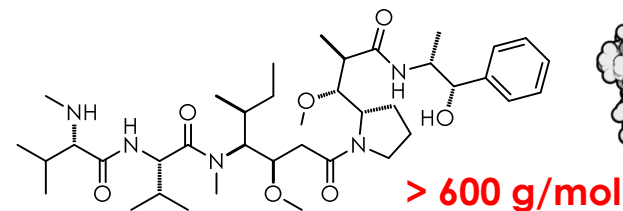
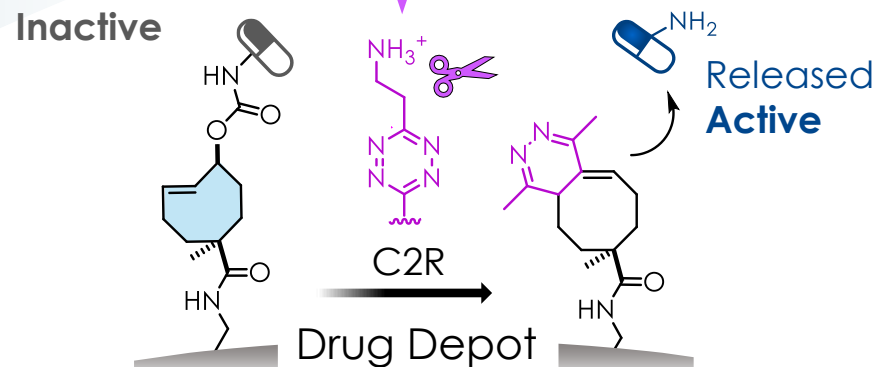
Electrode



Charged Tetrazine



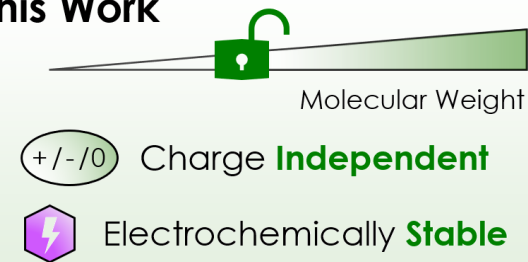
Immobilized Inactive



Monomethyl auristatin E

Keytruda (PD-L1)

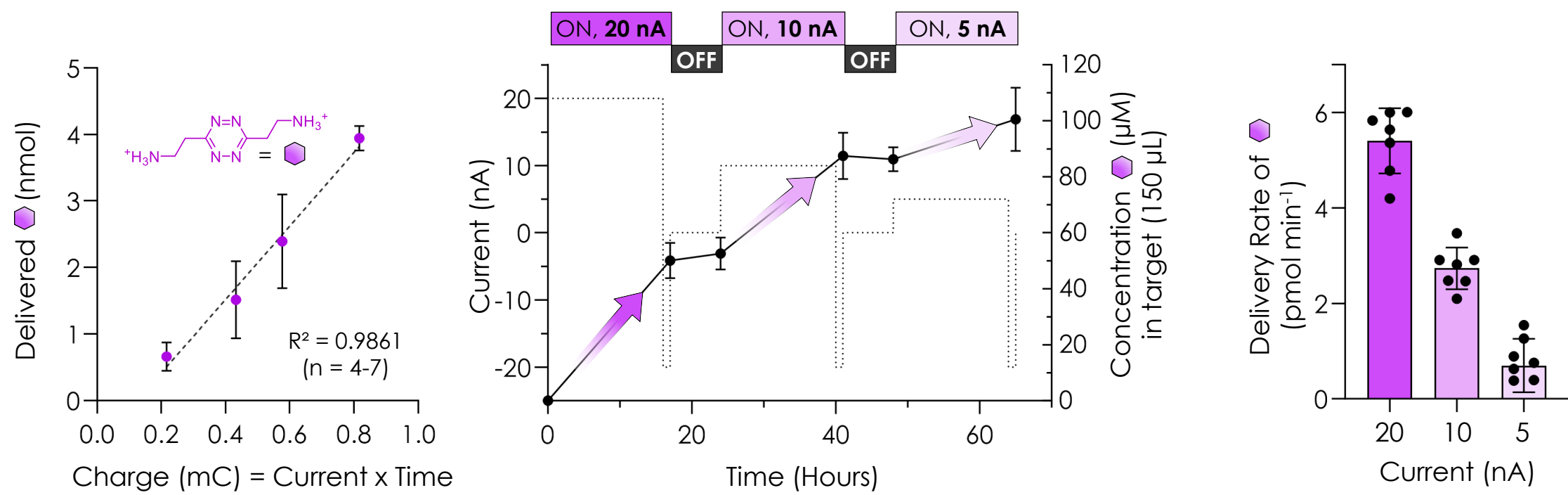
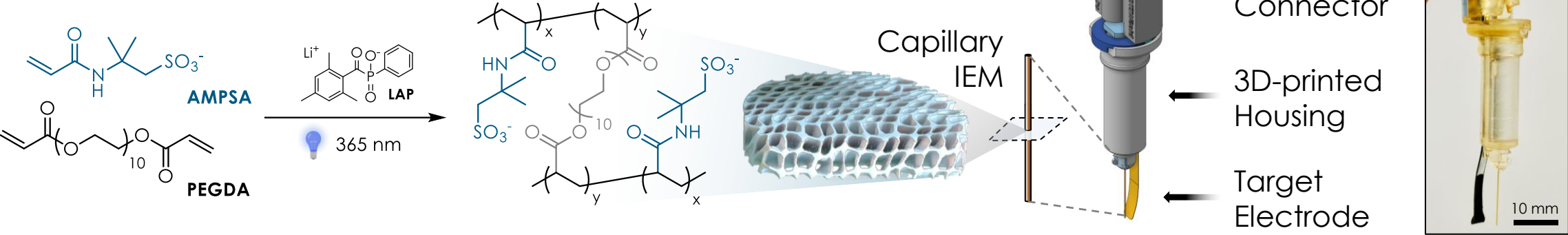
This Work



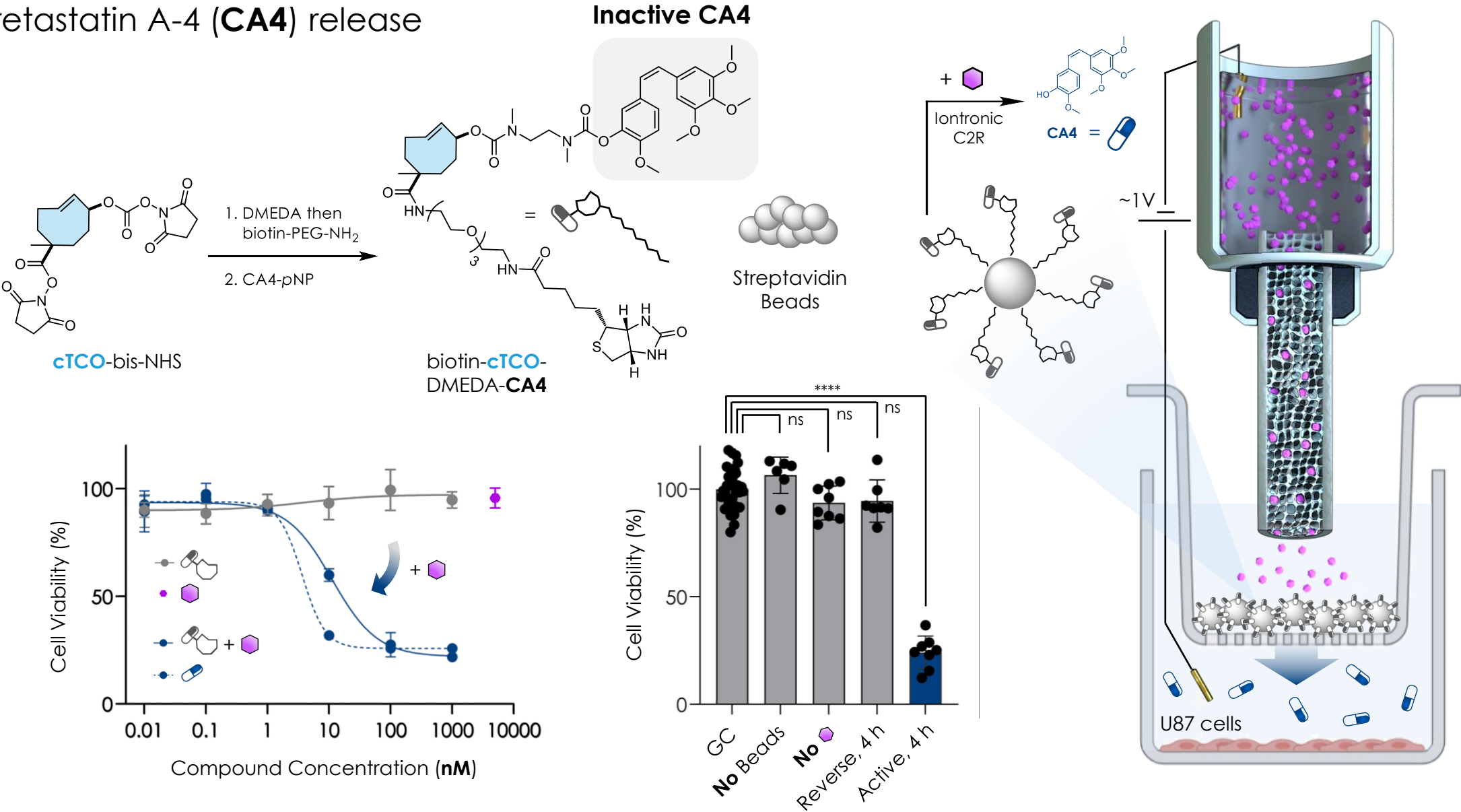
Nat Commun **2026**,17, 4629



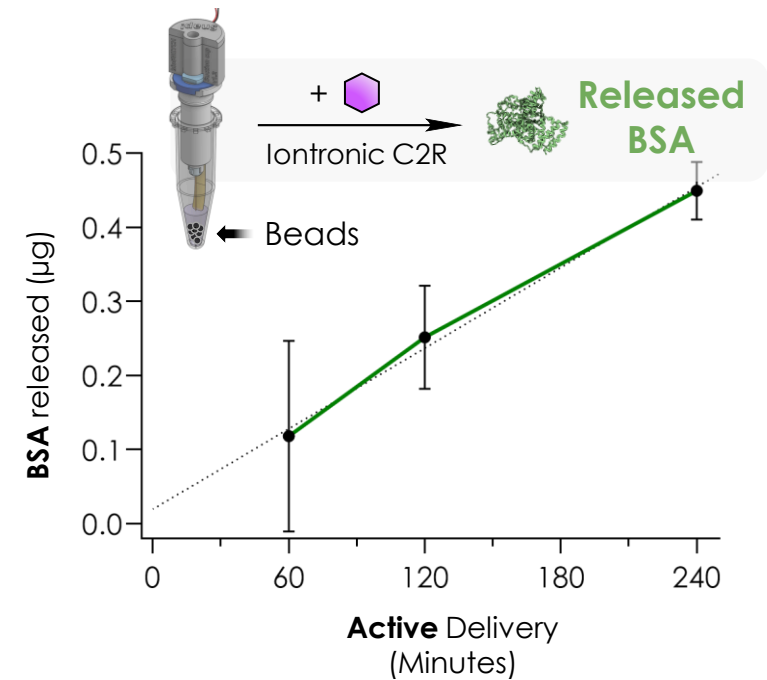
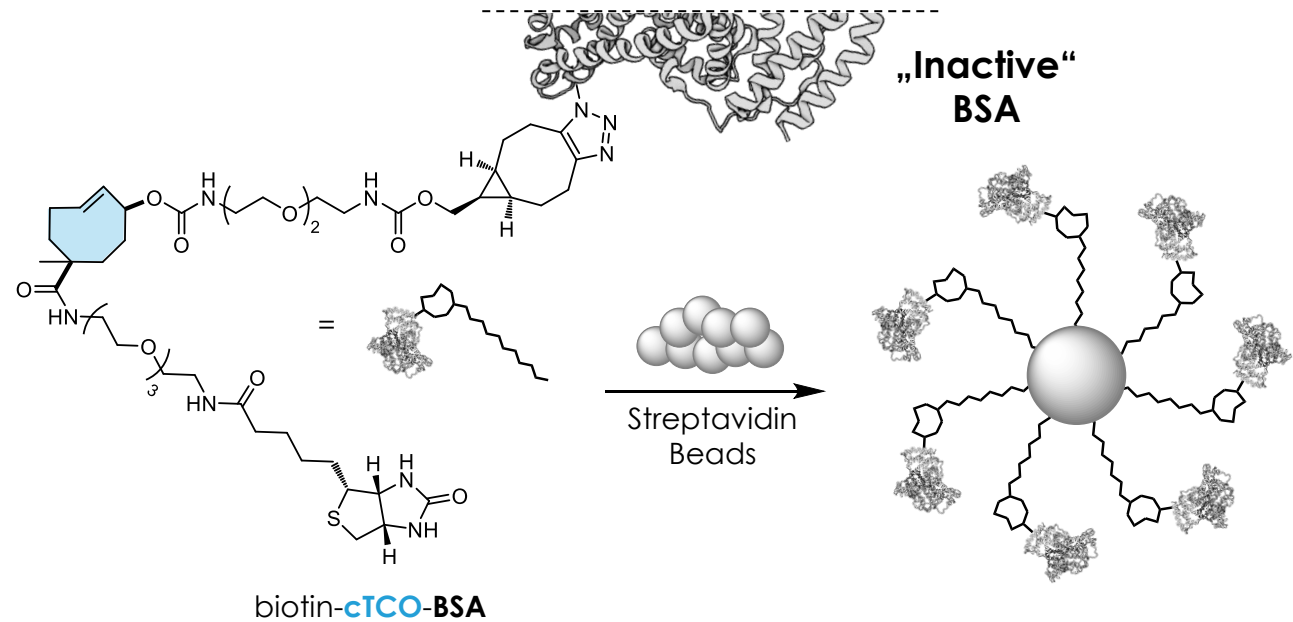
Controllable Iontronic **Tetrazine** Transport



Combretastatin A-4 (CA4) release



Bovin Serum Albumin (BSA, 66 kDa) release

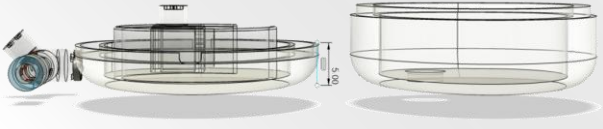


Take-away

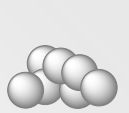
Tetrazine Delivery Decouples
Iontronic Transport Limits from **Drug Properties**

Implant

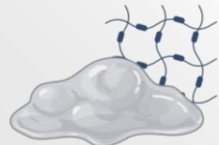
Ø = 3 cm



Depot



Beads

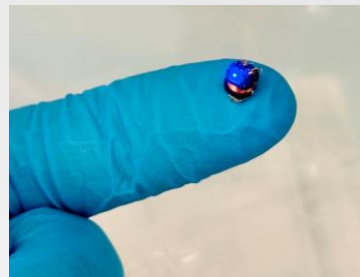


Hydrogel

In Vivo



SPOTlight



Ø = 1-2 mm

„rice-grain sized implant“



WPT



Acknowledgements



Johannes Bintinger

Hannes Mikula

Nikolaus Poremba

Andreas Löffler

Patrick Keppel

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Moa Hörberg

Rassen Boukraa

Daniel Simon

Christian Bayer

Linda Waldherr

Rainer Schindl



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Grant # 101099963

bioSWITCH

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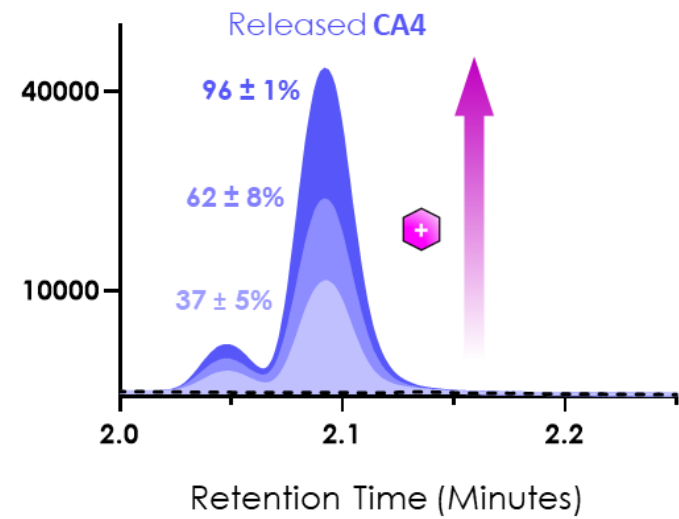
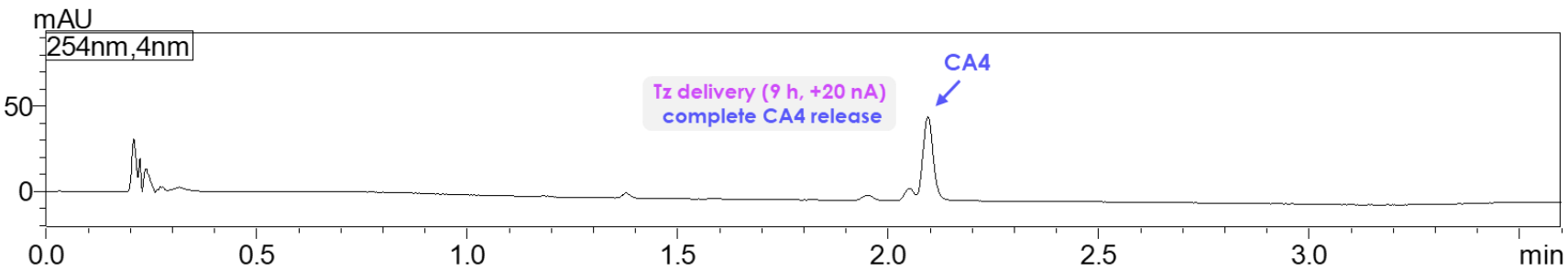
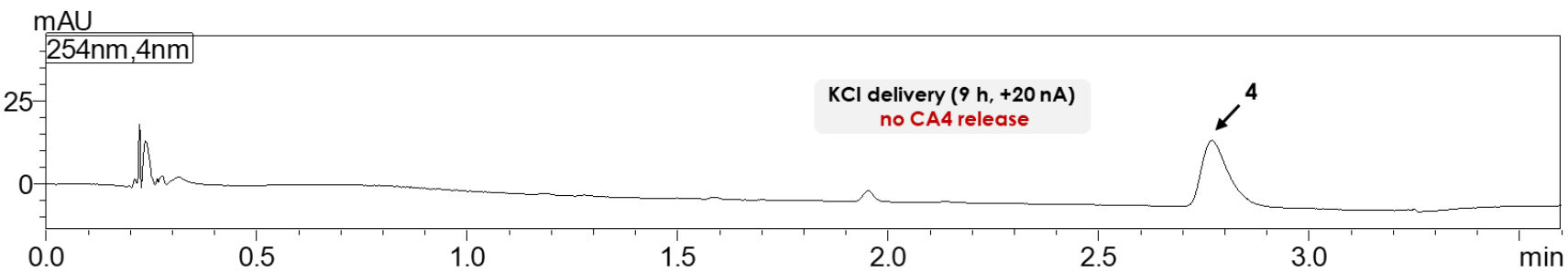
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- Tz, delivered for 9 h
- Tz, delivered for 6 h
- Tz, delivered for 3 h
- - - KCl, delivered for 9 h

