



International Conference on
Microrobotics for Real-World
Medical Applications

14 - 16 October 2026

Donostia / San Sebastian (Spain)

CONFERENCE PROGRAM BOOKLET

14-16 October 2026 | Donostia-San Sebastian

www.nanogune.eu/MIRA2026

Organized by



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Welcome to MIRA 2026

Dear colleagues,

It is our great pleasure to welcome you to the first edition of MIRA 2026 - Medical Microrobotics for Real-World Medical Applications.

Medical microrobotics is emerging as one of the most exciting frontiers in modern biomedicine. By combining advances in robotics, materials science, nanotechnology, engineering, and medicine, the field is opening new possibilities for minimally invasive interventions, targeted therapeutic delivery, enhanced diagnostics, and access to previously unreachable regions of the human body.

The ambition of MIRA 2026 is to bring together the diverse communities required to make this vision a reality. Throughout the conference, researchers, clinicians, engineers, entrepreneurs, and industry representatives will explore the scientific, technological, regulatory, and translational challenges that must be addressed to move medical microrobotics from laboratory demonstrations to clinical practice.

We would like to thank all speakers, authors, sponsors, exhibitors, and participants for contributing to this first edition. We hope you enjoy the scientific program, networking opportunities, and your stay in Donostia-San Sebastian.

Welcome to MIRA 2026.

Mariana Medina-Sánchez
Conference Chair
CIC nanoGUNE & Ikerbasque



Warm Greetings from California,

Our exciting field of microrobotics has experienced tremendous growth over the past two decades. These remarkable new capabilities have unlocked promising biomedical and environmental applications, with many more breakthroughs on the horizon. Many thanks to Mariana and her team for organizing this wonderful gathering of microrobotic experts in beautiful San Sebastián. Enjoy the stimulating discussions and excellent seafood! Cheers to our incredible global microrobotics community.

The Best is Yet to Come!!!!



Joe Wang
University of California San Diego

When I open a seminar or a lecture on my research in surgical and interventional robotics, I often begin with a simple statement: surgery and interventions must be targeted.

To navigate the human body, diagnose disease, and deliver therapy precisely where it is needed, we must develop machines at the right scale: not as small as drug molecules, and not as large as conventional surgical robots. We need miniature robotic systems: smart shuttles and implants, ranging in size from fractions of a centimeter down to microns.

Traditional surgical robotics provides us with valuable technologies for imaging, navigation, and registration. But these technologies alone are not enough. At the miniature scale, we must rethink the very foundations of robotic design: actuation, sensing, and control. This requires us to move beyond the traditional boundaries of robotics and increasingly integrate knowledge and methods from other disciplines, including physics, chemistry, and biology.

This is both a formidable challenge and an extraordinary opportunity. It calls for new ideas, new technologies, and, above all, a new way of thinking about how machines can interact with the human body. And perhaps, when we embark this journey, we will rediscover the vision expressed by Richard Feynman more than six decades ago: "There's Plenty of Room at the Bottom."



Arianna Menciassi
Scuola Superiore Sant'Anna
The BioRobotics Institute

How will microrobotics deliver meaningful clinical benefit? An oncologist's perspective

The decisive milestone for medical microrobotics will be meaningful improvement of patient care. As an oncologist, I see promise in technologies presented at MIRA 2026 that could increase efficacy, reduce toxicity, or reach difficult-to-treat disease sites. Translation should begin with a precise question: which unmet clinical need requires this technology's capabilities?

MIRA 2026 in San Sebastián connects clinicians, engineers, materials scientists, and entrepreneurs around targeted delivery, minimally invasive interventions, imaging, diagnostics, and robotic and cell-based systems. Its focus extends from laboratory studies and preclinical models to first-in-human trials and emerging spin-offs.

In oncology, convergence between nanomedicine, microrobotics, and advanced cellular therapies could address complementary barriers. Microrobots might direct payloads to defined sites, nanoscale carriers facilitate delivery into selected cells, and cell-based systems contribute biological sensing or tissue interactions. Integration with immunotherapy or gene editing may create treatment opportunities, provided each component adds measurable value.

Development must encompass the entire therapeutic pathway: patient selection, manufacturing, administration, monitoring, and complication management. Preclinical studies must establish whether these technologies improve biological specificity or safety. Persistent cellular modification and irreversible genome editing require different safeguards from transient drug delivery.

Initial indication selection will be critical. Local delivery may benefit confined disease compartments or overcome toxicity that limits systemic dosing. In disseminated malignancies, however, treating one lesion may leave substantial disease elsewhere. Developers should define populations and comparators early and demonstrate advantages of active navigation or controlled release over existing approaches. Reproducible manufacturing, meaningful potency assays, and early regulatory dialogue should accompany development. First-in-human trials require focused objectives, risk mitigation, and rescue strategies.

My optimism rests on sustained partnerships involving patients from the outset. Successful technologies alone or combined with current therapies will hopefully contribute to better care.



Martin Bornhäuser
University Hospital, TU Dresden

Venues

Aquarium Donostia-San Sebastián | Main conference venue

The scientific program on Thursday and Friday will take place at the Aquarium Donostia-San Sebastián, located at the western end of the harbor, at the foot of Mount Urgull. From the city center, follow the promenade toward the Old Town and continue along the harbor, passing the Nautical Club and the port area. The entrance to the Aquarium is situated at the far end of the harbor, below Mount Urgull. **Access to the auditorium is located halfway up the stairs at the end of the harbor (check image below).**



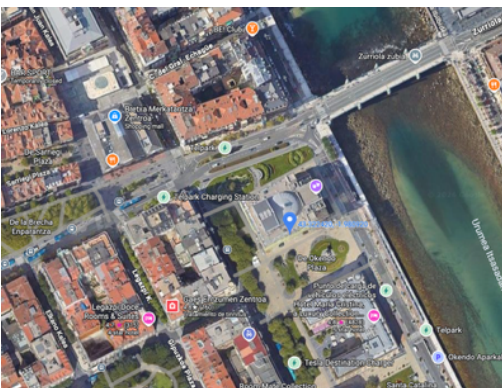
Address: Plaza de Carlos Blasco Imaz, 1. 20003 Donostia-San Sebastián, Gipuzkoa, Spain

<https://www.google.com/maps/search/?api=1&query=Aquarium+Donostia+San+Sebastian+Plaza+Carlos+Blasco+Imaz+1>]

Sala Club, Victoria Eugenia Theatre | Inaugural talk and Welcome Reception

The opening event of MIRA 2026 will take place at Sala Club, inside the Victoria Eugenia Theatre. The theater is located beside the River Urumea, opposite the María Cristina Hotel and next to the Kursaal Bridge. The venue is within walking distance of the Old Town, the Boulevard, the Kursaal Congress Center, and the main city-center bus stops.

Access to Sala Club is through a lateral entrance, at the square between the Victoria Eugenia Theatre and the Hotel María Cristina.



Address: República Argentina, 2. 20004 Donostia-San Sebastián, Gipuzkoa, Spain

https://www.google.es/maps/@43.3222577,-1.9816416,18.01z?entry=ttu&q_ep=EgoyMDI2MTAwNi4wKXMDSoASAFQAw%3D%3D

Scientific Program

The program below reflects the final scientific and networking schedule for MIRA 2026. Minor adjustments may be announced on site if required.

Wednesday 14 October

19:00 Inaugural Talk & Welcome reception

Patient testimonial with Antxon Vega Fernández, Ander Izeta and Mariana Medina-Sánchez

Bradley Nelson (ETH Zurich)
Clinically Ready Microrobots

Thursday 15 October

Translational Therapies & Medical Microrobotics

8:30 Registration

9:00 Welcome and opening remarks

9:10 Session 1 – Chair Simone Schuerle
Advanced therapies and Nanomedicines

9:15 Keynote talk

Ander Izeta (IIS Biogipuzkoa)
Advanced therapies: from basic research to a paradigm change in clinical practice

9:55 Contributed talk

Ylenia Jabalera (CIC bioGUNE)
Evolution-Inspired Technologies for Precision Medicine

10:10 Contributed talk

Marek Grzelczak (Centro de Física de Materiales)
Membrane-targeted nanoparticles for neuronal photo-modulation

10:25 Contributed talk

Upashi Goswami (Polymat)
Charge-Engineered Nanogels as Drug Delivery Platforms against Staphylococcus aureus for Bovine Mastitis Therapy

10:40 Contributed talk

Yu Cheng (Tongji University)
An intracellular magnetic micromotor drives spatiotemporal mechano-immunotherapy

10:55 Coffee break & Posters

11:20 Session 2 - Chair Hakan Ceylan
Functional Materials for Nano-Microrobotics

11:25 Keynote talk

Salvador Pané (ETH Zurich)
Biomedical Magnetic Microrobots: A Materials Perspective

12:05 Invited talk

Ambarish Ghosh (IISc, Bangalore)
From Physics to Physiology with Magnetic Micro- and Nanobots

12:30 Contributed talk

Stefano Palagi (Sant'Anna School of Advanced Studies)

From cell mimicry to functional autonomy: celloid microrobots for in situ medicine

12:45 Contributed talk

Verónica Salgueiriño (Universidade de Vigo)

Biodegradable Tunable Magnetic Remanence in Hybrid Elongated Nanostructures for Adaptive Nanorobotic Navigation

13:00 Contributed talk

Kristin Fichna (IBEC)

Active Nanomotors Improve ADC Therapy in Bladder Cancer Tumoroids

13:15 Lunch & Posters & Tech demos open

14:20 Session 3 - Chair Stefano Palagi
Medical Applications I

14:25 Keynote talk

Metin Sitti (Koç University)

Wireless medical milli/microrobots for theranostic applications

15:05 Featured talk

Hakan Ceylan (Mayo Clinic)

Preventive Endovascular Robots: A New Paradigm for Vascular Interventions

15:25 Featured talk

Giovanni Pittiglio (Worcester Polytechnic Institute)

Magnetic Robots for Cardiovascular Interventions

15:45 Coffee break & Posters

16:10 Session 4 - Chair Zhi Chen
In vivo Imaging

16:15 Invited talk

Veronica Iacovacci (Sant'Anna School of Advanced Studies)

Vision in Motion: a Perception-Action-Locomotion Framework for Medical Microrobots

16:40 Invited talk

Daniel Razansky (ETH Zurich)

In Vivo Optoacoustic Navigation of Labeled Microrobots and Cells for Image-Guided Therapy and Super-Resolution Angiography

17:05 Featured talk

Tian Qiu (DKFZ, Dresden)

Wireless Magnetic Localization of Microrobots Toward Clinical Interventions

17:25 Featured talk

Richard Nauber (TU Dresden)

Deep-Learning-Based Photoacoustic Feedback and Coded VCSEL Illumination for Translational Real-Time Microrobot Control

17:45 Poster Session

18:50 Conference Dinner: Taste of Gipuzkoa Experience (Conference Networking dinner)

Friday 16 October Medical Microrobotics & Tech Transfer

9:00 Session 5 - Chair Paul Wrede
Cell-Based Microrobotics

9:05 Keynote talk

Li Zhang (CUHK)

Biophysics-informed design of biohybrid microrobots

9:45 Invited talk

Simone Schuerle (ETH Zurich)

Engineering Synthetic and Biohybrid Medical Microrobots for Targeted Delivery and Acoustic Sensing

10:10 Contributed talk

Sylvain Martel (Ecole Polytechnique de Montreal)

Targeting tumour hypoxic zones with magneto-aerotactic bacterial microrobots

10:25 Contributed talk

Songsong Tang (University of Science and Technology of China)

Biohybrid Micro/Nanorobots for Precision Therapy

10:40 Featured talk

Rana Ajeeb (CIC nanoGUNE)

Magnetic CAR-TCell Microrobots to Enhance Cell Accumulation and Retention in Solid Tumors

11:00 Coffee break & Posters

11:25 Session 6 - Chair Friedrich Striggow
Medical Applications II

11:30 Invited talk

Wei Gao (Caltech)

Synthetic Medical Micro/Nanorobots for In Vivo Biomedical Applications

11:55 Contributed talk

Tohid Didar (McMaster University)

Medical Micro- and nano-robots for active and targeted phage delivery in respiratory infections

12:10 Contributed talk

Paul Wrede (ETH Zurich)

Biodegradable Acoustic Microrobots for Rapid Imaging-Guided Thrombotic Lesion Reperfusion

12:25 Contributed talk

Florian Fage (Movalife Microrobotics)

Bridging Microfluidics and Optical Microrobotics for Biomimetic Sperm Selection and Assisted Fertilization

12:40 Contributed talk

Hemin Pan (University of Bern)

Sonotweezers: Multiscale Reconfigurable In Vivo Manipulation in Model Organism

12:55 Lunch & Poster

14:15 Session 7 - Chair David Castellanos
Medical Applications III

14:20 Keynote talk

Daniel Ahmed (University of Bern)

Translating Ultrasound Microrobots and Microtechnologies from Preclinical Models towards Clinical Applications

14:50 Contributed talk

Zesheng Li (Harbin Institute of Technology)

Magnetically Actuated and Enzyme-Functionalized Flask-Shaped Nanorobots for Active Mucus Penetration and Ferroptosis Blockade in Ulcerative Colitis

15:05 Contributed talk

Apabrita Mallick (VSB - Technical University of Ostrava)

Magnetically Actuated Micro/Nanorobots Enabling Biofilm Eradication and Catalytic Transformations Across Space, Biomedical, and Chemical Environments

15:20 Awards / Wiley Intervention – Special Issue of the Conference

15:35 Coffee break

15:55 Session 8 - Chair Ainara García

Tech transfer

16:00 Keynote talk

Samuel Sánchez (ICREA/IBEC)

Therapeutics in Motion

16:40 **Lightning start-up pitches**

- Edison Genera (Movalife Microrobotics)
- Shanmukh Srinivas (Theranautilus)
- Javier Plou (Prospect Biotech)
- Cornel Dillinger (SonoStent)
- Endika de la Iglesia (Gaiker Technology)
- Mato Knez (Novanano)
- Valentin Gantenbein (Swiss Vascular)

17:15 **Matchmaking, brainstorming & roadmapping (Break-up groups on selected topics)**

Discussion topics:

Group 1: From Lab to Patient: Clinical Translation of Medical Microrobots

What is needed to bring medical microrobots into first-in-human studies?

Group 2: Manufacturing, Scalability and Quality Assurance

How can we manufacture microrobotic technologies at clinically and commercially relevant scales?

Group 3: Regulatory Pathways and Market Access

How do we navigate regulation, reimbursement, and adoption?

Group 4: Synergies Between Medical Microrobotics and Advanced Therapies

How can microrobotics accelerate the clinical impact of cell, gene, and regenerative therapies?

Group 5: Innovation, Technology Transfer and Venture Creation

How do we transform promising research into successful clinical and commercial ventures?

18:15 Closing remarks

Social Program

Welcome Reception & Inaugural Talk

Wednesday, 14 October | 19:00

Sala Club, Victoria Eugenia Theatre



Join us for the opening event of MIRA 2026 at the Sala Club of the Victoria Eugenia Theatre, one of Donostia-San Sebastian's most prominent cultural venues. The evening will begin with the **inaugural lecture by Bradley Nelson (ETH Zürich), "Clinically Ready Microrobots"**, followed by an informal reception and an opportunity to meet fellow participants.

Conference Dinner: Taste of Gipuzkoa Experience

Thursday, 15 October | Bus departure from the Aquarium at 18:50

Sidreria Iparraguirre



The conference dinner will offer participants an opportunity to experience local gastronomy in a traditional Basque cider house while continuing scientific conversations in an informal setting.

Transportation is provided from the Aquarium and back to the city.

The return trip will stop at two different locations. Please choose the one you prefer to go back to your accommodation.

1. San Sebastian Martir Church. Plaza de Alfonso XIII. <https://maps.app.goo.gl/xSXTkmu6js27rB3T7>
2. Victoria Eugenia Theater. Calle República Argentina, 2. <https://maps.app.goo.gl/azKvBenP4jtepNwH8>

Organization and Committees

MIRA 2026 is organised by CIC nanoGUNE. The conference is supported by an international group of researchers and professionals contributing to its scientific direction, academic evaluation, and organisation.

Conference Chair

Mariana Medina Sánchez

CIC nanoGUNE and Ikerbasque

Scientific Committee

- **Arianna Menciassi** · Sant'Anna School of Advanced Studies
- **Martin Bornhäuser** · Carl Gustav Carus University Hospital
- **Bradley Nelson** · ETH Zürich
- **Samuel Sánchez** · IBEC
- **Joe Wang** · UCSD

Academic Committee

- **Daniel Ahmed** · University of Bern
- **Bahareh Behkam** · Virginia Tech
- **Hakan Ceylan** · Mayo Clinic
- **Ambarish Ghosh** · Indian Institute of Science
- **Maria Guix** · University of Barcelona
- **Veronica Iacovacci** · Sant'Anna School of Advanced Studies
- **Veronika Magdanz** · University of Waterloo
- **Salvador Pané** · ETH Zürich
- **Tian Qiu** · German Cancer Research Center, DKFZ
- **Friedrich Striggow** · CIC nanoGUNE

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- **Mariana Medina Sánchez** · CIC nanoGUNE
- **Itziar Otegui** · CIC nanoGUNE
- **Dane Ruscuklu** · CIC nanoGUNE
- **Friedrich Striggow** · CIC nanoGUNE

Sponsors and Institutional Support

MIRA 2026 gratefully acknowledges the organizations supporting the first edition of the conference.

Main Sponsors



Sponsors



Institutional Support



Participant Information

Respectful Participation

Mira 2026 is committed to providing a professional, inclusive, and respectful environment for all participants.

We expect all attendees and organizers to treat one another with courtesy and respect, fostering constructive scientific discussion and collaboration throughout the conference.

Harassment, discrimination, intimidation, or any form of inappropriate behaviour will not be tolerated.

If you experience or witness conduct that may compromise the conference environment, please contact the organizing committee at mira@nanogune.eu or in person.

Mobility

Donostia-San Sebastián city center is compact and pedestrian-friendly. **Walking** is probably the simplest way to travel between hotels and the two conference venues.



Thanks to San Sebastian Tourism, we can offer **free city bus transport** to all the researchers taking part on MIRA 2026. The company Dbus makes it easy for people living or visiting the city to move quickly through it in a less polluting way for the environment. You can find all the lines and tours around the city at the Dbus website and in the Donostia Transport App.

A Few Words in Euskera

English	Euskera	Spanish
Hello	Kaixo	Hola
Good morning	Egun on	Buenos días
Good afternoon	Arratsalde on	Buenas tardes
Thank you	Eskerrik asko	Gracias
You're welcome	Ez horregatik	De nada
Please	Mesedez	Por favor
Yes	Bai	Sí
No	Ez	No
Goodbye	Agur	Adios
Cheers!	Topa!	¡Salud!

More practical information is provided on the conference website:

<https://www.nanogune.eu/en/nanogune/newsroom/events/mira-2026/welcome-donostia-san-sebastian>

Testimony of a patient

Arratsaldeon, buenas tardes, good afternoon

Ante todo, quiero darles la bienvenida a esta hermosa ciudad que es Donostia San Sebastián, y espero y deseo que su estancia sea muy agradable y se lleven un buen recuerdo cuando vuelvan a sus casas.

Mi nombre es Antxon Vega Fernández, tengo 79 años, y he padecido un linfoma de no Hodgkin durante 13 años aproximadamente. Voy a intentar explicarles mi experiencia personal, espero no aburrirles demasiado.

Mis conocimientos de medicina, son totalmente nulos, pues no me gusta enredar en internet, creo que puede crear más confusiones que conocimientos, y por supuesto que mi confianza con los profesionales que me atienden es total y absoluta.

En noviembre del año 2010, falleció mi esposa a consecuencia de un mieloma múltiple. Pasó por un tratamiento de quimioterapia y le hicieron un autotransplante de médula, que aunque en principio supuso una notable mejoría, al poco tiempo tuvo una recaída de la cual desgraciadamente y a pesar de los cuidados recibidos, no pudo recuperarse.

Por esas fechas, también me llegó la hora de la jubilación de mi trabajo por lo que tuve que replantearme seriamente mi vida.

El año 2011, me matriculé en la Universidad del País Vasco para hacer una licenciatura en Ciencias Humanas para personas mayores. Una de las clases las impartía un médico y versaban sobre diversas enfermedades, una de ellas era sobre el linfoma. Por aquel entonces padecía unos síntomas como fatiga, sudoración nocturna, pérdida de peso, hinchazón de los ganglios, que casualmente coincidían con los descritos en el libro.

Acudí al médico de atención primaria que me derivó al hospital, donde estuve ingresado unos días haciéndome una serie de pruebas, con las que me diagnosticaron un linfoma de no Hodgkin, ya en un estado bastante avanzado.

Cuando te dan la noticia que tienes un cáncer que además te dicen que es crónico e incurable, sufres un impacto emocional muy fuerte que tienes que asumirlo e intentar superarlo. Creo que soy una persona bastante positiva, e intento ver el lado bueno de las cosas

El año 2012, empecé con unos tratamientos de quimioterapia, tengo el recuerdo de uno de los medicamentos que me suministraban vía venosa, el "Rituximab", que me causaba unas reacciones bastante fuertes y un malestar general, que duraba unos días.

Tras varios años de tratamiento con quimioterapia y radioterapia, con mejorías, y sucesivas recaídas, me propusieron el cambio a un nuevo equipo médico en Onkologikoa especializado en linfomas. Junto con el tratamiento, también

Arratsaldeon, buenas tardes, good afternoon

First of all, I'd like to welcome you to this beautiful city, Donostia-San Sebastián, and I hope your stay here is very pleasant and that you'll take home fond memories when you return to your homes.

My name is Antxon Vega Fernández; I'm 79 years old, and I've been living with non-Hodgkin's lymphoma for about 13 years. I'm going to try to explain my personal experience; I hope I don't bore you too much.

I have absolutely no medical knowledge, as I don't like to get lost in the internet—I think it can create more confusion than knowledge—and, of course, I have complete and absolute trust in the professionals who care for me.

In November 2010, my wife passed away as a result of multiple myeloma. She underwent chemotherapy and received an autologous bone marrow transplant, which, although it initially led to a significant improvement, was followed shortly thereafter by a relapse from which, unfortunately and despite the care she received, she was unable to recover.

Around that time, I also reached retirement age from my job, so I had to seriously rethink my life.

In 2011, I enrolled at the University of the Basque Country to pursue a bachelor's degree in Human Sciences for Older Adults. One of the classes was taught by a doctor and covered various diseases, one of which was lymphoma. At that time, I was experiencing symptoms such as fatigue, night sweats, weight loss, and swollen lymph nodes—which, coincidentally, matched those described in the book.

I went to see my primary care physician, who referred me to the hospital, where I was admitted for a few days to undergo a series of tests. As a result, I was diagnosed with non-Hodgkin's lymphoma, which was already at a fairly advanced stage.

When you're told you have cancer—and that it's chronic and incurable—you experience a very strong emotional shock that you have to come to terms with and try to overcome. I think I'm a pretty positive person, and I try to look on the bright side of things

In 2012, I began chemotherapy treatments. I remember one of the medications they administered intravenously, "Rituximab," which caused me quite severe reactions and general discomfort that lasted a few days.

After several years of chemotherapy and radiation therapy—with periods of improvement followed by relapses—I was offered the opportunity to switch to a new medical team at Onkologikoa that specialized in lymphomas. Along with the treatment, I was also offered

me ofrecieron la posibilidad de participar en un ensayo clínico aleatorio que estaban desarrollando por entonces en colaboración con Bio Gipuzkoa, que combinaba el ejercicio físico durante el tratamiento farmacológico. Fué una experiencia muy positiva que marcó claramente un antes y un después en la evolución tanto física como psíquica de mi enfermedad.

Con posterioridad, la hematóloga que me atiende la Dra. Zeberio, me comentó sobre la posibilidad de acceder a un proyecto pionero para desarrollar nuevas terapias CAR-T de tratamiento contra el cáncer que estaba dando muy buenos resultados. Por supuesto que me pareció una propuesta excelente, y no dudé un instante en empezar con unas pruebas de idoneidad para ver si podía ser receptor de este innovador tratamiento.

Después de haber pasado por consulta de varios especialistas, me explicaron básicamente, en que este tratamiento consistía en la administración de mis propias células modificadas genéticamente para reconocer y destruir las células cancerosas. Debo reconocer, que si no fuese porque la persona que me lo explicó era una gran profesional de mi total confianza, hubiese pensado que se trataba de un truco de magia.

Me programaron una sesión de aféresis, donde me extrajeron los linfocitos que posteriormente enviaron a un laboratorio a Países Bajos para tratarlos genéticamente, mientras tanto recibí varias sesiones preparatorias de quimioterapia.

Cabía la posibilidad que para recibir este tratamiento tuviera que desplazarme al Clinic de Barcelona donde ya lo tenían implantado desde hacía algún tiempo, no fue necesario.

El protocolo indicaba que el ingreso, tenía que ser con un acompañante que compartiría conmigo el aislamiento durante el tratamiento. A mediados del mes de marzo de 2025 ingresamos mi hijo Asier y yo en la planta de hematología del Hospital Donostia. Una experiencia, que aunque dura, fué muy positiva tanto desde el punto de vista médico como humano, por la extraordinaria atención que recibimos los dos por parte de todo el personal durante el tiempo que duró el ingreso.

Al recibir el alta médica, estaba en una situación precaria con una gran debilidad, hasta el extremo de necesitar los primeros días un andador para poder desplazarme, por lo que tuve que ir a vivir con mis hijos durante algo más de un mes, ya que actualmente vivo solo. Después de ese periodo de tiempo pude volver a mi domicilio, para ir recuperándome poco a poco.

Posteriormente, tras varias analíticas y algunos PET, en una de las habituales consultas periódicas, la Dra. Zeberio emocionada, me dió un abrazo y me comunicó que estaba curado del linfoma. Creo que para el equipo médico también es muy importante este momento, pues después del esfuerzo llegar a un final feliz.

Mi reacción en ese momento creo que fué muy fría ya que me costaba creerlo que después de tantos años eso fuera cierto, ya

the chance to participate in a randomized clinical trial they were conducting at the time in collaboration with Bio Gipuzkoa, which combined physical exercise with drug therapy. It was a very positive experience that clearly marked a turning point in both the physical and psychological progression of my illness.

Later, my hematologist, Dr. Zeberio, told me about the possibility of participating in a pioneering project to develop new CAR-T therapies for cancer treatment that was yielding very good results. Of course, I thought it was an excellent proposal, and I didn't hesitate for a moment to begin the eligibility tests to see if I could be a candidate for this innovative treatment.

After consulting with several specialists, they explained to me, in simple terms, that this treatment involved administering my own cells, which had been genetically modified to recognize and destroy cancer cells. I must admit that if the person who explained it to me hadn't been a highly skilled professional whom I trusted completely, I would have thought it was some kind of magic trick.

I was scheduled for an apheresis session, during which my lymphocytes were extracted and subsequently sent to a laboratory in the Netherlands for genetic treatment; in the meantime, I underwent several preparatory chemotherapy sessions.

There was a possibility that, in order to receive this treatment, I would have to travel to the Clinic in Barcelona, where they had been offering it for some time, but that wasn't necessary.

The protocol stipulated that I had to be admitted with a companion who would share the isolation room with me during treatment. In mid-March 2025, my son Asier and I were admitted to the hematology ward at Donostia Hospital. Although it was a difficult experience, it was very positive from both a medical and a human perspective, thanks to the extraordinary care both of us received from the entire staff throughout our stay.

Upon being discharged, I was in a precarious condition and extremely weak—so much so that I needed a walker to get around for the first few days. As a result, I had to move in with my children for a little over a month, since I currently live alone. After that period, I was able to return home to recover little by little.

Later, after several lab tests and a few PET scans, during one of my regular checkups, Dr. Zeberio—visibly moved—gave me a hug and told me I was cured of lymphoma. I think this moment is also very important for the medical team, since it's a happy ending after all their hard work.

I think my reaction at that moment was rather reserved, since I had a hard time believing that, after so many years, it could actually be true—I had already gotten used to living

me había acostumbrado a vivir con la enfermedad casi casi ya éramos “amigos”. No creo para nada en los juegos de azar, pero sinceramente en este caso pienso que he sido un afortunado que me tocó la lotería.

No tengo palabras para expresar mi agradecimiento a todos los profesionales que me han atendido a lo largo de mi enfermedad la atención ha sido exquisita, tanto a nivel médico como humano. Les daba continuamente la gracias, y me decían que ese era su trabajo. Efectivamente, yo les decía que entendía que era su trabajo, pero que el trabajo se puede hacer bien o mal y ellos lo hacían muy bien, además transmitían una empatía y un cariño que para el paciente es de una importancia vital, para sortear los malos momentos, que por supuesto los hay.

En este país tenemos un excelente servicio público de salud. Este tratamiento que he recibido, tiene un coste de más de 300.000 €, una cantidad inasumible para mi economía, por lo que estaré todo lo que me resta de vida en deuda con la Sanidad pública.

También quiero aprovechar la ocasión, para expresar mi agradecimiento a todas las personas que como ustedes dedican su vida a la investigación, personas anónimas en un mundo de ídolos; que con su esfuerzo investigando nuevas terapias nos ayudan a vivir mejor.

Eskerrik asko, Muchas gracias, Thank you



Antxon Vega

with the disease; we were practically “friends” by then. I don’t believe in games of chance at all, but honestly, in this case, I think I was lucky enough to win the lottery.

I have no words to express my gratitude to all the professionals who have cared for me throughout my illness; the care has been exceptional, both medically and personally. I kept thanking them, and they told me that was just their job. Indeed, I would tell them that I understood it was their job, but that a job can be done well or poorly—and they did it very well. Moreover, they showed empathy and kindness that are vitally important to the patient in getting through the tough times—which, of course, there are.

In this country, we have an excellent public health care system. The treatment I have received costs more than 300,000 €, an amount I cannot afford, so I will be in debt to the public health care system for the rest of my life.

I’d also like to take this opportunity to express my gratitude to all the people who, like you, dedicate their lives to research—anonymous individuals in a world of idols—who, through their efforts to discover new therapies, help us live better lives.

Eskerrik asko, Muchas gracias, Thank you

Abstracts

Keynote talks



BRADLEY NELSON

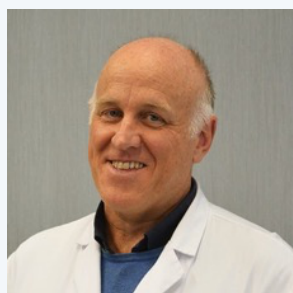
ETH Zürich, Switzerland

Bradley Nelson has been Professor of Robotics and Intelligent Systems at ETH Zürich since 2002, where he leads pioneering research in microrobotics and nanorobotics, pushing robotics toward minimally invasive medical diagnostics and therapy. His path to robotics spans mechanical engineering studies at the University of Illinois and the University of Minnesota, early industry experience in computer vision at Honeywell and software engineering at Motorola, and service teaching mathematics in Botswana before earning a Ph.D. in Robotics from Carnegie Mellon University.

Prof. Nelson's work at the intersection of robotics, nanotechnology, and biomedicine has been recognized with numerous honors, including the Grand Hamdan International Award for AI in Healthcare and selection to the Scientific American 50, celebrating leadership in science and technology. He is a member of the Swiss Academy of Engineering Sciences (SATW) and a Foreign Member of the Chinese Academy of Sciences (CAS). Beyond the lab, he has shaped research and education through major leadership roles at ETH, serving twice as Department Head of Mechanical and Process Engineering, as Chairman of the ETH Electron Microscopy Center, and as a member of the Research Council of the Swiss National Science Foundation.

Clinically Ready Microrobots

In this talk, I will present recent progress toward a clinically ready, human-scale microrobot platform, spanning microrobot fabrication, magnetic field generation and control, and closed-loop navigation strategies. I will also highlight emerging applications enabled by this platform, including concepts for telestroke medicine, where rapid, remote intervention could expand access to time-critical care. Together, these advances bring the long-standing "Fantastic Voyage" vision closer to practical medical reality.



ANDER IZETA

BioGipuzkoa Health Research Institute, Spain

Dr. Ander Izeta is a cell biologist and tissue engineer. He has been the Principal Investigator of a consolidated Group at the BioGipuzkoa Health Research Institute since 2010 and Head of the Advanced Therapies and Personalized Medicine Area since 2024. In addition, he is the section Head of the Advanced Therapies Unit at OSI Donostialdea, where he coordinates the technical aspects of the application of CAR-T cell therapies in Osakidetza, the Basque Health Service. He is a recognized expert in stem cells, regenerative medicine and tissue engineering, with >20 years of experience applied primarily to skin and muscle.

Advanced therapies: from basic research to a paradigm change in clinical practice

Text Advanced therapies constitute a novel class of medicinal products, based on the use of cells, genes and engineered tissues. After many decades of failed attempts for clinical translation of basic research, in the last few years we have witnessed an explosion of novel medicines, mainly CAR-T cells that are revolutionizing treatment of hematological cancers and gene therapies for rare diseases. In fact, advanced therapies are among the most

successful innovative therapies available in terms of quality-adjusted life years (QALY) gained for patients suffering incurable disease. Clinical development of these therapies onto autoimmune diseases and solid tumor treatments are well advanced, and the combination of new generation drugs and improved clinical handling has improved their safety profile by diminishing side effects of medications. However, access to advanced therapies is still limited worldwide. This is due to the relatively high cost of potentially curative treatments that have to be dealt with in one-off payments, and to the need of health economic assessments to adapt to the evidence provided in the approvals of this novel class of drugs. In this talk, I will review the highs and lows of advanced therapy development, the incredible advances that we have witnessed as well as the main challenges ahead for the field.



SAMUEL SÁNCHEZ ORDÓÑEZ

ICREA / IBEC, Spain

Prof. Samuel Sánchez Ordóñez is an ICREA Research Professor and Group Leader at Institute for Bioengineering of Catalonia (IBEC), where he also serves as Deputy Director for Internationalization. Samuel has developed an international research career across Japan and Germany, including at Max Planck Institute for Intelligent Systems. He leads the Smart Nano-Bio-Devices group, pioneering self-powered nanorobots, nanomedicine, and biohybrid robotics. His team achieved the first in vivo imaging of nanobots and recently demonstrated their therapeutic potential against bladder cancer in a landmark study published in *Nature Nanotechnology*. He has authored more than 200 scientific publications, with an h-index of 84 and over 23,000 citations, and is inventor on 9 patents. Samuel is founder and CSO of Nanobots Therapeutics, which is developing the MotionTx platform for next-generation cancer treatments. He has received numerous distinctions, including the MIT TR35 Innovator of the Year (2014), the Princess of Girona Award (2015), the National Research Award for Young Talent (2016), the RSEQ Scientific Excellence Award (2022), the Constantes y Vitales Award for Young Talent in Biomedicine (2023), and the Jaume I Award in New Technologies (2026). His work published in *Nature Nanotechnology* was selected among the top three research achievements in Spain by *La Vanguardia* and was featured in *National Geographic* in October 2024.

Therapeutics in Motion

Engineering medical nanomotors/nanobots will imply the use of biocompatible materials and bio-friendly propulsion mechanisms. Our strategy comprises the use of biocatalysts such enzymes for converting biologically available fuels into a propulsive force. Moreover, nanoparticles' chassis are generally recognized as safe (GRAS) material, FDA or EMA approved materials. In my talk, I will present how we bioengineer hybrid nanobots combining the best from the two worlds: biology (enzymes) and (nano)technology (nano- micro-particles) providing swimming capabilities, biocompatibility, imaging, multifunctionality and actuation in vitro and in vivo. I will present some of the proof-of-concept applications of biocompatible nanobots such as the efficient transport of drugs into cancer cells and 3D spheroids (1), the imaging of swarms of nanobots in vivo in confined spaces like the bladder of living mice (2). Moreover, I will present our recent advances in the treatment of bladder cancer in mice using radionuclide-labelled nanobots (3) and STING agonist (4). Nanobots are actively crossing mucus layers present in the colon of mice (5), synovial fluids of joints (6), the vitreous or the skin.



METIN SITTI

Koç University, Turkey

Prof. Dr. Metin Sitti is the President and Professor of Koç University in Istanbul, Turkey since fall 2023. Formerly, he was a Director of the Physical Intelligence Department at Max Planck Institute for Intelligent Systems, Germany (2014-2023), Professor at ETH Zürich, Switzerland (2020-2024), Professor at Carnegie Mellon University, USA (2002-2014), and Research Scientist at UC Berkeley, USA (1999-2002). He received his BSc (1992) and MSc (1994) degrees from Boğaziçi University, Turkey, and PhD degree from University of Tokyo, Japan (1999). His research interests include wireless medical devices, small-scale mobile robots, bioinspiration, and physical intelligence. He is a member of National Academy of Engineering in USA, Academy Europea, CORE Academy, and Max Planck Society (2014-2023). He received the Highly Cited Researcher recognition (since 2021), Frontiers of Science Award (2025), Materials Science Leader Award (since 2023), Breakthrough of the Year Award in the Falling Walls World Science Summit (2020), ERC Advanced Grant (2019), Rahmi Koç Science Medal (2018), SPIE Nanoengineering Pioneer Award (2011), and NSF CAREER Award (2005). He has supervised and mentored over 70 (18 current) PhD students and 80 (10 current) postdocs, where over 65 of his group alumni are professors around the world. He has published 2 books and over 440 journal articles and has over 30 issued patents. He is the editor-in-chief of Journal of Micro-Bio Robotics and associate editor in Science Advances journal.

Wireless medical milli/microrobots for theranostic applications

Wireless small-scale medical robots have the unique capability of navigating, operating and staying inside hard-to-reach, tight, risky and deep sites inside our body. This talk reports theranostic applications of our novel milli- and microscale wireless miniature medical devices and robots down to cell size that could achieve various minimally invasive medical functions, such as targeted active drug delivery, neural stimulation, clot opening, liquid biopsy, biofluid pumping, cauterization, and hyperthermia. Due to miniaturization limitations on on-board actuation, powering, sensing, computing and communication, new materials and methods need to be introduced in creating and controlling such robots. Moreover, they need to be tracked under medical imaging modalities, such as ultrasound, fluoroscopy, photoacoustic imaging, PET, and MRI, for their precise and safe operation. 3D microprinting and assembly-based fabrication methods and biocompatible and multifunctional soft composites with embedded micro/nanomaterials are proposed to create novel medical milli/microrobots. Soft-bodied medical miniature robot designs enable active shape programming-based adaptive, multimodal and multifunctional navigation and functions, and safe operation. External physical forces, such as magnetic fields, acoustic waves and light, and physical or chemical (e.g., catalytic) interactions with the operation medium are used to actuate and steer such miniature robots wirelessly as a single robot or robot collectives. These robots are aimed to save lives of more patients by curing diseases not possible or hard to cure and decrease the side effects and invasiveness of disease treatments drastically.



LI ZHANG

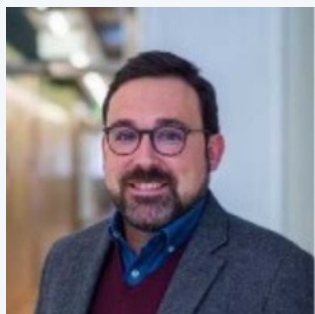
The Chinese Koç University, Hong Kong

Li Zhang is a Professor in the Department of Mechanical and Automation Engineering (MAE) and a Professor by Courtesy in the Department of Surgery at The Chinese University of Hong Kong (CUHK). Dr. Zhang's primary research interests include small-scale robotics and their applications for translational biomedicine. He has authored or co-authored over 400 publications (H-index: 96), including Science Robotics, Nature Machine Intelligence, Nature Reviews Bioengineering, Nature Materials, Nature Biomedical Engineering, Nature Synthesis as the corresponding author. His research work on artificial bacterial flagella was indexed by the Guinness Book of World Records 2012 for the "Most Advanced Mini Robot for Medical Use." And his research works on magnetic slime robot and

microrobotic swarm for endovascular application was selected as “Top 10 Innovation and Technology News in Hong Kong” in 2022, 2023 and 2024. Dr. Zhang is elected as Fellow of ASME, IEEE, RSC, AAIA, HKIE, and is recognized as a distinguished young scholar of China-America Frontiers of Engineering in CAFOE 2026. He serves as Senior Editor for IEEE T-ASE and IEEE T-RO, and as Associate Editor for Science Advances (AAAS).

Biophysics-informed design of biohybrid microrobots

Biohybrid microrobots integrate biological components with synthetic structures to navigate complex biological environments, for example, for the delivery of drugs, microsurgery and in vivo diagnostics. In this talk, I will present a biophysics-informed design framework for biohybrid microrobots by connecting biophysical principles with biohybrid solutions. We first identify the biophysical constraints imposed by the human body that limit microrobot integrity, locomotion, navigation and functionality. We then examine the biophysical mechanisms through which biological cells, microorganisms and their derivatives adapt to these challenges, and explore how these can be utilized to improve the performance of microrobots. Building on these insights, we describe how biohybrid microrobots translate biophysical strategies into engineering solutions across four design domains: deformation, actuation, navigation and programming. Finally, we discuss persisting in vivo challenges, key considerations for clinical translation and future developments.



SALVADOR PANÉ

ETH Zürich, Switzerland

Salvador Pané i Vidal is Professor of Materials for Robotics at the Institute of Robotics and Intelligent Systems and Co-Director of the Multi-Scale Robotics Lab at ETH Zürich. His research bridges materials science, chemistry, electrochemistry, and small-scale robotics, with a particular focus on magnetic materials, conductive polymers, hydrogels, and their use in micro- and nanorobotic systems for biomedical applications. He has coordinated major European research projects and received several European Research Council grants. He is also co-founder of Magnes AG and Oxyle AG.

Magnetic Biomedical Microrobots: A Materials Perspective

Untethered magnetic micro- and nanorobots are tiny machines that can be propelled and steered by externally applied magnetic fields. One of the ultimate goals of small-scale robotics is to develop devices capable of delivering drugs or performing other medical tasks within the confined spaces of the human body¹. Other envisioned applications include environmental remediation and “on-the-fly” chemistry². Recent progress in this field has been closely linked to advances in materials science and manufacturing, which have enabled increasingly sophisticated robotic architectures and functionalities. However, despite many impressive demonstrations, challenges related to locomotion, multifunctionality, biocompatibility, biodegradability, and clinical translation remain. Addressing these challenges requires not only the development of new functional materials but also innovative strategies for their processing and integration into robotic systems.

In this talk, I will present several of our recent advances in magnetic microrobotics, highlighting the central role of materials in enabling new functionalities and biomedical applications. First, I will discuss how advances in materials processing and microfabrication enable the development of magnetic microrobots based on rigid, soft, and hybrid material systems. In particular, I will present our recently developed magnetic microrobot platform for targeted drug delivery³, which integrates a clinical electromagnetic navigation system, catheter-based deployment, and biodegradable gelatin capsules to enable precise, image-guided navigation and controlled therapeutic release. The capabilities of this platform have been demonstrated under physiological conditions in anatomically realistic vascular models and large-animal studies. I will then turn to multiferroic microrobots based on magnetoelectric composite

materials, which combine magnetic responsiveness with the ability to generate local electric fields under externally applied magnetic fields⁴. These systems offer opportunities for wireless electrostimulation, extending the functionalities of magnetic microrobots beyond navigation and drug delivery. In particular, I will present our recent work on biohybrid magnetoelectric microrobots that integrate neural progenitor cells with magnetoelectric materials to promote neuronal differentiation and spinal cord regeneration⁵. Together, these examples illustrate how advances in the design, processing, and integration of functional materials are expanding the capabilities of magnetic microrobots and bringing them closer to biomedical applications.

1. B. J. Nelson and S. Pané, et al., *Science*, 2023, vol. 382 (6675), 1120.
2. H. Zhou et al., *Chemical Reviews*, 2021, vol. 121, 4999.
3. F. C. Landers et al., *Science*, 2025, vol. 390, 710–715.
4. M. Dong et al., *Advanced Functional Materials*, 2020, vol. 30, 1910323.
5. H. Ye et al., *Nature Materials*, 2026, vol. 25, 1458–1469.

Invited talks



AMBARISH GHOSH

Indian Institute of Science, India

Ambarish Ghosh studied Physics at the Indian Institute of Technology, Kharagpur, completed his PhD in Physics at Brown University, USA, and was a postdoctoral fellow at Harvard University, USA. Currently, he is a professor at the Indian Institute of Science, Bangalore, and is also a co-founder of a medical device startup, Theranautilus. His research spans quantum fluids, plasmonics, driven colloidal systems, and their applications in biotechnology. He received the Oral Innovations Award from International Association from Dental Research in 2026.

From Physics to Physiology with Magnetic Micro- and Nanobots

With current advances in nanotechnology, there have been several strategies to realize the dream of a "nano-voyager," that can carry out therapeutic and diagnostic tasks in living beings. We will talk about our approach toward this problem using magnetic manipulation. I will share examples where this system can impact diverse applications in biology and medicine, and the journey toward commercialization and human trials.



VERONICA IACOVACCI

Sant'Anna School of Advanced Studies, Italy

Veronica Iacovacci obtained the M.Sc. Degree in Biomedical Engineering at University of Pisa in 2013 (full marks, cum laude) with a thesis entitled "Design and development of a mechatronic implantable system for the refilling of artificial organs". In October 2013 she joined the Surgical Robotics and Allied technologies Area at Scuola Superiore di Studi Universitari e Perfezionamento Sant'Anna (SSSA) as a PhD student and she obtained the Ph.D. in Biorobotics (full marks, cum laude) with a thesis on smart magnetic microsystems for targeted therapy. Both theses were awarded as best thesis by the Italian national Bioengineering group. From October 2018 to March 2019 she was Post-doctoral Fellow at the Multi-Scale Robotics Lab at ETH Zurich and from April 2019 to September 2020 at the BioRobotics Institute of Scuola Superiore Sant'Anna. From September 2023 to August 2023 Veronica was Marie Curie Skłodowska Global Fellow jointly at Scuola Superiore Sant'Anna (Pisa - Italy) and at the Chinese University of Hong Kong (Hong Kong - SAR) with the project (MAMBO - Magnetic swarm for liver chemoembolization). Dr. Iacovacci was recently awarded with an ERC Starting grants to develop the first generation of implantable microrobots. She is currently Associate Professor in Biomedical Robotics. Her research interests include medical microrobots and fully implantable devices with a focus on programmable magnetic structures, high resolution imaging and tracking and wireless activation at small scales. She serves as Associate editor for the IEEE Transactions on Medical Robotics and Bionics and for the main conferences dealing with medical robotics. She is principal investigator in several European projects and supervisor of about 10 PhD and MSc students.

Vision in Motion: a Perception-Action-Locomotion Framework for Medical Microrobots

Medical micro- and nanorobots have been demonstrated for a variety of non-invasive biomedical applications. However, most of these demonstrations have been carried out in *in vitro* settings and under optical microscopy, being significantly different from the clinical practice. Better control and imaging are among the challenges to be faced to help microrobots meet clinical needs and perform real medical tasks



DANIEL RAZANSKY

ETH Zürich, Switzerland

Daniel Razansky is Full Professor of Biomedical Imaging with a double appointment at the Faculty of Medicine, University of Zurich and the Department of Information Technologies and Electrical Engineering, ETH Zürich in Switzerland. Previously he was Professor of Molecular Imaging Engineering at the Technical University and Helmholtz Center Munich in Germany. He earned Biomedical and Electrical Engineering degrees from the Technion - Israel Institute of Technology and conducted postdoctoral research at the Harvard Medical School. His Lab pioneered several bioimaging technologies for pre-clinical research and clinical diagnostics, among them the multi-spectral optoacoustic tomography and its multimodal combinations with therapeutic and diagnostic ultrasound, fluorescence microscopy, and magnetic resonance imaging. Prof. Razansky's research has been recognized by the German Innovation Prize, IPPA James Smith Prize, and multiple awards from the ERC, NIH, HFSP, SNSF, and DFG. He is a Fellow of the IEEE, SPIE, and Optica Societies.

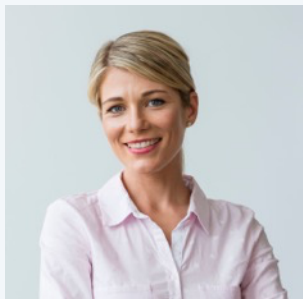
In Vivo Optoacoustic Navigation of Labeled Microrobots and Cells for Image-Guided Therapy and Super-Resolution Angiography

Microscale agents capable of navigating the vasculature promise to transform precision medicine, yet their clinical translation requires technologies that can simultaneously visualize, localize, manipulate, and monitor their interactions with living tissues deep inside the body. The talk focuses on the recent advances establishing volumetric optoacoustic imaging as a unified platform for image-guided microrobotic interventions and functional vascular imaging. By combining spectrally engineered contrast agents, magnetic actuation, focused ultrasound, and high-speed three-dimensional optoacoustic tomography, we demonstrate real-time tracking and navigation of both synthetic microrobots¹⁻³ and labeled endogenous cells⁴ within intact microvascular networks. Rather than serving solely as therapeutic carriers, these microscale agents also function as dynamic imaging probes whose localization enables super-resolution reconstruction of vascular architecture while simultaneously quantifying blood flow and cellular dynamics with spatial precision exceeding the acoustic diffraction limit⁵. Integration of multifunctional particle designs with therapeutic payloads, acoustically and magnetically responsive materials further enables targeted drug delivery, non-invasive guidance, and optoacoustically monitored focused ultrasound therapy⁶. Extending these concepts to living blood cells introduces biocompatible, multiplexed probes capable of interrogating microcirculatory physiology and guiding therapeutic interventions without compromising vascular function. Together, these developments establish a versatile framework in which imaging, navigation, therapy, and quantitative vascular phenotyping converge into a single theranostic platform, advancing the prospects of precision image-guided interventions and clinically translatable microrobotic medicine⁷.

1. P. Wrede, O. Degtyaruk, S. K. Kalva, X. L. Deán-Ben, U. Bozuyuk, A. Aghakhani, B. Akolpoglu, M. Sitti, & D. Razansky. Real-time 3D optoacoustic tracking of cell-sized magnetic microrobots circulating in the mouse brain vasculature. *Science Advances*, 8(19), eabm9132 (2022).
2. D. Nozdriukhin, S. Lyu, J. Bonvin, M. Reiss, D. Razansky, & X. L. Deán-Ben. Multifunctional microflowers for precise optoacoustic localization and intravascular magnetic actuation in vivo. *Advanced Healthcare Materials*, 14(7), 2404242 (2025).
3. D. W. Kim, P. Wrede, A. Rodríguez-Camargo, Y. Chen, N. O. Dogan, C. Glück, B. V. Lotsch, D. Razansky, & M. Sitti. Upconversion nanoparticle-covalent organic framework core-shell particles as therapeutic microrobots trackable with optoacoustic imaging. *Advanced Materials*, 37(49), 2418425 (2025).
4. L. Tang, Q. Zhou, H. Preuss, X. Chang, L. Glandorf, D. Nozdriukhin, E. Jessen, C. Glück, H. Zhang, Y. Chen, M. Reiss, Z. Feng, D. Schillinger, B. Weber, S. Wegener, M. El Amki, D. Razansky, & X. L. Deán-Ben. Multiplexed optoacoustic tracking and magnetic actuation of labeled blood cells in living mice. *Science Advances*, 12(26), aec8985 (2026).
5. D. Nozdriukhin, S. Lyu, D. Razansky, & X. L. Deán-Ben. Large-scale super-resolution optoacoustic imaging facilitated by FeNP/ICG-loaded coreless polyelectrolyte microcapsules. *Theranostics*, 15(13), 6412-6427 (2025).

6. N. Mahkam, Y. Chen, H. Estrada, A. Amitabh, A. Aghakhani, M. Sitti, & D. Razansky. Rigid hollow microparticles for enhanced focused ultrasound treatment under optoacoustic guidance. *Advanced Science*, 13(13), e12337 (2026).

7. P. Wrede, E. Remlova, Y. Chen, X. L. Deán-Ben, M. Sitti, & D. Razansky. Synergistic integration of materials in medical microrobotics for imaging and actuation. *Nature Reviews Materials*, 10, 888–906 (2025).



SIMONE SCHUERLE

ETH Zürich, Switzerland

Simone Schuerle is Associate Professor at ETH Zürich, Switzerland, where she heads the Medical System Lab. With her team, she develops diagnostic and therapeutic systems at the nano- and microscale with the aim of tackling a range of challenging problems in medicine. Prior to taking this position, she researched as postdoctoral scientist at the Koch Institute for Integrative Cancer Research at MIT on nanosensors for in vivo tumor profiling as well methods to wirelessly enhance drug transport (2014-2017). She is recipient of several awards, such as the Ernst Th. Jucker price for Cancer Research, the Prix Zonta for Women in Science, and fellowships from the SNSF, DAAD, Branco Weiss foundation and was honored with the distinction of “Young Scientist” by the World Economic Forum (WEF) in 2017. In 2014, she co-founded the spin-off MagnebotiX that offers electromagnetic control systems for wireless micromanipulation. She earned her PhD degree with specialization in microrobotics in 2013 at ETHZ, for which she was awarded with the ETH medal.

Engineering Synthetic and Biohybrid Medical Microrobots for Targeted Delivery and Acoustic Sensing

This work presents a multi-modal approach to overcoming physiological barriers using two distinct strategies: synthetic and biohybrid magnetic microrobots for high-precision therapeutic delivery, and molecularly responsive acoustic reporters for diagnostic imaging. By harnessing magnetic and acoustic fields to actuate micro-scale systems and receive signals, these platforms demonstrate how we can perform localized disease targeting and monitoring in deep-tissue environments.



WEI GAO

Caltech, USA

Wei Gao is a Professor of Medical Engineering and a Heritage Medical Research Institute Investigator at the California Institute of Technology. He earned his Ph.D. from the University of California, San Diego in 2014, followed by a postdoctoral fellowship at the University of California, Berkeley from 2014 to 2017. He serves as Senior Associate Editor of *Science Advances*, and as Associate Editor for *npj Flexible Electronics*, *Biosensors and Bioelectronics*, and *Sensors & Diagnosis*. He is a recipient of NSF Career Award, ONR Young Investigator Award, IAMBE Early Career Award, Sloan Research Fellowship, Pittcon Achievement Award, IEEE EMBS Early Career Achievement Award, IEEE EMBS Technical Achievement Award, IEEE Sensor Council Technical Achievement Award, MIT Technology Review 35 Innovators Under 35, and Falling Walls Breakthrough of the Year in Engineering and Technology. He is also recognized as a World Economic Forum Young Scientist and a Highly Cited Researcher (Web of Science, since 2020). He is an elected Fellow of AIMBE, RSC, and IEEE. His research interests span wearable and implantable biosensors, digital medicine, bioelectronics, flexible electronics, additive manufacturing, and micro/nanorobotics.

Synthetic Medical Micro/Nanorobots for In Vivo Biomedical Applications

The 1966 film *Fantastic Voyage* inspired the concept of miniature machines traversing the human body to diagnose and treat disease. This once-futuristic vision is now being realized through the development of synthetic micro/nanorobots engineered for in vivo biomedical applications. In this talk, I will highlight recent advances in the design of microrobots powered by bioavailable fuels or externally applied fields such as ultrasound and magnetism. These systems enable a range of sophisticated capabilities, including biosensing, targeted drug delivery, bioimaging, and cellular isolation. I will discuss our recent work on ultrasound-propelled microrobots that achieve deep-tissue navigation and controllable drug release guided by real-time ultrasound imaging. In parallel, I will present biofuel-powered micro/nanomotors designed for effective tissue penetration and programmable therapeutic delivery, particularly in oncology settings. These platforms integrate responsive materials, wireless control, and clinical imaging interfaces, transforming synthetic motors into intelligent, adaptable therapeutic agents. Our results reveal the vast potential of medical microrobots in addressing unmet clinical needs across gastrointestinal disorders, inflammation, cancer, and precision medicine.



DANIEL AHMED

University of Bern, Switzerland

Daniel Ahmed is currently directing the Acoustic Robotic Systems Lab (ARSL) at the ARTORG Center for Biomedical Engineering Research, Faculty of Medicine, University of Bern. Previously, he was an Assistant Professor of Acoustic Robotics in the Department of Mechanical and Process Engineering at ETH Zürich. His research develops ultrasound technologies: robotics, implants, catheters and microsystems for life-science applications, diagnostics, and translational medicine. He received his B.S., M.S., and Ph.D. in Engineering Science and Mechanics from The Pennsylvania State University. He has published articles in *Nature*, *Nature Electronics*, *Nature Machine Intelligence*, and *PNAS*. He has secured competitive funding at the national and European levels, including an ERC Starting Grant, ERC Proof of Concept, EIC Pathfinder Open, BRIDGE Discovery, and multiple SNSF and Innosuisse grants. His achievements include the Falling Walls Science Breakthrough of the Year 2021 (Engineering & Technology, 2021), the ETH Dandelion Entrepreneurship Award, and a DWI Fellowship at the Leibniz Institute for Interactive Materials (Aachen University). He has cofounded two startups: SonoRobotics and SonoStent.

Translating Ultrasound Microrobots and Microtechnologies from Preclinical Models toward Clinical Applications

Microrobots offer transformative opportunities for life sciences and medicine, yet their integration into in vivo and preclinical models remains in its early stages. At microscopic scales, the physics of motion is entirely distinct from our macroscopic world – a bacterium swimming in fluid obeys very different rules than a human in water. Drawing inspiration from biology, my team develops microrobotic systems that operate safely and effectively within living environments using ultrasound as both an energy source and a means of control. Ultrasound provides unique advantages: it is noninvasive, biocompatible, and capable of deep tissue penetration. We have established a diverse family of ultrasound-powered microrobots and microtechnologies, including neutrophil-inspired navigators capable of upstream motion, starfish-larva-inspired ciliary swimmers for active manipulation, and bacteria-like double-helical devices for targeted thrombus disruption. More recently, we introduced autonomous and programmable control of microrobots through reinforcement learning. We were the first to translate ultrasound microrobotic systems into living organisms – first by manipulating microparticles within the vasculature of zebrafish embryos, and subsequently by navigating and manipulating microrobots in the brain vasculature of live mice. More recently, we developed a new class of US-driven artificial muscles and soft robots and demonstrated their use in manipulating excised bladder, stomach, and intestinal tissues, as well as serving as bio-integrated patches for mechanical actuation and drug delivery in the heart and bladder. This lecture will highlight our recent advances in ultrasound

microrobotics and catheters their integration with preclinical biological systems, and emerging applications paving the way toward clinical translation and bio-integrated medical devices.

Featured talks

Rana Ajeeb

Magnetic CAR-T Cell Microrobots to Enhance Cell Accumulation and Retention in Solid Tumors

Rana Ajeeb¹, María Soledad Orellano², Carla Solé Cañadas³, Marcelo Calderon^{2,4}, Andrea Garcia Lizarribar⁵, Bergoi Ibarlucea⁵, Mariana Medina- Sánchez^{1,4,6}

1 CIC nanoGUNE, San Sebastián, Spain

2 Polymer Science and Technology Department, Faculty of Chemistry University of the Basque Country (UPV/EHU)

3 Instituto de Investigación Sanitaria Biodonostia, Donostia/ San Sebastián, Spain

4 IKERBASQUE, Basque Foundation for Science, Bilbao, Spain.

5 TecNALIA, Donostia/San Sebastián, Spain

6 Cluster of Excellence-CeTI, TUD Dresden University of Technology, Dresden, Germany

Abstract

Adoptive cell therapies, such as Chimeric Antigen Receptor (CAR)-T cells, have significantly advanced the treatment of hematologic malignancies. However, their application to solid tumors is partly hindered by their inability to reach, accumulate, and persist at their site of action, resulting in suboptimal clinical response or invasive administration procedures. In this project, we investigate a magnetic targeting strategy to enable noninvasive control of primary human CAR-T cells and combine it with hyaluronidase-loaded nanogels to facilitate infiltration into the tumor core. We compared three different approaches for magnetic functionalization, varying both particle type and functionalization procedure to identify formulations that maximise magnetic responsiveness. The first approach involved metabolic labelling of T cells followed by click-chemistry conjugation of 1 µm polymeric magnetic particles to the cell membrane, yielding up to 28% functionalization with cell actuation velocities up to 1.7 µm/s under a rotating magnetic field (RMF) of 30 mT and 2 Hz. However, < 10% of the functionalized cells were motile. In the second approach, T cells were simply incubated with 1 µm polystyrene particles, resulting in 38% functionalization rate to the cell membrane, but with a similar low percentage of responsive motile cells. Finally, >80% of T cells incubated with 50 nm fluidMAG-PAS nanoparticles were responsive to the same RMF and exhibited the highest motility among groups, reaching 4.8 µm/s. In parallel, we developed hyaluronidase-loaded N-isopropylacrylamide-based nanogels with 80% encapsulation efficiency and found that the blank nanogels did not decrease the metabolic activity of primary human T cells at concentrations up to 250 µg/mL. Together, these results establish a microrobotic platform for magnetically guiding CAR-T cells while incorporating an extracellular matrix-degrading function. Next steps include evaluating the function of primary T cells when functionalized with both magnetic particles and hyaluronidase-loaded nanogels, ex vivo evaluation of T cell motility under physiologically relevant parameters, and in vivo pilot assessment of the efficacy of CD-19 CAR-T cell microrobots in a CD19-responsive orthotopic murine lung cancer model.

1. Zhang, P., Zhang, G. & Wan, X. Challenges and new technologies in adoptive cell therapy. *Journal of Hematology & Oncology* 16, 97 (2023). <https://doi.org/10.1186/s13045-023-01492-8>

2. Hu, H., Busa, P., Zhao, Y. & Zhao, C. Externally triggered drug delivery systems. *Smart Materials in Medicine* 5, 386-408 (2024). <https://doi.org/https://doi.org/10.1016/j.smaim.2024.08.004>

3. Tang, X. et al. Magnetic-Acoustic Sequentially Actuated CAR T Cell Microrobots for Precision Navigation and In Situ Antitumor Immunoactivation. *Adv Mater* 35, e2211509 (2023). <https://doi.org/10.1002/adma.202211509>

Hakan Ceylan

Preventive Endovascular Robots: A New Paradigm for Vascular Interventions

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Abstract

Microrobots offer new possibilities for minimally invasive endovascular interventions, yet their development remains largely centered on proof-of-concept demonstrations that do not fully account for the constraints of clinical use. In this talk, I present a translational perspective grounded in two application-driven microrobot platforms, EndoBot and AmorphoBot. EndoBot is designed for preventive immunomodulation at the endothelial interface, targeting early-stage vascular pathologies that lead to narrowing, where current standard-of-care approaches remain limited. AmorphoBot focuses on achieving stable and durable occlusion in hard-to-treat arterial aneurysms. I will demonstrate how clinical factors, including local anatomy, physiology, biocompatibility, actuation limits, imaging, control, and procedural workflow, collectively shape the design of microrobot systems. Rather than treating translation as a downstream step, we emphasize the criticality of integrating clinical context and unmet needs early as foundational drivers of system-level engineering.

Giovanni Pittiglio

Magnetic Robots for Cardiovascular Interventions

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Abstract

Magnetically actuated robots can reach deep cardiovascular targets that conventional tools struggle with. By embedding magnetic material in a soft catheter or an untethered device and steering it with fields generated outside the body, we can navigate the cerebral vasculature, thread peripheral vessels, or place a tool against the heart wall — remotely, atraumatically, and without transmitting force along a stiff shaft. Two limitations stand between this approach and routine clinical use.

The first is degrees of freedom (DoFs). An external field couples to a device through only a few controllable torques and forces, so the dexterity available for steering is intrinsically limited, and that limit tightens as the device shrinks and its magnetic content with it. The second is force. Reaching the target is not sufficient: an ablation catheter must maintain contact with the chamber wall for up to a minute at a clinically meaningful force, and a guidewire must steer through tortuous anatomy without buckling. Both DoFs and force can be increased, but typically at the cost of larger actuation units — generating enough field over a large enough working volume tends to produce external hardware that is difficult to integrate into existing clinical setups.

This talk concerns how to ease that trade-off. Permanent magnets are central to the approach: they are energetically convenient, producing strong fields at a size and DoF that are clinically translatable, with no power or cooling required. The design goal is to shape the device and the field together so that usable DoFs and force improve without a corresponding growth in actuator size and complexity.

I will illustrate this through a sequence of designs. Soft magnetic catheters, magnetized along their length and actuated by a pair of permanent-magnet arms, give up the steering DoFs that are unnecessary in known anatomy, instead following the path of least resistance through wall contact to reduce trauma and targeting error^{1,2}. Magnetic ball-chain catheters take the opposite approach: by packing the body almost entirely with spherical permanent

magnets, they generate clinically relevant ablation forces and stable wall contact using only two small rotating magnets, reducing the actuator footprint rather than the capability^{3, 4}. Rotational ring-pair actuators address the constraint from the hardware side, recovering a tunable force response from compact, stationary magnets that modulate force through relative rotation alone, without repositioning large masses around the patient⁵.

Across soft magnets, magnet chains, and these mechanical designs runs a common direction: more degrees of freedom and more usable force, achieved with as little added size and complexity as possible. That axis — rather than raw field strength — is what makes magnetic cardiovascular robotics clinically translatable, and the same underlying physics of magnetization, field shaping, and slender-body mechanics carries the idea from the cerebral vasculature to the heart.

1. G. Pittiglio, P. Lloyd, T. da Veiga, et al. Patient-Specific Magnetic Catheters for Atraumatic Autonomous Endoscopy. *Soft Robotics*. 2022;9(6):1120-1133. doi:10.1089/soro.2021.0090
2. G. Pittiglio, J. H. Chandler, T. da Veiga et al. Personalized magnetic tentacles for targeted photothermal cancer therapy in peripheral lungs. *Commun Eng* 2, 50 (2023). <https://doi.org/10.1038/s44172-023-00098-9>
3. G. Pittiglio, A. Donder and P. E. Dupont, "Continuum Robot Shape Estimation Using Magnetic Ball Chains," 2024 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), Abu Dhabi, United Arab Emirates, 2024, pp. 11004-11009, doi: 10.1109/IROS58592.2024.10801952.
4. G. Pittiglio, F. Leuenberger, M. Mencattelli, M. McCandless, E. O'Leary and P. E. Dupont, "Magnetic Ball Chain Robots for Cardiac Arrhythmia Treatment," in *IEEE Transactions on Medical Robotics and Bionics*, vol. 6, no. 4, pp. 1322-1333, Nov. 2024, doi: 10.1109/TMRB.2024.3465828.
5. A. Sayres and G. Pittiglio, "Design of Magnetic Continuum Robots with Tunable Force Response Using Rotational Ring Pairs," 2026 International Symposium on Medical Robotics (ISMR), Knoxville, TN, USA, 2026, pp. 66-72, doi: 10.1109/ISMR69606.2026.11536338.

Tian Qiu

Wireless Magnetic Localization of Microrobots Toward Clinical Interventions

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Abstract

Medical microrobots hold immense promise for precise disease diagnosis, targeted drug delivery, and minimally invasive interventions. However, wireless navigation through complex and dynamic environments of the human body remains a major challenge, requiring accurate real-time localization for closed-loop control. Effective guidance of these microrobots demands a localization modality that simultaneously provides high spatial accuracy, high refresh rate, deep-tissue penetration, and ideally radiation-free operation.

Magnetic localization has emerged as a promising solution to these requirements. However, conventional permanent-magnet-based localization methods often suffer from limited signal-to-noise ratio (SNR) and poor capability for distinguishing multiple targets. To address these challenges, oscillatory magnetic localization approaches have recently been developed, including small-scale magneto-oscillatory localization (SMOL) ¹ and magneto-mechanical resonators (MMRs) ^{2,3}. These methods combine the strong magnetic field of a permanent

magnet with a mechanically oscillating microsystem to generate an alternating magnetic field that can be detected by a magnetic sensor array for six-degrees-of-freedom localization.

Here, we present recent advances in both the hardware and software of the SMOL system. We miniaturized the magnetic trackers and engineered distinct mechanical resonance frequencies to enable simultaneous localization of multiple targets in soft tissue ⁴. Furthermore, by integrating an optimized magnetic excitation strategy using three electromagnetic coils with a multi-stage searching algorithm, the system localizes trackers without requiring prior knowledge of position or orientation. Experimental validation in ex vivo porcine liver demonstrates accurate localization over a depth of 10 cm. The miniaturized, wireless tracking technology provides accurate, real-time, and radiation-free localization, offering a promising solution for the navigation of medical microrobots and other minimally invasive surgical instruments toward future clinical applications.

1. F. Fischer, C. Gletter, M. Jeong, et al., "Magneto-oscillatory localization for small-scale robots," npj Robotics, 2, 1: 1, 2024.
2. B. Gleich, I. Schmale, T. Nielsen, et al., "Miniature magneto-mechanical resonators for wireless tracking and sensing," Science, 380, 6648: 966, 2023.
3. J. Faltinath, F. Mohn, F. Foerger, et al., "Natural frequency dependence of magneto-mechanical resonators on magnet distance," IEEE Sensors Journal, 25, 20: 38073, 2025.
4. L. Tan, J. K. Mariyanna, M. Zhang, et al., "Multi-target wireless localization of miniaturized magneto-oscillatory trackers in soft biological tissues," under review.

Richard Nauber

Deep-Learning-Based Photoacoustic Feedback and Coded VCSEL Illumination for Translational Real-Time Microrobot Control

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Abstract

Micro- and nanorobotic technologies are increasingly investigated for minimally invasive diagnosis and therapy, including reproductive medicine, targeted delivery, and image-guided interventions¹. However, clinical translation remains limited by the lack of real-time localization and feedback control under tissue, especially when magnetic actuation, biological background signals, and compact imaging hardware must operate together in a clinically realistic workflow². Photoacoustic imaging is well suited for this task because it combines optical contrast with ultrasound-based penetration, while dual ultrasound/photoacoustic acquisition can provide complementary anatomical and microrobot-specific information^{3,4}.

The research hypothesis of this work is that photoacoustic tracking, combined with real-time closed-loop magnetic control, deep-learning-based localization, and coded vertical-cavity surface-emitting laser (VCSEL) illumination, can provide a practical control architecture for translating magnetic microrobots from laboratory demonstrations toward clinically deployable systems.

A real-time closed-loop platform was developed to integrate synchronized dual-mode ultrasound/photoacoustic imaging, graphics processing unit (GPU)-based reconstruction, microrobot localization, and eight-coil magnetic actuation within a 100 ms control cycle. Imaging and actuation were time-multiplexed to reduce electromagnetic interference during feedback control. Localization was evaluated using both threshold-based tracking and a You Only Look Once (YOLO)-derived deep-learning detector trained on curated photoacoustic data, with the tested microrobot excluded from training to assess transfer to an unseen device type. To address the translational need for compact and potentially safer photoacoustic systems, a VCSEL illumination source was tested with either single-pulse excitation or length-7 Barker-coded excitation followed by matched filtering.

The system controlled a 300 μm magnetic spiral microrobot along an approximately 1.6 mm figure-of-8 trajectory at 20 mm imaging depth, reaching an average velocity of $467 \pm 114 \mu\text{m/s}$. Compared with an optical reference, ultrasound-only threshold tracking missed more than 91% of detections and yielded a root-meansquare (RMS) error of $114 \pm 17 \mu\text{m}$. Photoacoustic threshold tracking reduced missed detections to 17.4% with an RMS error of $62 \pm 16 \mu\text{m}$. Deep-learning-based photoacoustic tracking further reduced missed detections to 16.9% with comparable accuracy of $67 \pm 15 \mu\text{m}$, indicating generalization to a microrobot type not included MIRA 2026 – Microrobots for Real-World Medical Applications during training. With VCSEL illumination, Barker-coded excitation has been shown to increase the photoacoustic image signal-to-noise ratio (SNR) from 42.9 dB to 50.5 dB at equal acquisition time.

These results support the central hypothesis that photoacoustic feedback can close an important translational gap for medical microrobotics by linking real-time localization, magnetic control, and compact imaging hardware. The platform addresses several requirements for clinical adoption: feedback under tissue, reduced actuation-imaging interference, compatibility with portable illumination, and tracking methods that can generalize beyond a single microrobot design. This positions photoacoustic closed-loop control with deep-learning-based tracking and coded VCSEL illumination as a key enabling technology for future clinical micro- and nanorobotic interventions.

1. R. Nauber, S. R. Goudy, M. Goeckenjan, M. Bornhäuser, C. Ribeiro, and M. Medina-Sánchez, "Medical microrobots in reproductive medicine from the bench to the clinic," *Nature Communications*, vol. 14, no. 1, p. 728, 2023.
2. M. Medina-Sánchez and O. G. Schmidt, "Medical microbots need better imaging and control," *Nature*, vol. 545, no. 7655, pp. 406–408, May 2017.
3. A. Aziz, J. Holthof, S. Meyer, O. G. Schmidt, and M. Medina-Sánchez, "Dual Ultrasound and Photoacoustic Tracking of Magnetically Driven Micromotors: From In Vitro to In Vivo," *Advanced Healthcare Materials*, vol. 10, no. 22, p. 2101077, 2021.
4. A. Aziz, R. Nauber, A. S. Iglesias, M. Tang, L. Ma, L. M. Liz-Marzán, O. G. Schmidt, and M. Medina-Sánchez, "Nanomaterial-decorated micromotors for enhanced photoacoustic imaging," *Journal of Micro-Bio Robotics*, vol. 19, no. 1–2, pp. 37–45, 2023.

Contributed talks

Ylenia Jabalera

Evolution-Inspired Technologies for Precision Medicine

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Abstract

Nature has spent billions of years evolving sophisticated molecular machines capable of recognizing, modifying, and reshaping genetic information. By exploring their evolutionary history and resurrecting ancient molecular systems, we can uncover unique functionalities that have been lost over time and harness them to create next-generation genome-editing technologies. In this talk, I will present our work on ancestral CRISPR nucleases^{1,2} and emerging genome engineering platforms. These evolution-guided technologies offer new opportunities for precise and efficient genome engineering, expanding the current capabilities of genetic medicine. I will discuss how such approaches could be adapted to correct disease-causing mutations and their potential application in the development of future therapies for amyotrophic lateral sclerosis (ALS) and other inherited disorders.

1. Alonso-Lerma, B., Jabalera, Y., Samperio, S. et al. Evolution of CRISPR-associated endonucleases as inferred from resurrected proteins. *Nat Microbiol* 8, 77–90 (2023).

2. Jabalera, Y., Tascón, I., Samperio, S. et al. A resurrected ancestor of Cas12a expands target access and substrate recognition for nucleic acid editing and detection. *Nat Biotechnol* 43, 1663–1672 (2025).

Marek Grzelczak

Membrane-targeted nanoparticles for neuronal photo-modulation

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Abstract

Selective targeting of nanoparticles to the neuronal interface is central to the tailored development of precision neurotechnologies^{1,2}. Here, we report targeting gold bipyramids, as a model nanomaterial, to the membrane of primary neurons using a well-known bioorthogonal approach³. In a two-step process, linker molecules anchor to receptors that expose trans-cyclooctene, which forms a covalent bond with the tetrazine functional group on nanoparticles, leading to the retention of hundreds of nanoparticles per cell. Selective labeling of neuronal membranes with plasmonic nanoparticles via a bioorthogonal strategy enabled inhibition of neuronal activity through photothermal effects under NIR laser irradiation in synchronized cell cultures. The linker and/or nanoparticles alone have a negligible effect on neuromodulation. Nanoparticle retention at the membrane is rapid, requiring only one hour of total incubation, with no cytotoxic effect. These results expand the repertoire of light-activated nanomaterials for non-invasive neuromodulation.

1. N. S. S. Mousavi, K. B. Ramadi, Y.-A. Song, S. Kumar, *Commun Mater* 2023, 4, 101.

2. X. Li, H. Xiong, N. Rommelfanger, X. Xu, J. Youn, P. A. Slesinger, G. Hong, Z. Qin, *Matter* 2021, 4, 1484.

3. K. Ojima, K. Shiraiwa, K. Soga, T. Doura, M. Takato, K. Komatsu, M. Yuzaki, I. Hamachi, S. Kiyonaka, *Nat Commun* 2021, 12, 831.

Upashi Goswami

Charge-Engineered Nanogels as Drug Delivery Platforms against *Staphylococcus aureus* for Bovine Mastitis Therapy

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Abstract

Bovine mastitis (BM) is an inflammation of mammary gland primarily caused by bacterial infection¹. It is one of the most predominant infectious diseases affecting dairy cattle worldwide, causing substantial economic losses, reduced milk quality, and compromised animal welfare. The primary strategy for BM treatment and prevention is the antibiotic therapy. However, the extensive use of antimicrobials in dairy production has contributed to the emergence of antimicrobial resistance (AMR), posing a major threat to both animal and public health.

Among the principal mastitis pathogens, *Staphylococcus aureus* is particularly difficult to eradicate, due to its adaptability to endorse persistence. Specifically, *S. aureus* forms biofilms that protect bacteria from antimicrobial agents and host immune defences, while its capacity to invade and survive within mammary epithelial cells enables intracellular persistence and recurrent infections. These characteristics markedly reduce the efficacy of conventional antibiotic treatments, emphasizing the need for innovative therapeutic approaches that improve antimicrobial delivery while minimizing antibiotic use. To advance the clinical translation of precision antimicrobial therapies, we developed charge-engineered p(NIPAM)-based nanogels (NGs). The nanogels are designed to improve antibiotic performance by enhancing penetration into bacterial biofilms, inhibiting biofilm formation, and enabling efficient intracellular delivery to target bacteria residing within host cells.

A library of p(NIPAM)-based nanogels incorporating neutral, cationic, anionic, zwitterionic, and dendritic polyglycerol (dPG)-crosslinked architectures was synthesized by free-radical polymerization and were characterized by dynamic light scattering, zeta potential analysis, AFM, FT-IR, and 1H-NMR spectroscopy. Ceftiofur was subsequently loaded into the nanogels and their biological activity was evaluated through antimicrobial susceptibility assays, inhibition and eradication of *S. aureus* biofilms, bacterial surface hydrophobicity measurements, cellular uptake in bovine mammary epithelial cells (MAC-T), intracellular antibacterial activity, cytocompatibility, and cytokine modulation in LPS-stimulated THP-1 macrophages.

All nanogel formulations exhibited homogeneous nanoscale dimensions (120 - 340 nm) and tuneable surface charge while maintaining good cytocompatibility. Although unloaded nanogels showed no intrinsic antibacterial activity, they significantly altered bacterial surface hydrophobicity, suggesting modulation of bacterial adhesion and biofilm development. Following ceftiofur loading, all formulations distinctly inhibited biofilm formation, whereas eradication of was strongly influenced by nanogel surface chemistry. Zwitterionic DMAPS-functionalized nanogels showed disruption of established biofilms and the largest reduction in biofilm metabolic activity, indicating that complementary surface charges facilitate interactions with the negatively charged extracellular matrix and improve antibiotic penetration. All formulations were efficiently internalized by MAC-T cells, with acrylic acid-functionalized nanogels exhibiting the highest uptake. Enhanced intracellular delivery resulted in significantly improved elimination of intracellular *S. aureus*, with selected formulations achieving complete bacterial eradication under optimized conditions. Furthermore, several nanogel formulations significantly reduced TNF- α and IL-1 β secretion in activated macrophages without compromising cell viability, demonstrating immunomodulatory properties not observed with free ceftiofur.

These findings demonstrate that rational engineering of nanogel surface chemistry can simultaneously improve antibiotic delivery, biofilm eradication, intracellular antimicrobial activity, and inflammatory modulation. Such multifunctional nanocarriers represent promising translational drug delivery platforms for the treatment of persistent biofilm-associated infections. They support the development of more effective antimicrobial therapies while contributing to strategies aimed at reducing AMR.

1. Journal of Dairy Science (2018), 101(10), 9493-9504;

2. Biomedicine & Pharmacotherapy (2024), 170, 115967;
3. Materials Today Chemistry (2022), 23,100606

Yu Cheng

An intracellular magnetic micromotor drives spatiotemporal mechano-immunotherapy

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Abstract

Mechanical signals run through the entire lifecycle of cells, including immune cells. Intracellular mechanics is widely presented during various biological processes to sense and respond to complex signals within and outside of cells. Immune cells adapt to the mechanical environments with their structural plasticity during migration and communication. For instance, T cells activation through bounding to major histocompatibility complex (MHC) molecules of antigen-presenting cells (APCs), was realized by reorganizing their cytoskeleton system to form the immunological synapse between these cell types. However, how intracellular mechanics exert influence on both immune activation and anti-tumour immunity is unexplored. Magnetic micromotors, with the property of easy internalization and wireless programmed mechanical actuation, provide a promising strategy to study and regulate intracellular mechanics in deep tissues. Previous studies found that micro/nano-motors could generate magnetic forces to cause tumour cell death under a high frequency rotating magnetic field. However, it is unclear whether the intracellular mechanics could be altered via micromotors to induce different types of cellular responses, especially cell immunity for cancer treatment. Here, our team presents an integrated intracellular magnetic torque (IIMT) paradigm that is coupled with magnetic fields to promote cancer immunotherapy through the action of mechanical forces. An intelligent torque-regulator (ITR) with a rod-like microstructure was designed which facilitated uptake by both dendritic cells (DCs) and tumours. Interestingly, ITRs could exert divergent roles in DCs or tumour cells depending on the shape aspect ratio and mechanical intensity applied. Controlled by the external programmed magnetic field, low-intensity mechanoporation in lysosomes promoted antigen cross-presentation in DCs and canonical NLRP3 inflammasome activation, whereas high-intensity torque enhanced tumour cell destruction and antigen release. Furthermore, *in vivo* studies including the big animal experiments unveiled that sequential activation of high-intensity torque followed by low-intensity torque activity effectively suppressed the tumour growth. Thus, through selectively regulating intracellular mechano-signals in the immune system, IIMT plays a double-edged role in anti-tumour immunity, which builds on a growing interest in micro/nanomotor-triggered immune activation and paves the way for programmed cancer immunotherapy.

1. Yingze Li, Mengge Zheng, Zhenyan Zhu, Yajuan Zhang#, Peng Ning, Haotian Chen, Rui Gao, Chang Xu, Xueyan Wei, Yali Liu, Yingying Wang, Ruimei Zhou, Yuan Li, Zhenguang Li, Cheng Lv, Chen Liu, Junfang Xu, Zihan Guo, Zhixiang Hu, Lan Fang, Ke Wei, Mengying Feng, Changshi Zhou, Yunlang She, Weiyan Sun, Erzhen Chen, Gustavo R Plaza, Bin He, Jason Miska, Weiwei Yang, Yichao Tang, Haipeng Liu, Chang Chen, Yu Cheng. Dynamic magneto-mechanical force in lysosomes instructs durable macrophage repolarization for antitumor immunity. *Cell Research*, 2026, 36(3): 197-218.

2. Rui Gao, Chang Xu, Chen Liu, Zhenyan Zhu, Min Wang, Xueyan Wei, Peng Ning, Wei Zhang, Yingze Li, Yajuan Zhang, Junwu Shen, Yifan Tong, Feng Tao, Xiaolei Chen, Xiaoyi Jiang, Huan Ren, Cheng Lv, Gustavo R. Plaza, Jason Miska, Haiming Fan, Xiaoqing Zhang, Yichao Tang, Yalei Dai, Weiwei Yang, Bin He, Yu Cheng. An intracellular magnetic micromotor drives spatiotemporal mechano-immunotherapy. *Advanced Materials*, 2025, 37(47): e04404.

Kristin Fichna

Controlled Chemical Signaling between Enzymatic Nanomotors

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†Equal contribution

Emna Ouni & Samuel Sánchez are co-PIs in this work

Abstract

Antibody-drug conjugates (ADCs) have transformed urothelial carcinoma treatment, yet their efficacy remains limited by poor intratumoral transport, particularly in locoregional therapies such as intravesical treatment for non-muscle invasive bladder cancer (NMIBC). Although Enfortumab vedotin (EV) targets the bladder cancer biomarker Nectin-4, clinical responses are not consistently predicted by antigen expression, indicating that physical transport barriers substantially influence therapeutic outcome¹. Here, we investigated whether urease-powered nanomotors could overcome these barriers through active fluid mixing to enhance EV delivery independently of target expression.

Poly(lactic-co-glycolic acid) (PLGA)-based urease nanomotors were synthesized and coadministered with EV. Particle image velocimetry confirmed sustained nanomotor-driven fluid convection under therapeutically relevant conditions. Therapeutic efficacy was evaluated using bladder patient-derived xenograft (PDX) tumoroids generated in a microcavity-array platform from three independent patient tumors spanning the clinical spectrum of Nectin-4 expression^{2,3}. This New Approach Methodologies (NAMs)-compliant platform preserves clinically relevant tumor heterogeneity and three-dimensional architecture. Nanomotor internalization, EV penetration, and lysosomal trafficking were monitored by fluorescence microscopy and quantitative label-free holotomography, enabling longitudinal, non-destructive three-dimensional analysis. Treatment response was further quantified using a novel refractive-index-based viability metric (RI Std), providing a label-free measure of therapeutic efficacy.

Nanomotor-driven convection markedly enhanced EV penetration throughout tumoroids, accelerated lysosomal trafficking, and significantly potentiated therapeutic efficacy across all three PDX models, including those with negligible Nectin-4 expression. Quantitative label-free holotomography captured treatment-induced structural and refractive-index changes, establishing a robust framework for longitudinal therapeutic monitoring⁴. These findings identify nanomotor-driven fluid mixing as a tunable physical mechanism that shifts the limiting

determinant of ADC efficacy from receptor abundance to active drug transport. By integrating enzyme-powered nanomotors with human PDX tumoroids and quantitative label-free holotomography, this work provides a clinically translatable strategy to enhance locoregional bladder cancer therapy and overcome transport barriers limiting the efficacy of ADCs and other biologics, potentially expanding treatment to patients with low target expression.

1. Alt, M., Stecca, C., Tobin, S., Jiang, D. M. & Sridhar, S. S. Enfortumab vedotin in urothelial cancer. *Ther. Adv. Urol.* 12, 1756287220980192 (2020).
2. Wadman, M. FDA no longer has to require animal testing for new drugs. *Science* 379, 127–128 (2023).
3. Ouni, E. et al. Mechanosensitive interactions of tumoroids with an engineered environment promote cell proliferation and enhance drug response detection. *Cell Biomater.* 1, 100149 (2025).
4. Kim, G., Hugonnet, H., Kim, K. et al. Holotomography. *Nat. Rev. Methods Primers* 4, 51 (2024).

Zesheng Li

Magnetically Actuated and Enzyme-Functionalized Flask-Shaped Nanorobots for Active Mucus Penetration and Ferroptosis Blockade in Ulcerative Colitis

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Abstract

Oral 5-aminosalicylic acid (5-ASA) and the herbal formula Wuweikushen are first-line ulcerative colitis (UC) therapies, yet rapid intestinal transit and gastric-acid degradation restrict colonic residence to minutes, preventing sustained local drug levels. Conventional nanocarriers diffuse passively and cannot actively breach the dense colonic mucus or withstand peristaltic washout.

Inspired by magnetotactic bacteria, leukocyte rolling, and whipworm-secreted proteases, we developed a magnetically driven, enzyme-functionalized flask-shaped nanorobot — A/W-P@FBots — that combines magnetic propulsion, papain-mediated mucus degradation, and microbial-enzyme-triggered drug release in a single 743-nm platform. Flask-shaped carbon nanoparticles were synthesized hydrothermally, loaded with Fe₃O₄ cores and dual therapeutics (5-ASA + Wuweikushen) by vacuum perfusion, and coated by layer-by-layer assembly of chitosan/alginate with a papain-embedded outer shell.

In vitro, the nanorobots were superparamagnetic and released <23% of drug at pH 1.0 but ~40% at pH 7.4. Under a rotating magnetic field, they navigated at 12.3 ± 1.5 μm/s and traced "HIT" trajectories with 26.5 μm mean deviation. In a DSS-induced mouse colitis model, magnetic guidance produced 12-hour colonic retention—far longer than the minute-scale residence of passive carriers—and substantially increased mucosal accumulation vs. non-magnetic controls. Magnetically targeted A/W-P@FBots recovered body weight, lowered disease activity index, reversed colon shortening, and reduced inflammatory infiltration. Mechanistically, the treatment regenerated goblet cells, restored MUC2 secretion, and reassembled tight-junction proteins (ZO-1, Ecadherin, Claudin-4, Occludin). Transcriptomics showed that combined 5-ASA/Wuweikushen delivery suppressed intestinal epithelial ferroptosis by restoring glutathione metabolism and upregulating GPX4 while downregulating ACSL4—a pathway not previously linked to UC combination therapy. 16S rRNA sequencing further showed that magnetic guidance rebalanced gut microbiota and restored short-chain fatty acids.

This work moves from material synthesis and in vitro actuation to preclinical validation, showing that multifunctional microrobots cross biological barriers inaccessible to passive platforms and establishing ferroptosis inhibition as a new mechanistic target for UC nanomedicine.

1. Li, Z.; Di, Y.; Jin, L.; Qu, B.; Zhang, H. Gallium Liquid Metal Microdroplets for Constructing Active Therapeutic Agents in Photothermal Therapy of Ulcerative Colitis. *Micromachines* 2025, 16, 1420.

2. Zhang, H.; Di, Y.; Jin, L.; Yang, S.; Li, Z.; Qu, B. Collective Magnetic Mesoporous Silica Nanorobots for Targeted Oral Capsaicin Delivery in Colitis Intervention. *Micromachines* 2026, 17, 272.

Apabritta Mallick

Magnetically Actuated Micro/Nanorobots Enabling Biofilm Eradication and Catalytic Transformations Across Space, Biomedical, and Chemical Environments

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Abstract

Magnetically actuated micro- and nanorobots offer a versatile platform for performing targeted tasks in environments where conventional tools are ineffective or infeasible. This talk presents an integrated research program demonstrating how such microrobots enable biofilm eradication, precise motion control, and catalytic transformations across spaceflight, biomedical, and chemical settings. The central focus is the ESA CONREX mission, the first microrobotic biofilm-eradication experiment selected for deployment on the International Space Station.

CONREX investigates how magnetically actuated microrobots interact with bacterial biofilms under microgravity-relevant flow, adhesion, and mass-transfer conditions^{1, 2}. The experiment employs a multi-microcell architecture enabling parallel testing of five nanorobot variants, each combining magnetic propulsion, mechanical disruption, and light-activated ROS generation. Sequential eradication cycles—initial activation, mandatory performance evaluation, biofilm recovery, and repeated actuation—are distributed across a multi-day timeline to capture both immediate and long-term microrobot-biofilm dynamics. Ground studies show that combined magnetic-photochemical actuation achieves 70–85% biofilm reduction per cycle, with enhanced removal. These results support CONREX's multi-day autonomous operation strategy and its relevance for future spacecraft hygiene systems and clinical biofilm management.

Beyond spaceflight, we demonstrate that the same microrobotic principles translate to biomedical devices, including catheter-like cannula systems where nanorobots penetrate and disrupt lumen-attached biofilms under low-shear conditions. In parallel, we explore the chemical dimension of microrobotic functionality: microrobots equipped with catalytic surfaces can perform on-robot chemical transformations, including ammonia production from nitrogenous precursors under mild conditions^{3, 4}. These catalytic microrobots leverage magnetic actuation to enhance mass transfer, increase catalyst-substrate contact, and outperform static catalytic particles. This chemical capability illustrates how microrobots can serve not only as mechanical or antimicrobial agents but also as mobile catalytic platforms capable of operating in confined or distributed reaction environments.

Together, these results establish magnetically actuated micro/nanorobots as a cross-domain technology capable of addressing challenges in spacecraft biofilm control, clinical infection management, and distributed chemical synthesis. The upcoming CONREX on-orbit experiment will provide unprecedented insight into microrobot behaviour in microgravity, informing the next generation of intelligent, multifunctional microrobots designed for real-world medical and industrial applications⁵.

1. Mayorga-Martinez, C.C., Zelenka, J., Klima, K., Kubanova, M., Ruml, T. and Pumera, M., 2023. Multimodal-Driven Magnetic Microrobots with Enhanced Bactericidal Activity for Biofilm Eradication and Removal from Titanium Mesh. *Advanced Materials*, 35(23), 2300191.

2. Mayorga-Martinez, C.C., Zhang, L. and Pumera, M., 2024. Chemical multiscale robotics for bacterial biofilm treatment. *Chemical Society Reviews*, 53(5), 2284-2299.

3. Jancik-Prochazkova, A., Jancik, J., Palacios-Corella, M. and Pumera, M., 2024. Microrobots enhancing synthetic chemistry reactions in non-aqueous media. *Advanced Functional Materials*, 34(49), 2409459.

4. Mallick, A., Kim, J. and Pumera, M., 2025. Magnetically propelled microrobots toward photosynthesis of green ammonia from nitrates. *Small*, 21(14), 2407050.

5. CONREX- Czech Orbital NanoRobots EXperiment. 2025. <https://ceskacestadovesmiru.cz/conrex/>

Sylvain Martel

Targeting tumour hypoxic zones with magneto-aerotactic bacterial microrobots

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Abstract

The formation of tumour hypoxic zones occurs when the rate of proliferating cancer cells outgrows the formation of neovascular vessels. The lack of such neovascular vessels combined with the consumption of oxygen by the cancer cells result in the formation of such hypoxic zones that are not only characterized by a lower level of oxygen but also by a more acidic environment, hence a lower pH. Such characteristics not generally found in proximity of the tumoral region can be used by microrobots as specific targets within the tumoral volume. Indeed, the insufficient spatial resolution and contrast enhancement of medical imaging modalities at providing precise and reliable information to treat all cancer cells can be compensated by embedding functionalities in microrobots to target autonomously hypoxic zones. Such level of autonomy allows effective distribution of therapeutics throughout the whole tumour volume without relying entirely on an inadequate external imaging system¹.

The lower pH level of tumour hypoxic zones is the result of the metabolic adaptation of hypoxic cells consuming glucose to compensate for the lack of oxygen, hence providing, as the lower level of oxygen, the specificity required for microrobots to target hypoxic zones. Once hypoxic cells are eliminated, the pH level may not remain sufficiently low to provide the specificity required if additional treatments are necessary. But the elimination of such hypoxic cells does not significantly change the level of oxygen since hypoxic cells do not primarily consume oxygen, hence maintaining the specificity required for additional treatments. Therefore, in a clinical point-of-view, targeting a lower level of oxygen may be a preferable option.

Due to present technological constraints, implementing a hypoxia targeting system in artificial microrobots is not a viable approach. Instead, the implementation of such hypoxia targeting system and other critical functionalities as depicted in can be achieved with live magneto-aerotactic bacteria, also known as magnetotactic bacteria (MTB)², being used as a component of biohybrid microrobots.

1. Felfoul, O. et al. Magneto-aerotactic bacteria deliver drug-containing nanoliposomes to tumour hypoxic regions. *Nat. Nanotechnol.*, 11, 941–947, 2016.

2. Blakemore, R.P. Magnetotactic bacteria. *Science*, 190, 377–379, 1975.

Songsong Tang

Biohybrid Micro/Nanorobots for Precision Therapy

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Abstract

Micro/nanorobots are miniaturized robotic systems capable of autonomous motion and functional operation at micro- and nanoscale dimensions. By converting environmental energy sources, such as chemical fuels, light,

ultrasound, electric fields, and magnetic fields, into propulsive forces, these systems enable controllable movement and on-demand functional output. Owing to their ability to perform precise manipulation in confined microscopic environments, micro/nanorobots offer a new paradigm for biomedical operations at the micro/nanoscale. They hold great promise for improving early disease diagnosis and therapeutic efficacy, and may provide key technological support for the next stage of development in precision medicine and robotics. Despite these opportunities, current micro/nanorobotic systems still face major limitations in terms of body materials and propulsion strategies, including reliance on toxic fuels, limited propulsion duration, and insufficient biocompatibility and biological functionality. To address these challenges, this talk will focus on structural design and propulsion mechanisms, and present my research on biohybrid medical micro/nanorobots. Specifically, I will discuss robotic systems constructed from natural biological entities or biomaterials, including cells, vesicles, and proteins, and powered by bioavailable substances or external energy fields. These strategies enable the development of medical robotic platforms for precise manipulation across different length scales and for diverse biomedical applications.

Tohid Didar

Medical Micro- and nano-robots for active and targeted phage delivery in respiratory infections

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Abstract

The rapid spread of multidrug-resistant (MDR) pathogens poses a critical global health challenge. Bacteriophage therapy has attracted renewed interest for MDR respiratory infections because lytic bacteriophages (phages) selectively infect susceptible bacterial hosts and propagate through replication and bacterial lysis^{1,2}. However, conventional phage administration is limited by non-uniform pulmonary deposition, restricted transport within complex airway structures, and poor penetration through mucus and established biofilms³. To address these challenges, we developed complementary phage-delivery platforms based on magnetically guided aerosols and self-propelled microrobots.

As a non-invasive pulmonary delivery approach⁴, we developed magnetically responsive aerosol formulations to improve regional deposition of phage-containing particles. The Fe₃O₄ concentration was optimized to produce uniform phage-loaded magnetic particles (451.6 ± 32.5 nm), low polydispersity (PDI < 0.3), and a high phage encapsulation efficiency (99.76 ± 0.15%). The nanorobots exhibited positive surface charge (+20 to +30 mV), and morphological and elemental analyses confirmed uniform particle formation and incorporation of magnetic iron oxide. Using a nebulizer coupled to a six-stage viable Andersen cascade impactor, we applied an external magnetic field to one impactor stage to simulate magnetically guided regional deposition. Under these conditions, the optimized magnetic formulation increased particle deposition fraction by 45.3 ± 11.6%, demonstrating enhanced deposition at the magnetically targeted stage.

For more complex respiratory infections requiring localized intratracheal delivery, we developed Mg-based bubble-propelled microrobots for active phage delivery and biofilm treatment. The microrobots generate H₂ bubbles through Mg–water reactions, enabling autonomous locomotion and localized fluid mixing⁵. The presence of pulmonary surfactant activates their propulsion. This represents the first application of chemically propelled microrobots for active phage delivery and respiratory biofilm treatment. The Mg microrobots exhibited an average propulsion velocity of 102.78 ± 10.68 µm/s, maintaining active motion in media with viscosities up to 3306.7 mPa·s. H₂ bubble streams further enhanced phage distribution more than 24-fold, supporting improved transport within viscous environments.

Following 6 h of treatment with mature biofilms, phage-loaded microrobots achieved a 9 log₁₀ CFU/mL reduction in bacterial viability which was more than 10,000-fold greater bacterial reduction compared with free phage, static

phage-microrobots, and microrobots without phage. They also produced more than 1000-fold greater phage titre amplification and 38.6% greater biomass reduction compared to mentioned groups. These findings highlight the synergistic effects of active microrobot motion and phage-mediated bacterial lysis to biofilm disruption. Additionally, Mg microrobots reduced intracellular ROS levels up to 74.1% and increased M2-associated macrophage polarization up to 3639.7%, which is favourable for tissue healing after chronic inflammation. We then developed an alveolus-on-a-chip model infected with clinical *Pseudomonas aeruginosa* isolates, and treatment with phage microrobots resulted in more than 99.99% reduction in bacterial burden, while no adverse effects on cellular morphology were observed in uninfected models.

These findings establish complementary microrobotic strategies for pulmonary phage delivery, with magnetically guided aerosols enabling non-invasive regional deposition and Mg microrobots providing biofilm disruption for more complex infections. This multimodal approach provides a promising framework for improving phage-based treatment of MDR respiratory infections while overcoming transport barriers that limit conventional phage therapy.

1. Weissfuss, C. et al. Adjunctive phage therapy improves antibiotic treatment of ventilator-associated pneumonia with *Pseudomonas aeruginosa*. *Nature Communications* 16, 4500 (2025).
2. Bayat, F. et al. High throughput platform technology for rapid target identification in personalized phage therapy. *Nature Communications* 15, 5626 (2024).
3. You, X. et al. Phage co-transport with hyphal-riding bacteria fuels bacterial invasion in a waterunsaturated microbial model system. *The ISME Journal* 16, 1275–1283 (2022).
4. Weiner, I. et al. Phage therapy with nebulized cocktail BX004-A for chronic *Pseudomonas aeruginosa* infections in cystic fibrosis: a randomized first-in-human trial. *Nature Communications* 16, 5579 (2025).
5. Rashidy Ahmady, A. et al. Micro-and nano-Bots for infection control. *Advanced Materials* 37, 2419155 (2025).

Paul Wrede

Biodegradable Acoustic Microrobots for Rapid Imaging-Guided Thrombotic Lesion Reperfusion

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Abstract

Thrombotic lesions in the brain are a major cause of death and disability¹, and rapid restoration of blood flow is essential to prevent irreversible damage. Current drug-based treatments often fail in severe cases and carry a high risk of bleeding, highlighting the need for safer and more effective approaches². Each minute of untreated large-

vessel occlusion is estimated to cost millions of neurons and billions of synapses³, underscoring the urgency of intervention. Here we show a minimally invasive strategy that uses focused ultrasound to actively guide biodegradable carriers to clots, where they deliver therapy with high precision. This approach integrates real-time imaging with controlled navigation, enabling targeted clot dissolution in a preclinical model of treatment-resistant thrombotic lesions. We achieved reperfusion within ~40s being one to two orders of magnitude faster compared to conventional timelines^{4,5}, potentially preserving hundreds of millions of neurons. We further demonstrate that these carriers can be steered through the human skull in laboratory tests, overcoming a key barrier to clinical translation. By uniting navigation, imaging, and localized drug delivery into a single platform, our work opens new possibilities for treating inaccessible or treatment-resistant clots, transforming thrombotic lesion treatments.

1. Feigin, V. L. et al. World Stroke Organization (WSO): Global Stroke Fact Sheet 2022. *Int. J. Stroke* 17, 18–29 (2022).
2. Owolabi, M. O. et al. Primary stroke prevention worldwide: translating evidence into action. *Lancet Public Health* 7, e74–e85 (2021).
3. Saver, J. L. Time Is Brain—Quantified. *Stroke* 37, 263–266 (2006).
4. Nowak, B. et al. Recanalization and reperfusion in clinically-relevant porcine model of stroke. *Front. Neurosci.* 19, 1572925 (2025).
5. Molina, C. A. et al. Time Course of Tissue Plasminogen Activator–Induced Recanalization in Acute Cardioembolic Stroke: A Case-Control Study. *Stroke* 32, 2821–2827 (2001).

Florian Fage

Bridging Microfluidics and Optical Microrobotics for Biomimetic Sperm Selection and Assisted Fertilization

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Abstract

Assisted reproductive technologies (ART) still rely largely on manual laboratory procedures, with sperm quality assessment remaining highly dependent on embryologist expertise and subjective evaluation of motility and morphology. Although embryo development is extensively monitored after fertilization, quantitative and reproducible characterization of spermatozoa before fertilization remains limited. In parallel, repeated handling steps expose gametes to changing environmental conditions throughout the ART workflow. Microfluidic technologies address part of these limitations by providing tightly controlled microscale environments and biomimetic sperm selection mechanisms such as thigmotaxis or rheotaxis^{1,2}. While these devices efficiently enrich high-quality sperm populations and reduce sperm DNA fragmentation³, they remain largely restricted to sperm preparation. The development of automated ART platforms will therefore require complementary technologies capable of objective sperm characterization and precise robotic manipulation of gametes during subsequent fertilization steps⁴.

To address these challenges, we developed an integrated platform combining microfluidic sperm selection with real-time image analysis. A PDMS device exploiting sperm thigmotaxis was used to passively isolate highly motile spermatozoa from human semen samples obtained in collaboration with the Reproductive Biology Department of

Tenon Hospital (AP-HP, Sorbonne Université). Experiments involving human samples were approved by the Comité d'Éthique de la Recherche of Sorbonne Université (CER 2023 – Dupont – Optobots – OVO and CER 2021-059). After selection, image-processing algorithms detected and tracked spermatozoa to quantify their trajectories, swimming velocities and morphological features. These descriptors were then used to classify sperm motility according to conventional clinical criteria, reducing operator dependence and improving the reproducibility of sperm evaluation. In parallel, optical microrobots were implemented to explore controlled sperm capture, transport and positioning in the context of downstream fertilization steps.

The device demonstrated robust performance across patient samples with an average recovery yield of $18.1 \pm 2.5\%$ (mean $\pm$ SEM). Progressive motility reached $87.8 \pm 3.1\%$, significantly higher than both raw semen ($51.8 \pm 10.4\%$) and density-gradient centrifugation ($70.5 \pm 11.5\%$). Sperm DNA fragmentation was reduced from $5.8 \pm 4.9\%$ in raw semen to $2.9 \pm 3.6\%$ after selection, suggesting efficient enrichment of high-quality spermatozoa. Real-time image analysis further provided objective and reproducible measurements of sperm motility and morphology immediately following sorting.

Spermatozoa were captured and transported under optical control toward target oocytes. Before sperm injection, laser microsurgery enabled localized perforation of the zona pellucida, providing controlled access to the oocyte surface. In addition, AI-based YOLO8 image-processing algorithms were developed to detect and track the zona pellucida and the oolemma of oocytes for real-time monitoring and quality control during fertilization.

This work supports the feasibility of combining biomimetic sperm selection, automated image-based characterization, optical microrobotics and laser microsurgery within a clinically relevant ART workflow. By integrating efficient sperm sorting, real-time quality assessment and contactless microrobotic handling, this approach opens a route toward lab-on-a-chip platforms for more standardized, automated and controlled assisted fertilization procedures.

1. Khodamoradi K. et al. Recent Microfluidic Innovations for Sperm Sorting. Chemosensors, 2021.
2. Ahmadkhani A. et al. Qualified Sperm Selection Based on Rheotaxis and Thigmotaxis in a Microfluidic System, Biomedical Engineering Letters, 2023.
3. Pujol A. et al. A Microfluidic Sperm-Sorting Device Reduces the Proportion of Sperm with Double-Stranded DNA Fragmentation. Zygote, 2022.
4. Medina-Sánchez M. et al. Cellular Cargo Delivery: Toward Assisted Fertilization by Sperm-Carrying Micromotors. Nano Letters, 2016.

Verónica Salgueiriño

Tunable Magnetic Remanence in Hybrid Elongated Nanostructures for Adaptive Nanorobotic Navigation

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Abstract

Optical tracking of spherical magnetic nanostructures reveals motion departing from classical diffusion, modulated by confinement, dipolar interactions, and temperature. Unlike passive nanoparticles or active carriers limited by biological barriers, our system offers adaptive, externally controlled magnetic navigation, a critical advantage for biomedical applications. By establishing correlations between bead size, morphology, and field dependent moment,

we provide a framework for machine learning-assisted control, enabling autonomous, environment-responsive navigation.

Elongated magnetic nanostructures can be similarly controlled using rotating magnetic fields at varying frequencies. Notably, these elongated structures can exhibit tunable remanence when designed as Fe_3O_4 halfellipsoids within a SiO_2 shell, switchable between antiparallel-coupled (zero stray field) and ferromagnetically coupled (maximum stray field) states, a capability unattainable in standard superparamagnetic or ferromagnetic carriers. Micromagnetic simulations confirm tunable remanence from zero to maximum, enabling precise control over particle interactions and chain formation.

This work exemplifies the unique functionalities of magnetic nanostructures to work as medical microrobotics; tunable remanence, programmable assembly, and adaptive motion, surpassing existing delivery systems and offering transformative solutions for niche medical cases where current therapies fall short, particularly in lifethreatening diseases such as glioblastoma or pancreatic cancer.

1. P. Steinkraus et al. Tunable Magnetic Remanence of Antiferromagnetically coupled $\text{Fe}_3\text{O}_4@\text{SiO}_2$ Nanoparticles for In Vivo Biomedical Applications. ACS Appl. Nano Materials 2025, 8, 19731.
2. I. Fernández-Rodríguez et al. Programmable Dynamics of Magnetic Nanobeads via Anomalous Diffusion and Fieldinduced Assembly (submitted, 2026).
3. C. Román-Freijeiro et al. Programmable Dynamics of Magnetic Elongated Nanostructures with tunable magnetic remanence (in preparation, 2026).

Stefano Palagi

From cell mimicry to functional autonomy: *celloid* microrobots for *in situ* medicine

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Abstract

Bioinspiration has been a powerful engine for microrobotics, translating biological strategies for propulsion, adaptation and navigation into artificial microscale systems¹. Yet, many synthetic microrobots still rely on externally imposed motion and lack the onboard physical and functional complexity required to move through soft biological tissues. Here I discuss a cell-inspired route to microrobotics in which cells of our own body, especially immune cells performing amoeboid interstitial migration, become design models for microrobots that deform, adapt and eventually navigate in tissue-like environments².

We define these systems as celloids: artificial, cell-like micromachines that borrow organisational and functional principles from living cells without being living systems themselves. In our approach, bottom-up synthetic biology and active soft matter are combined to build microrobots based on Giant Unilamellar Vesicles (GUVs), which consist of a liquid interior enclosed by a nanometre-thin phospholipid membrane. These vesicles can be loaded with active particles, to explore self-sustained shape changes, or with magnetic ferrofluids, to enable remote actuation and control³. This architecture transfers key cellular principles—compartmentalisation, membrane-mediated deformability and integration of functional components—into fully synthetic microrobots.

This celloid approach has enabled magnetic microrobots that are ultra-soft rather than merely small. Ferrofluidloaded vesicles undergo large magnetic-field-induced deformations, form protrusions, passively adapt to obstacles and move through confined spaces narrower than their nominal size⁴. These results indicate that

deformability is not a secondary material property, but an onboard functionality that can unlock behaviours inaccessible to rigid or even soft hydrogel-based microrobots.

This concept motivates the next step: using ultra-soft microrobots to infiltrate solid tumours as a demanding example of medical access through dense, heterogeneous and mechanically restrictive tissues. Such environments limit the penetration of conventional therapeutics and targeted delivery systems. We are therefore exploring whether magnetically actuated ultra-soft microrobots can penetrate realistic *in vitro* tumour models, such as spheroids and hydrogel-based constructs, thereby providing a first laboratory validation of microrobotics-enabled *in situ* administration⁵. In this view, microrobots are not replacements for drugs or nanocarriers, but precise administration agents that could position, release or activate therapeutic payloads locally, complementing and supporting existing drug delivery strategies while reducing systemic exposure.

Looking forward, the same cell-inspired logic points beyond deformability toward richer onboard functionalities: autonomous or supervised navigation, sensing of biochemical and physical cues, long-term tissue residency, diagnostic monitoring and reactive therapeutic intervention. Progress along this path will require validation platforms that are more informative than simple acellular phantoms, yet ethically and mechanistically more controllable than early animal models. Advanced *in vitro* models can therefore become not only a preclinical filter, but also an engineering environment in which microrobot design, actuation and biological interaction are iteratively co-developed.

Finally, I argue that medical microrobotics should embrace open innovation models. Because the value of these technologies depends on shared validation methods, interoperable actuation platforms and clinically meaningful benchmarks, open, collaborative translational pathways may accelerate progress more effectively than conventional closed business models alone.

1. Palagi, Stefano, and Peer Fischer. "Bioinspired microrobots." *Nature Reviews Materials* 3.6 (2018): 113-124.
2. CELLOIDS, "Cell-inspired particle-based intelligent microrobots," ERC H2020 project GA 948590.
3. Cecchi, Dario, et al. "Using the droplet transfer method to reliably prepare Giant Unilamellar Vesicles." *JoVE (Journal of Visualized Experiments)* 223 (2025): e68340. E. De Remigis et al., "Infiltration of Cell-Inspired Ultra-Deformable Magnetic Microrobots in Restrictive Environments," *IEEE Transactions on Medical Robotics and Bionics*, 2024, doi: 10.1109/TMRB.2024.3503898.
4. De Remigis, Eugenia, et al. "Infiltration of cell-inspired ultra-deformable magnetic microrobots in restrictive environments." *IEEE Transactions on Medical Robotics and Bionics* 7.1 (2024): 123-129.
5. SOFTINVADERS, "Ultra-soft microrobots for tumour penetration," ERC Proof of Concept project GA 101213190.

Hemin Pan

Sonotweezers: Multiscale Reconfigurable *In Vivo* Manipulation in Model Organism

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Abstract

Microscale manipulation within living organisms is essential for decoding the mechanical cues that govern development, tissue regeneration, and disease progression^{1, 2}. However, direct mechanical perturbation of native structures *in vivo* remains limited because targets are typically embedded within confined, dynamic, and optically heterogeneous environments. Furthermore, in the vasculature, micron-scale dimensions, physiological flow, and weak acoustic contrast further complicate native-cell control^{3, 4}. Here we introduce Sonotweezers, a focused surface-acoustic-wave platform for programmable, label-free and contactless manipulation of native biological

structures in zebrafish larvae. Using orthogonally arranged focused interdigital transducers, Sonotweezers generate reconfigurable acoustic potential landscapes with sub-20 μm trapping foci, enabling selective actuation within confined vascular geometries. We demonstrate trapping, assembly and directional guidance of unlabeled blood cells ($\sim 10 \mu\text{m}$) under physiological flow, including selective capture of individual red blood cells within microscale intersegmental vessels while neighbouring vessels remain perfused. These interactions are reversible, enabling transient-flow arrest and recovery within seconds using endogenous cells alone. We further establish multiscale control by contactless pairing and translating otoliths ($\sim 50 \mu\text{m}$) and manipulating liposomal microbubbles ($\sim 1 \mu\text{m}$). Sonotweezers provides programmable platform for mechanical perturbation *in vivo*, enabling studies of hemodynamics, mechanotransduction, inflammatory cell trafficking and vestibular function.

1. Zhang Q, Feng S, Lin L, et al. Emerging open microfluidics for cell manipulation. *Chemical Society Reviews*, 2021, 50(9): 5333-5348.
2. Ma X, Liang X, Li Y, et al. Modular-designed engineered bacteria for precision tumor immunotherapy via spatiotemporal manipulation by magnetic field. *Nature Communications*, 2023, 14(1): 1606.
3. Bhosale Y, Vishwanathan G, Upadhyay G, et al. Multicurvature viscous streaming: flow topology and particle manipulation. *Proceedings of the National Academy of Sciences*, 2022, 119(36): e2120538119.
4. Li H, Li A, Zhao Z, et al. Precise droplet manipulation based on surface heterogeneity. *Accounts of Materials Research*, 2021, 2(4): 230-241.

Pitch talks

Edison Gerena

MovaLife Microrobotics: Creating the IVF Lab Technologies for the Future

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Abstract

Although in vitro fertilization (IVF) is the gold standard for infertility treatment, its clinical success remains limited by operator-dependent variability, manual micromanipulations, and suboptimal culture conditions. These limitations result in inconsistent success rates ranging from 15% to 60%, with global average of only 25%¹.

Founded in Paris in 2024, MovaLife Microrobotics is developing the first integrated microfluidic IVF platform designed to automate and standardize the entire IVF workflow. Our technology combines an instrumented incubator with disposable microfluidic chips embedding mobile microrobots. All critical micromanipulations are performed remotely using controlled hydrodynamic forces and untethered microrobots, eliminating manual pipetting while remaining compatible with existing embryology laboratory practices.

Unlike conventional workflows requiring multiple handling and culture steps², the complete IVF procedure, from gamete loading to implantation-ready embryos, is performed within a single microfluidic chip under tightly controlled physiological conditions. This approach minimizes embryo manipulation, reduces operator variability, improves workflow efficiency, and provides a highly standardized environment for embryo development.

Globally, more than 3 million IVF cycles are currently performed each year. However, unmet demand remains significant, with some experts predicting that the market may require over 20 million cycles annually in the coming years³. By combining medical microrobotics and microfluidics, MovaLife aims to establish a new standard for assisted reproduction, improving clinical outcomes while making IVF more reproducible, scalable, and accessible.

1. World Health Organization, "Infertility prevalence estimates, 1990–2021." [Online]. Available: <https://www.who.int/news-room/fact-sheets/detail/infertility>

2. Cairo Consensus Group. "'There is only one thing that is truly important in an IVF laboratory: everything' Cairo Consensus Guidelines on IVF Culture Conditions." *Reproductive BioMedicine Online* 40.1 (2020): 33-60.

3. E. Hariton et al., "Meeting the demand for fertility services: the present and future of reproductive endocrinology and infertility in the United States," *Fertil Steril*, vol. 120, no. 4, pp. 755–766, Oct. 2023.

Shanmukh Srinivas

Nanorobotics in Dentistry

Abstract

Background and Clinical Need:

The persistence of bacteria deep within the narrow geometry of dentinal tubules is a primary cause of root canal treatment failure globally. Similarly, dental hypersensitivity is triggered when these same tubules are exposed to the external environment, allowing fluid movement to stimulate nerves within the dental pulp. Current clinical interventions are fundamentally limited by their reliance on passive diffusion. Standard bactericidal chemicals cannot

reach the depths necessary to eliminate robust bacterial colonies like *Enterococcus faecalis*. Furthermore, traditional desensitizing treatments and resin sealers provide only superficial coverage, usually degrading within weeks and requiring continuous reapplication.

Technology and Innovation:

We present a novel therapeutic platform utilizing magnetic nanotechnology to actively manipulate treatments deep into the dentine tissue. Our approach comprises two distinct, specialized nanomaterials: Helical Magnetic Nanobots: Fabricated from silica with an embedded iron layer, these nanobots are driven by externally applied rotating and oscillating magnetic fields. CalBots: Spherical, superparamagnetic nanoparticles featuring an iron oxide core enclosed by a calcium silicate and silica shell.

Mechanism of Action and Efficacy:

Our technology actively overcomes the physical barriers of the tooth's anatomy to deliver targeted, permanent results: During root canal procedures, helical nanobots are magnetically driven up to 2000 μm into the dentinal tubules. Once isotopically distributed, the nanobots' iron layers act as localized heat sources under rapidly varying magnetic fields, utilizing magnetic hyperthermia to completely eradicate persistent bacterial colonies. For hypersensitivity, a gradient magnetic field draws CalBot particles up to 500 μm deep into exposed tubules. The CalBots self-assemble into flexible chains to navigate the complex topography. When suspended in a calcium oxide gel, CalBots undergo a selfsetting hydraulic cement reaction, forming a permanent and biocompatible calcium silicate hydrate gel plug. Controlled in vivo murine trials demonstrate that CalBot plug formation rapidly and fully reverses cold-water avoidance behaviours associated with hypersensitivity.

Conclusion:

Our magnetically powered nanomaterials offer unprecedented spatial control and deep-tissue penetration capabilities. By shifting from passive treatments to active, targeted nanomedicine, our startup provides highly effective, localized, and enduring therapies for root canal disinfection and dental hypersensitivity.

Javier Plou

Accelerating ATMP Decision-Making with Plasmonic-Enhanced Raman

Javier Plou^{1,2}, Youngfen Li², Francisco Carretero³, María Armesto³, Charles Lawrie^{3,4}, Andreas Seifert^{2,4}

1 Prospect

2 CIC nanoGUNE

3 Biogipuzkoa

4 Ikerbasque

Abstract

Advanced Therapy Medicinal Products (ATMPs) are transforming the treatment of cancer and other severe diseases, but their widespread adoption remains limited by the lack of rapid, information-rich analytical tools capable of supporting both manufacturing and clinical decisionmaking. Current analytical workflows are often labor-intensive, require large sample volumes, and provide delayed results, limiting their utility in time-critical settings.

Prospect has developed a proprietary plasmonic-enhanced Raman metabolomics platform that enables rapid, label-free molecular fingerprinting from microliter-scale liquid samples without complex sample preparation. The platform combines disposable plasmonic sensing cartridges with a portable Raman reader and AI-powered data analysis, delivering actionable metabolic information in minutes. The technology is designed for seamless integration into existing ATMP manufacturing workflows and clinical environments.

The sensing platform requires less than 1 μL of sample, performs measurements in under 30 seconds, and uses low-cost disposable cartridges manufactured through scalable processes. By capturing rich metabolic fingerprints rather than individual biomarkers, the platform can simultaneously monitor multiple biochemical pathways associated with cell activation, metabolism, product quality, therapeutic efficacy, and toxicity.

As a proof of concept, the technology has been validated in the monitoring of CAR-T cell therapy, where longitudinal metabolic profiling of patient plasma enabled prediction of therapeutic response with up to 90% classification accuracy several days after infusion. The platform also identified metabolic signatures associated with treatment-related toxicities, including cytokine release syndrome (CRS) and immune effector cell-associated neurotoxicity syndrome (ICANS), demonstrating its potential to support early clinical intervention.

Beyond patient monitoring, Prospect is expanding the platform toward real-time bioprocess monitoring, enabling non-destructive assessment of cell cultures and manufacturing processes through rapid metabolic fingerprinting. This unified analytical approach has the potential to accelerate process development, improve product consistency, and support data-driven decisionmaking throughout the ATMP lifecycle.

By integrating plasmonic-enhanced Raman spectroscopy, advanced machine learning, and scalable disposable sensors, Prospect aims to establish a new generation of rapid metabolomics tools for advanced therapies, reducing analysis time, sample consumption, and operational complexity while enabling faster and more informed decisions in both manufacturing and clinical practice.

Cornel Dillinger

From Microrobotic Propulsion to Responsive Surfaces for Implants: Cleaning Indwelling Urinary Devices

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Abstract

In urological care, biofilm buildup is particularly harmful because it can block ureteral stents and bladder catheters, complicates their removal, and drives infections that can progress to kidney failure¹. Patients undergoing long-term interventions need frequent device replacements, stents every 2-6 months, catheters every 2-4 weeks. Existing antimicrobial coatings initially inhibit bacterial adhesion, however, the precipitation of salts present in urine (encrustation) ultimately nullifies the effectiveness of these coatings². Safe long-term solutions remain an unmet clinical need.

SonoStent (in preparation to spin-off) develops a device surface patterned with soft polymeric microstructures ("arrays of cilia") that are responsive to external ultrasound³. On demand, transcutaneous ultrasound drives acoustic streaming around the microstructures, detaching biofilm and encrustation without device removal and replacing recurrent cystoscopic exchanges with non-invasive outpatient sessions. The acoustic actuation principle originally designed to move untethered microrobots is anchored here to an implant, turning a microrobotic propulsion mechanism into a therapeutic function⁴.

Our proof-of-concept study demonstrated that ultrasound-activated cilia clear carbonate crystal encrustation and biofilm from a stent-on-chip model within seconds, with accompanying cell-viability assays confirming the actuation is biocompatible with relevant cell lines⁵.

The commercialisation strategy builds on decentralised, simplified outpatient care: a one-time device placement is followed by recurring cleaning sessions performed without surgery, constituting the primary source of recurring revenue for SonoStent. Near-term milestones include prototype validation (2026), porcine feasibility (2027), a GLP

pivotal study (2028), and first-in-human evaluation (2029), supported by a commercial-readiness round currently being raised ahead of Series A.

1. Amado, Pedro, et al. "The interplay between bacterial biofilms, encrustation, and wall shear stress in ureteral stents: a review across scales." *Frontiers in urology* 3 (2024): 1335414.

2. Khatoon, Zohra, et al. "Bacterial biofilm formation on implantable devices and approaches to its treatment and prevention." *Heliyon* 4.12 (2018).

3. www.sonostent.com

4. Dillinger, Cornel, Nitesh Nama, and Daniel Ahmed. "Ultrasound-activated ciliary bands for microrobotic systems inspired by starfish." *Nature communications* 12.1 (2021): 6455.

5. Amado, Pedro, et al. "Ultrasound-activated cilia for biofilm control in indwelling medical devices." *Proceedings of the National Academy of Sciences* 122.18 (2025): e2418938122.

Endika de la Iglesia

Physiological in vitro barrier models as New Approach Methodologies for functional and safety assessment of advanced therapeutic and delivery strategies

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Abstract

The clinical translation of advanced therapeutic strategies, including targeted drug delivery systems, cell-based therapies and emerging micro- and nanorobotic approaches, requires robust New Approach Methodologies (NAMs) that reproduce key biological barriers under physiologically relevant conditions. Such models are essential to generate predictive information on safety, efficacy, permeability and barrier interaction before progression to more complex preclinical studies.

This work describes the development and characterization of physiological barrier models across complementary in vitro formats, including conventional 2D cultures, Transwell-based systems and microfluidic barrier platforms. The established models include blood–brain barrier (BBB), intestinal and pulmonary barrier models designed to support cytotoxicity and barrier-function assessment, as well as the functional testing of therapeutic compounds, nanomaterials and delivery technologies¹⁻⁵.

Depending on the experimental format and biological question, these workflows combine cellular readouts with barrier-specific measurements, including cytotoxicity assays, reactive oxygen species quantification, permeability and molecular transport studies, and assessment of barrier integrity using TEER and impedancebased measurements. The use of multiple platforms enables comparison between scalable screening systems and more complex models that reproduce compartmentalization, directional transport and dynamic microenvironmental features.

Rather than focusing on the development of micro- or nanorobotic treatments, these models address a key translational need in the field: the availability of reliable, quantitative and physiologically relevant NAMs for preclinical testing. By integrating barrier biology, functional safety readouts and advanced in vitro culture systems, this platform may support the evaluation and optimization of future therapeutic, microrobotic and delivery technologies.

1. García-Salvador A, Domínguez-Monedero A, Gómez-Fernández P, García-Bilbao A, Carregal-Romero S, Castilla J, Goñi-de-Cerio F. Evaluation of the Influence of Astrocytes on In Vitro Blood–Brain Barrier Models. Alternatives to Laboratory Animals. 2020;48(4):184–200. DOI: 10.1177/0261192920966954.

2. García-Salvador A, Katsumiti A, Rojas E, Aristimuño C, Betanzos M, Martínez-Moro M, Moya SE, Goñi-de-Cerio F. A Complete In Vitro Toxicological Assessment of the Biological Effects of Cerium Oxide Nanoparticles: From Acute Toxicity to Multi-Dose Subchronic Cytotoxicity Study. *Nanomaterials*. 2021;11(6):1577. DOI: 10.3390/nano11061577.
3. Carrillo-Romero J, Mentxaka G, García-Salvador A, Katsumiti A, Carregal-Romero S, Goñi-de-Cerio F. Assessing the Toxicity of Metal- and Carbon-Based Nanomaterials In Vitro: Impact on Respiratory, Intestinal, Skin, and Immune Cell Lines. *International Journal of Molecular Sciences*. 2024;25(20):10910. DOI: 10.3390/ijms252010910.
4. Carrillo-Romero J, Fernández-Méndez L, de la Iglesia E, Katsumiti A, Germán L, Di Silvio D, Ruíz-Cabello J, Carregal-Romero S, Goñi-de-Cerio F. In Vitro Evaluation of the Effect of Size and PEGylation on Inhalable Liposomes for Pulmonary Drug Delivery. *Nanomaterials*. 2026;16(3):200. DOI: 10.3390/nano16030200.
5. Polanco-Garriz I, Carrillo-Romero J, Venäläinen M, Lyyränen J, Pulli H, Suhonen S, et al. Using simple to more robust in vitro methods based on human pulmonary models to evaluate the acute and subacute toxicity of micro- and nanoplastics derived from 3D printing materials. *NanoImpact*. 2026;42:100631. DOI: 10.1016/j.impact.2026.100631.

Mato Knez

From Bioinspiration to Functional Materials: Engineering through Atomic Layer Processing

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Abstract

Nature-inspired materials offer a powerful route toward advanced platforms for biomedical microrobotics and medical devices, yet reproducing the unique combination of mechanical robustness, adaptability, biocompatibility, and biological protection found in living systems remains challenging. Here, we present a materials engineering strategy based on Atomic Layer Processing (ALP), including Atomic Layer Deposition, Molecular Layer Deposition, and Vapor Phase Infiltration, to create multifunctional organic-inorganic hybrid materials with precisely tailored properties. By integrating inorganic building blocks into polymers and biopolymers with atomic- and molecular-scale control, ALP enables the fabrication of lightweight materials exhibiting enhanced mechanical strength, stiffness, toughness, and environmental stability while preserving flexibility and processability. Beyond reinforcement, the approach introduces functionalities that are highly relevant for medical applications. Controlled incorporation of bioinspired inorganic components generates antimicrobial and antifungal surfaces and textiles that suppress microbial colonization while remaining compatible with soft and flexible substrates. The resulting materials also show excellent biocompatibility, supporting their potential use in implantable, wearable, and human-facing technologies. Furthermore, selective infiltration and molecular design enable self-healing and self-repairing behaviors in soft electronic systems, increasing durability under repeated deformation and damage. These capabilities are particularly attractive for next-generation microrobotic systems, wearable sensors, and soft robotic devices operating in demanding biological environments. A key advantage of ALP is its scalability and ability to uniformly functionalize complex three-dimensional structures, porous networks, fibers, and soft materials. This combination of precision, multifunctionality, and industrial compatibility positions ALP as a transformative manufacturing platform for intelligent medical materials and microrobotic technologies requiring antimicrobial protection, antifungal resistance, biocompatibility, self-healing behavior, and superior mechanical performance.

Valentin Gantenbein

Swiss Vascular

Abstract

Swiss Vascular, an ETH Zurich spin-off, was founded to provide scientists and developers with highly realistic test environments that accurately reproduce anatomical and physiological properties for medical-device development and testing.

Using medical imaging data, such as CTA or MRI, its silicone models reproduce arbitrary vessel geometries with geometric accuracy exceeding 99.9% and vessel diameters down to 800 μm . The models exhibit a friction coefficient of 0.044, compared with a reported value of approximately 0.04 for human vessels, and surface roughness down to 0.338 μm .

An ultra-clear silicone formulation with a refractive index of 1.41 (matching glycerol-water blood-mimicking fluids) supports index-matched optical imaging, particle tracking, and quantitative flow visualization. Pulsena, a heart-mimicking pumping system, provides controlled pulsatile circulation with adjustable physiological pressure profiles. Together, these capabilities support reproducible device testing and translation from in vitro experiments to in vivo studies.

The company's full simulators integrate artificial X-ray visualization for accurate procedural workflow testing and are widely used in medical education and surgeon training.

Posters

P1. Ana Sánchez Iglesias

Tailoring gold bipyramids for photothermal applications

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Ana Iglesias is the PI of the work

Plasmonic nanoparticles with five-fold symmetry offer an important advantage over their single-crystalline analogs due to their superior structural stability. The concentration of Au seeds is the sole factor determining the size and/or aspect ratio, and thus the optical properties of the nanoparticles. As a result, varying nanoparticle volumes while keeping their optical spectra unchanged remains a synthetically non-trivial task. We expand the chemical space for the synthesis of highly monodisperse penta-twinned gold bipyramids, achieving yields approaching 100%. In particular, we found that the combination of bromide ions and seed concentration allows for tailoring the dimensions and aspect ratio of gold bipyramids¹, enabling modulation of nanoparticle volumes while keeping their optical spectra unchanged. By exposing the nanoparticles to a constant position of the plasmon band under NIR laser irradiation, we found that larger AuBPs exhibited lower efficiencies, due to increased scattering contributions².

1. A. Sánchez-Iglesias, M. Grzelczak, *Small* **2025**, 21, 2407735.

2. A. M. Naik, A. Sánchez-Iglesias, J. L. Montaña-Priede, N. M. D'souza, J. Sancho-Parramon, S. A. Mezzasalma, A. Rao, M. Grzelczak, *Adv. Opt. Mater.* **2025**, 13, e01006.

P2. Jiaqi Yuan

An intracellular magnetic nanomotor drives programmable regulation of autophagy for peripheral nerve regeneration

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Persistent myelin debris creates a chronic inhibitory microenvironment that severely impairs peripheral nerve regeneration¹. Schwann cell autophagy is essential for myelin clearance², yet pharmacological strategies remain limited by systemic toxicity, rapid metabolism, irreversible activation, and poor spatiotemporal control^{3,4}. Force is a nonconsumable physical signal that can be delivered remotely, tuned in magnitude and frequency, and reapplied without adding molecular burden⁵; magnetic fields are particularly suited to this role because they penetrate tissue deeply and act noninvasively.

We therefore established dynamic force as a programmable regulator of autophagy. Ferrimagnetic vortex domain nanorings (FVIOs) were engineered as lysosome-localized intracellular nano-actuators and driven remotely by a rotating magnetic field to exert controllable micro-magnetic forces on Schwann cells with subcellular precision. Force regulated autophagy in a sharply window-dependent manner: 12–23 pN at 2–4 Hz reversibly induced lysosomal mechanical stress and promoted productive autophagic flux, whereas forces above 23 pN at frequencies above 5 Hz caused irreversible lysosomal disruption and autophagic blockade, both in vitro and in vivo.

Mechanistically, force within the effective window upregulated the Gal3-Trim16 axis, identifying it as a key mediator of force-triggered autophagy. At the subcellular level, magnetic actuation promoted the assembly of FVIOs into chain-like structures within lysosomes, and the resulting rotational-bouncing motion generated picoNewton-scale forces that remodeled lysosomal membrane mechanics.

Functionally, cyclic force activation accelerated myelin debris clearance, remodeled the inhibitory regenerative niche, and promoted axonal regrowth and motor recovery after peripheral nerve injury. In a sciatic nerve injury model, FVIO delivery combined with rotating magnetic stimulation improved remyelination, restored sciatic functional index scores, and limited denervation-associated muscle atrophy relative to untreated injured controls.

These findings define an actionable force-autophagy window and establish a precise, reversible, and repeatable mechanobiology-based strategy for neural repair. By decoupling autophagy control from chemical inducers, this platform offers a general route to program intracellular degradation on demand.

1. Vargas, M. E., Watanabe, J., Singh, S. J., Robinson, W. H., and Barres, B. A. (2010). Endogenous antibodies promote rapid myelin clearance and effective axon regeneration after nerve injury. *Proc. Natl. Acad. Sci. U.S.A.* 107, 11993- 11998.
2. Gomez-Sanchez, J. A., Carty, L., Iruarizaga-Lejarreta, M., Palomo-Irigoyen, M., Varela-Rey, M., Griffith, M., Hantke, J., Macias-Camara, N., Azkargorta, M., Aurrekoetxea, I., Gutierrez de Juan, V., Jefferies, H. B. J., Aspichueta, P., Elortza, F., Aransay, A. M., Martinez-Chantar, M. L., Baas, F., Mato, J. M., Mirsky, R., Woodhoo, A., and Jessen, K. R. (2015). Schwann cell autophagy, myelinophagy, initiates myelin clearance from injured nerves. *J. Cell Biol.* 210, 153- 168.
3. Li, R., Li, D., Wu, C., Ye, L., Wu, Y., Yuan, Y., Yang, S., Xie, L., Mao, Y., Jiang, T., Li, Y., Wang, J., Zhang, H., Li, X., and Xiao, J. (2020). Nerve growth factor activates autophagy in Schwann cells to enhance myelin debris clearance and to expedite nerve regeneration. *Theranostics* 10, 1649-1677.
4. Sarkar, S., Ravikumar, B., Floto, R. A., and Rubinsztein, D. C. (2009). Rapamycin and mTOR-independent autophagy inducers ameliorate toxicity of polyglutamine-expanded huntingtin and related proteinopathies. *Cell Death Differ.* 16, 46- 56.
5. Li, Y., Guo, Z., Fan, J., Zhou, R., Li, J., Hu, Z., Gu, W., Zheng, M., Xu, C., Tang, Y., Chen, C., and Cheng, Y. (2025). Intracellular mechanical stress-mediated autophagy cell death via nanospikes for cancer treatment. *Adv. Sci.* 13, e12256.

P3. Maria Soledad Orellano

Rational design of responsive nanogels for the treatment of genetic skin diseases

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Therapeutic treatment of severe skin diseases often alleviates symptoms without addressing the underlying cause. Genetic skin diseases, resulting from mutations that reduce or eliminate protein synthesis, could benefit from the local substitution of the missing protein¹. However, biomacromolecules are excluded from topical applications due to their high molecular weight and hydrophilicity, requiring specific carrier systems. Here, we develop polymeric nanogels (NGs) capable of encapsulating and transporting biomacromolecules into the skin, releasing them upon an environmental trigger²⁻³. N-isopropylacrylamide (NIPAM)-based NGs were rationally designed to enable efficient encapsulation of therapeutic biomacromolecules while providing tunable physicochemical properties, high colloidal stability, and excellent biocompatibility. Comprehensive physicochemical characterization confirmed the formation of well-defined NGs with controllable size, surface properties, and high loading capacity for protein-based therapeutics. Their cellular internalization, intracellular trafficking and interaction with in vitro skin 3D models was investigated. To achieve localized administration, the NG formulations were incorporated into a minimally invasive topical delivery platform capable of bypassing the stratum corneum and depositing the cargo directly into the viable epidermis. Our results showed that this combined delivery strategy enabled efficient transport of biologically active biomacromolecules into human skin while maintaining their functional activity after administration. Evaluation in advanced human skin models demonstrated localized biological responses consistent with intracellular delivery of active therapeutic cargo and restoration of disease-relevant cellular functions, highlighting the potential of this platform for treating inherited skin disorders. Beyond protein replacement, the modular design of these NIPAM-based NGs provides a versatile platform that can be adapted for the delivery of a broad range of therapeutic biomacromolecules, including emerging biologics and genome-engineering systems, while maintaining localized delivery and minimizing systemic exposure. Collectively, this work demonstrates that stimuli-responsive polymeric NGs represent a promising non-viral strategy for the cutaneous delivery of biomacromolecules. Their combination of efficient encapsulation, controlled release, excellent biocompatibility, and compatibility offers a versatile platform for localized therapy of genetic and acquired skin diseases and provides a foundation for the development of next-generation precision treatments targeting epithelial tissues.

1. N. Tiwari et al. *Angewandte Chemie Int. Ed.*, 2022, 61, e202107960

2. M. Witting et al. *Nanomedicine: Nanotechnology, Biology, and Medicine*, 2015, 11, 1179-1187

3. R. Plank et al. *Journal of Investigative Dermatology*, 2019, 139, 1191-1195.

P4. Mine Demir Khan

The Theranostic Diamond: HER2-Targeted Nanodiamonds for T1-Weighted MRI and Repurposed Ivermectin Delivery in Breast Cancer

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Magnetic resonance imaging (MRI) is a standard and critical method in clinical practice as a non-ionizing imaging modality capable of high-resolution deep-tissue imaging. Although it stands as a cornerstone of modern oncological diagnostics by offering exceptional soft-tissue contrast, the integration of real-time diagnostic imaging with targeted therapeutics—known as theranostics—remains a critical frontier for overcoming aggressive malignancies such as HER2-positive breast cancer. Furthermore, there is a growing clinical need for alternative T1-enhancing contrast agents, as conventional gadolinium-based contrast agents raise safety risks¹. To address this, the smallest nanoscale diamond particles, detonation nanodiamonds (NDs), have emerged as promising alternatives reported to effectively reduce longitudinal relaxation time (T1) and provide robust signal enhancement². In this study, we exploit the

intrinsic properties of NDs to significantly enhance longitudinal T1 magnetic resonance contrast, providing concentration-dependent signal enhancement that enables precise, noninvasive tracking of the nanoparticles via T1-weighted MRI. To translate this imaging capability into a targeted therapeutic vehicle, air-oxidized nanodiamonds were engineered into a core-shell structure by non-covalently wrapping them with a Bovine Serum Albumin (BSA) protein corona. The albumin shield provides exceptional structural stabilization for the BSA-NDs, preventing their inherent tendency to undergo severe aggregation and ensuring colloidal stability³. Active cellular targeting of this highly stable nanoparticle system was achieved by covalently conjugating an anti-HER2 monoclonal antibody (HER-BSA-NDs).⁴ Using the hydrophobic domains of the adsorbed BSA layer, the platform successfully encapsulated ivermectin (IVM)—a highly potent, repurposed antiparasitic drug capable of inducing apoptosis and immunogenic cell death in breast cancer cells⁵—whose clinical translation has historically been hindered by its extreme hydrophobicity and poor systemic solubility. *In vitro* evaluation with SKBR-3 cells demonstrated that functionalization with the anti-HER2 monoclonal antibody facilitated rapid, receptor-mediated endocytosis specifically in HER2-overexpressing breast cancer cell lines compared with non-targeted controls. Following internalization, IVM-loaded, anti-HER2-conjugated IVM/HER-BSA-NDs exhibited enhanced IVM delivery to cells, resulting in improved cell killing compared to the free drug. By sequentially linking intrinsic T1 MRI contrast, exceptional structural particle stability, anti-HER2 antibody precision, and the controlled delivery of a repurposed chemotherapeutic, IVM/HER-BSA-NDs offer a powerful, highly integrated strategy for image-guided breast cancer theranostics.

1. Do, C., DeAgüero, J., Brearley, A., Trejo, X., Howard, T., Escobar, G. P., & Wagner, B. (2020). Gadolinium-Based Contrast Agent Use, Their Safety, and Practice Evolution. *Kidney360*, 1(6), 561-568. <https://doi.org/10.34067/kid.0000272019>
2. Lazovic, J., Goering, E., Wild, A. M., Schützendübe, P., Shiva, A., Löffler, J., Winter, G., & Sitti, M. (2024). Nanodiamond-Enhanced Magnetic Resonance Imaging. *Advanced Materials*, 36(11), 2310109. <https://doi.org/10.1002/adma.202310109>
3. Khanal, D., Lei, Q., Pinget, G., Cheong, D. A., Gautam, A., Yusoff, R., ... & Chrzanowski, W. (2020). The protein corona determines the cytotoxicity of nanodiamonds: implications of corona formation and its remodeling on nanodiamond applications in biomedical imaging and drug delivery. *Nanoscale Advances*, 2(10), 4798-4812. <https://doi.org/10.1039/d0na00231c>
4. Zhang, T., Cui, H., Fang, C. Y., Cheng, K., Yang, X., Chang, H. C., & Forrest, M. L. (2015). Targeted Nanodiamonds as Phenotype-Specific Photoacoustic Contrast Agents for Breast Cancer. *Nanomedicine*, 10(4), 573-587. <https://doi.org/10.2217/nnm.14.141>
5. Olunga, R., Jaoko, W., Kipkoech, R., Natalia, G., Tai, R. J., Mutanu, L., ... & Anosike, U. G. (2026). Molecular targets of ivermectin as a potential repurposed drug in cancer therapy: A scoping review. *World Journal of Meta- Analysis*, 14(2), 121391.

P5. Soumen Ghosh

A Dual-Action Dendritic Molecular Glue Enables Caspase-3 Delivery and Survivin-IAP Axis Engagement for Amplified Cancer Cell Apoptosis

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Apoptosis, also known as programmed cell death, is a natural process that eliminates damaged, abnormal, or unwanted cells from the body. Central to this process is Caspase-3, the terminal executioner protease, which orchestrates the irreversible dismantling of cellular components, ultimately leading to cell death. However, apoptosis resistance remains a major challenge, often arising from the overexpression of inhibitor-of-apoptosis proteins (IAP) such as Survivin, which suppresses Caspase-3-mediated cell death. Here, we report a dual-action dendritic molecular glue, AbGlue, designed to combine intracellular Caspase-3 delivery with engagement of the Survivin-IAP axis. AbGlue contains multivalent guanidinium groups that form reversible salt-bridge interactions with Caspase-3,

enabling intracellular delivery while maintaining the enzyme in a temporarily inhibited state. Incorporation of a Survivin-binding Abbott ligand allows the system to interact with Survivin, restoring Caspase-3 activity and simultaneously reducing Survivin-mediated apoptosis resistance. In vitro enzymatic studies showed that AbGlue induced inhibition of Caspase-3 activity was restored after addition of Survivin. In HeLa cells, the AbGlue/Caspase-3 complex promoted direct cytosolic delivery, enhanced Caspase-3 activation, and induced stronger apoptosis compared with ligand-free control. This dual-function molecular glue strategy provides a promising platform for amplifying Caspase-3-mediated cancer cell apoptosis by combining protein delivery with suppression of an endogenous survival pathway.

1. N. B. Hentzen, R. Mogaki, S. Otake, K. Okuro, T. Aida, J. Am. Chem. Soc. 2020, 142, 18, 8080–8084
2. R. Mogaki, P. K. Hashim K. Okuro, T. Aida, Chem. Soc. Rev. 2017, 46, 21, 6480–6491.
3. S. Shin, B. J. Sung, Y. S. Cho, H. J. Kim, N. C. Ha, J. I. Hwang, C. W. Chung, Y. K. Jung, B. H. Oh, Biochemistry 2001, 40, 1117–1123.

P6. Amelia Franchin

Characterization of MLD thin-film coatings for polymeric biomedical microdevices

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Polymeric microdevices are increasingly employed in biomedical applications because of the versatility with which they can be fabricated into complex geometries while exhibiting tunable mechanical properties and biocompatibility. Applications range from minimally invasive microneedles for biosensing and drug delivery to microrobots for targeted therapeutic interventions. Despite their diversity, successful clinical translation depends on controlling device interactions with biological environments, motivating the development of advanced surface-engineering strategies. Thin-film surface functionalization using atomic layer deposition (ALD) and molecular layer deposition (MLD) offers a promising approach for tailoring these interfaces, particularly because these techniques enable conformal, low-temperature coating of temperature-sensitive polymeric substrates.¹⁻⁴ This project investigates the use of ALD and MLD thin-film coatings to engineer the surface physicochemical and mechanical properties of medical microdevices. The objective is to identify coatings that improve surface characteristics while preserving or even enhancing the mechanical integrity and intended functionality of the device.

Simplified flat polymer prisms, representing the constituent materials for various microdevices and microrobots, were fabricated by two-photon polymerization using the Nanoscribe Quantum X shape system to enable systematic characterization of candidate ALD/MLD coatings. Polymerized IPX-Q photoresist specimens were coated with titanium-ribose hybrid thin films by MLD using 100 deposition cycles at a chamber temperature of 95°C. Mechanical characterization was performed using nanoindentation (CETR UMT) to determine Young's modulus and hardness, while surface wettability and morphology were evaluated by contact-angle measurements and scanning electron microscopy (SEM), respectively. Candidate coatings demonstrating favorable physicochemical properties will subsequently be applied to the complete microdevices for biological and functional evaluation. X-ray reflectivity (XRR) measurements of a silicon reference substrate coated in the same deposition batch indicate the deposition of

an approximately 16 nm titanium-ribose hybrid film following 100 MLD cycles. The well-defined Kiessig fringes observed in the XRR oscillation curve indicated the formation of a smooth film with low interfacial roughness. Preliminary nanoindentation measurements of coated IPX-Q prism substrates, analyzed using linear mixed-effects modeling, demonstrated increased Young's modulus and hardness compared with uncoated controls, with the statistical model accounting for repeated indentations nested within regions and samples. Owing to the limited number of independent specimens, these findings should be considered preliminary. Static water contact-angle measurements suggested increased surface hydrophilicity after titanium-ribose coating. These preliminary findings indicate that ALD/MLD thin-film coatings can modify the mechanical and surface properties of polymeric biomedical substrates. Ongoing biological characterization will determine whether these physicochemical modifications translate into improved biological compatibility and reduced tissue interaction, supporting the future development of coated medical microdevices.

1. Luo X, Yang L, Cui Y. Microneedles: materials, fabrication, and biomedical applications. *Biomed Microdevices*. 2023;25(3):20. doi:10.1007/s10544-023-00658-y.
2. Yin J, Luan S. Opportunities and challenges for the development of polymer-based biomaterials and medical devices. *Regen Biomater*. 2016;3(2):129-135. doi:10.1093/rb/rbw008.
3. Pessoa RS, Fraga MA. Biomedical applications of ultrathin atomic layer deposited metal oxide films on polymeric materials. In: Benelmekki M, Erbe A, editors. *Frontiers of Nanoscience*. Vol. 14. Amsterdam: Elsevier; 2019. p. 291-307. doi:10.1016/B978-0-08-102572-7.00011-8.
4. Wang W, Fernandez AS, Botta G, et al. Conformal Metallosaccharide Hybrid Films for Protecting Wood Surfaces From Environmental Damage. *Adv Funct Mater*. 2026;36(53):e76434. doi:10.1002/adfm.76434

P7. Andrea García Lizarribar

Microfluidic platform for standardized evaluation of magnetically guided microrobots in cell-based therapies

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Magnetically controlled microrobots are emerging as promising tools for precision medicine, particularly in targeted cell-based therapies such as immunotherapy^{1,2}. However, the transition of these systems from laboratory concepts to clinically relevant solutions is hindered by the lack of standardized, scalable, and biologically compatible testing platforms. Current in vitro approaches often depend on complex electromagnetic infrastructures and fabrication processes that limit reproducibility, accessibility, and integration into translational workflows.

In this work, we present a user-oriented microfluidic platform specifically designed to bridge this gap and facilitate the translational development of magnetically guided microrobots. The system combines stereolithography-based fabrication with a compact magnetic actuation module, enabling a simplified yet robust environment for controlled evaluation under physiologically relevant conditions. The use of additive manufacturing allows rapid prototyping and reproducible production of microfluidic chips, while ensuring optical transparency and biocompatibility suitable for long-term cell culture and advanced imaging.

The proposed platform enables precise spatial control of microrobots within microfluidic channels using an intuitive magnetic steering mechanism, eliminating the need for bulky or highly specialized instrumentation. Its dual operation modes—continuous flow and static conditions—support the investigation of both dynamic interactions and localized

therapeutic effects. This versatility is particularly relevant for modelling key aspects of therapeutic delivery, including targeting efficiency, interaction with cellular environments, and localized response.

Overall, this work introduces a scalable and accessible testing framework that addresses critical bottlenecks in the translational pathway of microrobotics. By simplifying operation, improving reproducibility, and enabling biologically relevant assays, the platform contributes to accelerating the validation and future clinical integration of magnetic microrobots in advanced therapeutic strategies.

1. Medina-Sánchez, M., & Schmidt, O. G. (2017). Medical microbots need better imaging and control. *Nature* 2017 545:7655, 545(7655), 406–408. <https://doi.org/10.1038/545406a>

2. Gwisai, T., Günther, S., Mirkhani, N., Vizovisek, M., Menghini, S., Jacobs, M., Christiansen, M. G., Oberhuber, I., Poc, P., & Schuerle, S. (2024). Engineering Living Immunotherapeutic Agents for Improved Cancer Treatment. *Advanced Therapeutics*, 7(4), 2300302. <https://doi.org/10.1002/ADTP.202300302>

P8. Bahar Pehlivanöz

Tunable Acoustic Contrast Factor of Hollow Core-Shell Microrobots

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Acoustically responsive microparticles have significant potential as ultrasound-controlled microrobots for targeted therapy and drug delivery. Size adaptation and selective manipulation of acoustic microrobots in vascular environments requires precise control over particle geometry and hence the acoustic response. Existing acoustofluidic platforms enable wall trapping/manipulation of solid microparticles and cells, which often have a positive acoustic contrast factor that results in similar non-selective trapping behaviors¹. However, there is little experimental evidence on how the synthetic particle geometry and material design can create zero or negative acoustic contrast factor to enable selective acoustic manipulation of microrobots. Here, we synthesize hollow core-shell particles with tunable shell thickness to exploit the zero/negative acoustic contrast factor for selective acoustic response.

We use a soft templating method² to form droplet emulsions between 500 nm – 2 µm diameters. Then through sol-gel chemistry, a silica shell was grown on the droplets as a hard material to form a stable microsphere. Consequently, after the core-removal, hollow silica microparticles were fabricated. For reaching monodispersed emulsion and particle sizes, a tip sonicator with optimized sonication duration was used. To characterize particle structure and morphology, we used optical microscopy and scanning electron microscopy (SEM), and determined average size and polydispersity using static light scattering (SLS). We performed acoustic manipulation experiments in a 220 µm-diameter cylindrical microchannel mounted on a glass slide and coupled to a piezoelectric transducer. Flexural-wave excitation was applied from 100 to 200 kHz, and the responses of hollow particles with those of 1 and 2 µm solid silica particles were analysed. The 2 µm solid particles exhibited pronounced soft-wall trapping, whereas 1 µm silica particles showed weaker displacement due to reduced particle size and lower acoustic radiation force. In contrast, the hollow particles displayed localized motion and oscillatory streaming behavior distinct from conventional wall-directed trapping.

Further, to gain insights on the acoustophoretic motion of the particles, we used theoretical calculations based on the experimental parameters. For measured shell thickness of 76 ± 45 nm ($n=35$), and average particle size of 1 µm, the calculated acoustic contrast factor and acoustic radiation force were calculated as 0.204, 1.09 fN. The calculated

acoustic contrast factor, depending on effective density, compressibility, and acoustic radiation force can only change from positive to negative when the core-to-particle radius ratio reaches a minimum of $\alpha = r_i/r_o \approx 0.91$. Another parameter that can affect the acoustic forces will be the material property, which we predicted for Borosilicate glass, PMMA and PLGA.

These findings establish hollow-microparticle geometry as a tunable design parameter for controlling acoustic contrast factor and particle transport under flexural-wave excitation, while shell-material selection can further shift the predicted contrast-reversal conditions. The resulting design framework provides target geometries for the future fabrication of PMMA- and PLGA-based acoustically responsive carriers, offering a design guideline for ultrasound-responsive microrobotic navigation and drug delivery in vascular-scale environments.

1. Aghakhani, Amirreza, Hakan Cetin, Pelin Erkoc, Guney Isik Tombak, and Metin Sitti. "Flexural wave-based soft attractor walls for trapping microparticles and cells." *Lab on a Chip* 21, no. 3 (2021): 582-596.
2. Zoldesi, Carmen I., and Arnout Imhof. "Synthesis of monodisperse colloidal spheres, capsules, and microballoons by emulsion templating." *Advanced Materials* 17, no. 7 (2005): 924-928.
3. Wu, Di, Diego Baresch, Colin Cook, Zhichao Ma, Mengtong Duan, Dina Malounda, David Maresca et al. "Biomolecular actuators for genetically selective acoustic manipulation of cells." *Science Advances* 9, no. 8 (2023): eadd9186.
4. Leão-Neto, J. P., J. H. Lopes, and G. T. Silva. "Core-shell particles that are unresponsive to acoustic radiation force." *Physical Review Applied* 6.2 (2016): 024025.

P9. Barbara Nessiem

How Functional Is Functionalization? Quantifying Surface Bioconjugation on Janus Microrobots towards cellular modification

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Microrobotic systems offer a tailorable theranostic system that proves to be promising in surgical applications, biosensing, cargo delivery and even fertilization¹. Of those microrobotic systems is the Janus magnetic microrobots; the surface functionalization of Janus microrobots through bioconjugation plays a pivotal role in determining their specific targeting capability, colloidal stability, and therapeutic performance.

However, the quantitative assessment of bioconjugated functional groups and specific targeting efficiency remains challenging, with most studies relying on qualitative characterization methods^{2,3}. The major research question is how we can establish a design guideline for particle-based microrobotic drug delivery systems with the highest loading efficacy. In this study, we aim at identifying the maximum quantitative limit of antibody to antigen binding that can be loaded on the surface of our system. Further, we focus on the quantification of delivered liposomes with loaded Doxorubicin – a chemotherapeutic drug and quantifying the functional groups required to effectively and selectively bind to cancer cells to induce apoptosis. We systematically evaluate key surface parameters, including functional group density, conjugation efficiency, and surface accessibility. We employ techniques including cell counting, flow cytometry, fluorescence imaging, spectrophotometry and Enzyme-linked Immunosorbent Assay (ELISA) to incorporate the analysis of all physical and biochemical attributes of our system. We used Janus (Nickel+Gold coating on the half-surface) and plain spherical particles of 5µm in diameter to perform the quantitative analysis of the functional groups. Since quantifying the loading of functional groups will be directly proportional to the amount

of Streptavidin bound to the Janus microrobots, we conducted flow cytometry to determine the quantity and homogeneity of the Streptavidin bound.

The Janus microrobots showed at least half of the Streptavidin quantity compared to that in the plain microparticles, confirming the asymmetric binding due to the presence of AuNi cap. The Janus microrobots were then studied for their ability to be loaded with 160 nm of Doxorubicin loaded liposomes that each carried a X $\mu\text{g}/\text{mg}$ load of Doxorubicin. The maximum volume of the conjugated liposomes was obtained by a Tecan multimode microplate reader via measuring fluorescence before and after conjugation, enabling the determination of drug loading efficiency and loading capacity. As a final step the amount of Biotinylated Cetuximab was quantified using an ELISA to determine the amount of Cetuximab required for effective targeting of EGFR-overexpressing cancer cells.

Preliminary findings demonstrate the feasibility of a stepwise quantitative characterization strategy that independently evaluates each functional component of the bioconjugation process. The developed workflow enables the assessment of Streptavidin functionalization efficiency, liposomal drug carriers loading, and antibody conjugation while providing insight into the reproducibility and uniformity of surface functionalization. This study establishes a standardized methodology for correlating surface chemistry with the functional performance of Janus microrobots, providing a robust framework for the rational design and optimization of targeted drug delivery systems.

1. U. Bozuyuk, P. Wrede, E. Yildiz, M. Sitti, Roadmap for Clinical Translation of Mobile Microrobotics. *Adv. Mater.* 2024, 36, 2311462. <https://doi.org/10.1002/adma.202311462>
2. Yunus Alapan et al. ,Multifunctional surface microrollers for targeted cargo delivery in physiological blood flow. *Sci. Robot.* 5, eaba5726(2020). DOI:10.1126/scirobotics.aba5726
3. G. Aybar Tural, U. Bozuyuk, N. O. Dogan, Y. Alapan, M. B. Akolpoglu, A. Aghakhani, J. Lazovic, O. Ozer, M. Sitti, Magnetic Mesoporous Janus Microrollers for Combined Chemo- and Photothermal Ablation Therapy. *Adv. Therap.* 2024, 7, 2300319. <https://doi.org/10.1002/adtp.202300319>

P10. Chiara Catania

Toward Tumor Penetration: Preliminary Barrier Crossing of GUV-Based Microrobots in 3D Environments

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Cancer remains one of the major challenges in modern medicine, motivating the development of more precise and less invasive therapeutic approaches¹. Microrobots are emerging as promising tools for targeted drug delivery and minimally invasive therapies². To reach a tumor site, microrobots must move through complex biological barriers such as endothelial layers, extracellular matrices, and narrow intercellular spaces. In this work, we investigate the ability of biomimetic microrobots based on Giant Unilamellar Vesicles (GUVs) to deform and cross porous barriers, an important requirement for future biomedical applications^{3,4}.

Magnetic GUVs were fabricated using a droplet transfer method⁵. The vesicles consisted of a phospholipid bilayer membrane and encapsulated an aqueous ferrofluid, allowing magnetic actuation. The produced GUVs typically exhibited diameters between 50 and 100 μm , making membrane deformation essential for transport through micrometric pores. Preliminary osmolarity tests were performed to evaluate vesicle stability and deformation under different external conditions. Hypertonic environments promoted partial vesicle deflation and suggested possible strategies to improve deformability.

To evaluate barrier crossing, magnetic GUVs were tested using a custom 3D-printed insert with porous membranes. Pore sizes of 5 μm , 2 μm , and 0.4 μm were selected to investigate the ability of microrobots to cross barriers with different pore sizes. A permanent magnet was used to drive the vesicles toward the membrane. After the experiment, the solution collected below the membrane was analyzed by phase-contrast microscopy to evaluate microrobot transport.

The results showed that magnetic GUVs were able to cross the 5 μm membrane under magnetic actuation. In contrast, no vesicles were detected below the 2 μm or 0.4 μm membranes. These findings suggest that the current GUV formulation is not able to deform sufficiently to pass through highly restrictive pores. Vesicle size, membrane composition, and osmotic conditions are therefore key factors influencing transport efficiency.

In conclusion, this study is a first step toward understanding how GUV-based microrobots can cross physical barriers relevant to tumor targeting. While GUVs were able to cross 5 μm pores, no transport was observed through 2 μm or 0.4 μm pores, indicating that further optimization of vesicle deformability is required. Current studies are focused on the interaction between magnetic GUVs and tumor cells to better understand their behavior in biological environments. The next step will be the use of tumor spheroids, which provide a more realistic three-dimensional tumor model, to investigate microrobot penetration, navigation through the small spaces between cells, and distribution within tumor-like tissues. These studies will help assess the potential of GUV-based microrobots to reach regions that are difficult to access with conventional therapies.

1. Tang, M. *et al.* Innovative theranostic hydrogels for targeted gastrointestinal cancer treatment. *J Transl Med* 22, 970 (2024).
2. Hou, Y. *et al.* A review on microrobots driven by optical and magnetic fields. *Lab on a Chip* 23, 848–868 (2023).
3. Waeterschoot, J., Gosselé, W., Lemež, Š. & Casadevall i Solvas, X. Artificial cells for in vivo biomedical applications through red blood cell biomimicry. *Nat Commun* 15, 2504 (2024).
4. Fletcher, M., Elani, Y., Keyser, U. F. & Tivony, R. Giant unilamellar vesicles as a model system for studying ion transport. *Biophys Rev* 17, 1105–1118 (2025).
5. Using the Droplet Transfer Method to Reliably Prepare Giant Unilamellar Vesicles. <https://app.jove.com/t/68340/using-droplet-transfer-method-to-reliably-prepare-giantunilamellar>.

P11. David Castellanoes-Robles

Multifunctional soft biodegradable microrobots for drug delivery and reproduction medicine

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This work focuses on the development of multifunctional, soft, biodegradable microrobots fabricated through droplet microfluidics for biomedical applications. These microrobots integrate medicine, microfabrication, and nanomaterials at multiple levels, to provide functionalization and actuation, enabling effective operation at the microscale under physiological conditions. In particular, the research explores droplet microfluidics as a versatile and scalable fabrication strategy for producing hydrogel-based microsystems with controlled size, composition, and functionality under mild processing conditions.

Using alginate and gelatin, different classes of microscale carriers were engineered and tailored for targeted delivery and biomedical intervention. A key feature of this approach is its versatility in integrating functional components

directly during fabrication. By incorporating a broad range of nanomaterials—including magnetic, upconversion, plasmonic, and gas-filled nanoparticles, as well as liposomal and polymersomal systems—the resulting microcarriers can be endowed with capabilities such as active navigation, real-time imaging, remote actuation, and environmentally triggered responses. In parallel, therapeutic and biological cargos, including drugs, DNA, and enzymes, can be encapsulated and transported within the same platform.

Large-scale production of uniform, monodisperse capsule microrobots was achieved using droplet microfluidics. The use of hydrogels provided enhanced biocompatibility in the performed assays. Magnetic actuation was demonstrated over extended periods (>10 h) of continuous closed-loop control under human body-like flow and viscosity conditions, as well as during interactions with different cell types. Hybrid ultrasound and photoacoustic imaging capabilities were achieved by incorporating light-absorbing and gas-filled particles into the capsules. Controlled degradability was enabled through chemical modification of the hydrogel matrix, allowing tunable degradation kinetics and, consequently, controlled drug-release rates. Altogether, by combining precise microscale fabrication with the integration of functional nanomaterials and therapeutic agents, this strategy provides a versatile foundation for future applications in targeted drug delivery, diagnostics, localized therapy, and minimally invasive medicine.

1. David Castellanos-Robles, Farzin Akbar, and Mariana Medina-Sánchez. "Geometry matters: Gamete transport using magnetic microrobots." (2024): 540-551.
2. David Castellanos-Robles, Raphaël CL-M. Doineau, Azaam Aziz, Richard Nauber, Song Wu, Silvia Moreno, Konstantina Mitropoulou, Franziska Hebenstreit, and Mariana Medina-Sánchez. "Multimodal Imaging, Drug Delivery, and On-Board Triggered Degradation in Soft Capsule Rolling Microrobots." *Advanced Intelligent Systems* 6, no. 12 (2024): 2400230.
3. Aziz, Azaam, David Castellanos-Robles, Zhi Chen, Ronald Naumann, Harini Raghu Kumar, Richard Nauber, Carla Ribeiro, Ripla Arora, and Mariana Medina-Sánchez. "Magnetically Controlled Microrobots for In Vivo Non-Invasive Embryo Transfer." *bioRxiv* (2025): 2025-09.
4. Sumaiya Tahera Rahman, David Castellanos-Robles, Fatemeh Rajabasadi, and Mariana Medina-Sánchez. "Optimization of Smart Microactuators Utilizing 2D and 3D Lithography." In *2024 International Conference on Manipulation, Automation and Robotics at Small Scales (MARSS)*, pp. 1-6. IEEE, 2024.

P12. Debayan Dasgupta

A wireless implantable light source and magnetically steered microcarriers for deep-tissue upconversion imaging in vivo

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Near-infrared upconversion nanoparticles (UCNPs) are attractive reporters for deep-tissue imaging and light-triggered therapy¹, but external excitation is attenuated on both the excitation and the emission path, so the

usable signal decays double-exponentially with depth. We show that relocating the light source into the body, co-localised with the UCNP, and adding magnetic control of both the source and UCNP-loaded microcarriers, could overcome this limit and enable imaging together with steered cargo transport at depth.

We built a miniaturised ($0.4 \times 0.5 \times 0.2$ mm), inductively powered implantable infrared LED, driven wirelessly by a ~900 MHz phased-array transmitter². UCNP-loaded gelatin microcarriers (~75 μ m) containing iron nanorods were produced by microfluidic droplet generation. Optical attenuation was quantified in undiluted Intralipid phantoms; magnetic actuation was characterised under a rotating field ($B_0 = 500$ G); and the system was validated in the peritoneal cavity of an immunodeficient mouse.

Co-localising the source eliminates the excitation path and produces a signal advantage that grows exponentially with depth. We demonstrate that one-way illumination extended the visibility limit from 1.0 to 2.0 mm, a depth at which two-way laser illumination gave no detectable signal. In vivo, X-ray confirmed magnetic reorientation of the implant, and UCNP fluorescence tracked microcarrier displacement, steering carriers to trace the letters “I” and “T”. By unifying wireless implantable illumination with frequency-selective magnetic control of microrobotic carriers, the platform offers a route to deep-tissue imaging and targeted transport in settings such as intraperitoneal disease that are poorly served by intravital or two-photon microscopy.

1. Medina-Sánchez, M., Schmidt, O. Medical microbots need better imaging and control. *Nature* **545**, 406–408 (2017).
2. Bandari, V.K., Nan, Y., Karnaushenko, D. *et al.* A flexible microsystem capable of controlled motion and actuation by wireless power transfer. *Nat Electron* **3**, 172–180 (2020).

P13. Ekaterina Kvitka

Dissolvable Hydrogel Microneedle Patches for Targeted Action Against Acne-Causing Bacteria

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Acne vulgaris is one of the most common inflammatory skin disorders, affecting ~85% of adolescents and many adults worldwide¹. Current first-line therapies (topical retinoids, benzoyl peroxide, and antibiotics) frequently cause irritation, require long treatment durations, and can contribute to antibiotic resistance and relapse. In addition to inflammatory lesions, acne often results in permanent scarring with significant psychosocial burden². The primary etiological bacterium, *Cutibacterium acnes* (*C. acnes*), resides deep within sebaceous follicles, where conventional topical agents have limited access. Bacteriophages (phages) are bacterial viruses with inherent specificity and self-amplifying antibacterial activity and represent a promising antibiotic free approach for selectively reducing pathogenic bacteria while sparing commensals³. However, achieving effective phage delivery into deeper skin structures remains a critical challenge. **Objective.** We propose a minimally invasive microneedle (MN) strategy to deliver lytic phages intradermally for targeted treatment of acne-associated bacterial infection, *C. acnes* and *Staphylococcus aureus* (*S. aureus*)⁴.

Dissolvable MN patches were fabricated using biocompatible hydrogel matrices (hyaluronic acid). Encapsulated phage viability and stability were quantified by standard plaque assays. MN penetration and dissolution kinetics were evaluated ex vivo porcine skin. Controlled release behavior and phage recovery from MN-treated tissue were assessed to confirm delivery efficiency. Therapeutic efficacy was examined in vivo using a murine intradermal infection model induced with *C. acnes*. Treatment outcomes were monitored by bacterial burden reduction, lesion resolution, and inflammatory response. Histological analyses were performed to evaluate tissue repair, collagen content, and indicators of scar formation relative to untreated controls.

The fabricated dissolvable MN patches demonstrated sufficient mechanical robustness to reproducibly penetrate skin, achieving an insertion depth of ~500 µm in ex vivo porcine tissue and fully dissolving in under 5 minutes. Lytic phages were successfully encapsulated at therapeutically relevant titers, maintaining infectivity and stability for up to 14 days under the tested storage conditions. In vitro antibacterial assays confirmed potent activity, with MN-delivered phages achieving up to an 8 log₁₀ CFU reduction in bacterial burden after the first application, consistent with clearance-level dosing. In murine studies, MN-mediated phage delivery reduced bacterial burden and improved healing progression relative to untreated controls, supporting effective localized antimicrobial action with the potential to minimize off-target microbiome disruption due to phage specificity. Collectively, these results position dissolvable phage-loaded MN patches as a practical, targeted platform for antibiotic-free acne therapy with potential to mitigate inflammation and scarring.

1. Brito, S.; Baek, M.; Bin, B. H. Skin Structure, Physiology, and Pathology in Topical and Transdermal Drug Delivery. *Pharmaceutics* **2024**, *16* (11). DOI: 10.3390/pharmaceutics16111403 From NLM.

2. A. S. M. Morshed, T. N., Md Ashraf Uddin Ahmed, Fahmida Sultana Mili, Shuma Ikram, Mashiqur Rahman, Shamim Ahmed, Mohammad Borhan Uddin. Understanding the impact of acne vulgaris and associated psychological distress on self-esteem and quality of life via regression modeling with CADL, DLQI, and WHOQoL. *Scientific Reports* **2023**. DOI: <https://doi.org/10.1038/s41598-023-48182-6>.

3. B, Z.-P. Phage Therapy—Challenges, Opportunities and Future Prospects. *pharmaceutics* **2023**, *16* (12). DOI: 10.3390/ph16121638.

4. Kang, H.; Zuo, Z.; Lin, R.; Yao, M.; Han, Y.; Han, J. The most promising microneedle device: present and future of hyaluronic acid microneedle patch. *Drug Deliv* **2022**, *29* (1), 3087-3110. DOI: 10.1080/10717544.2022.2125600 From NLM.

P14. Friedrich Striggow

In Vitro Fertilization using Magnetotactic Sperm Cells

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In vitro fertilization (IVF) is essential treatment for many couples facing infertility, e.g. caused by male factors such as oligospermia (low sperm count) or asthenospermia (low sperm motility), where chances of natural fertilization are low. Medical microrobots can carry out task like drug or cell delivery while being controlled remotely and may

significantly reduce invasiveness, and patient burden of medical procedures. The magnetically assisted, targeted delivery of sperm cells to the site of fertilization in the fallopian tube offers a promising strategy to circumvent invasive procedures such as oocyte collection and embryo transfer, as well as in vitro culture and handling of oocytes and embryos, as they occur in conventional IVF.

Magnetic control of sperm cells has been demonstrated using various microstructures, out of which magnetic microparticles appear to be a promising approach, due to the ease of cell-particle conjugation, and the fast observed swimming speeds¹. To investigate the potential of such magnetotactic sperm cells (MSCs) in assisted reproductive technologies (ARTs), we developed a protocol for the conjugation and purification of MSCs in numbers sufficient for their use in a conventional IVF, we analysed the effect of particle conjugation on sperm health and carried out IVF to evaluate the fertilization potential of MSCs².

Magnetic separation of MSCs was used to separate magnetically functionalized sperm cells from nonfunctionalized sperm cells, resulting in samples largely free of non-functionalized sperm cells (99.7% MSCs). To evaluate the effect of magnetic particle conjugation on sperm health, we analysed acrosome integrity, DNA fragmentation, mitochondrial membrane potential, and oxidative stress in MSCs and particle-free sperm cells and observed no adverse effects. Notably, MSCs showed improved mitochondrial membrane integrity compared to the control samples after two hours of incubation. To assess the potential of sperm cells for fertilization of oocytes after conjugation to magnetic particles and to test the integration of MSC preparation into the workflow of ARTs, we performed IVF of bovine samples using MSCs and particle-free sperm cells of different concentrations. We observed successful fertilization of embryos in the MSC sample and development of embryos. IVF cycles using MSCs resulted in embryos developing to the blastocyst stage at a comparable rate as those from particle-free sperm cells of the same concentration. Lower concentrations of particle-free sperm cells (comparable to those remaining in the MSC sample after purification) did not result in any development of embryos to blastocysts. Additionally, we implemented automated image-based recognition, magnetic manipulation, and pre-clustering routines that increased guidance efficiency to facilitate manipulation of MSCs.

These results demonstrate that magnetic conjugation of sperm cells can be carried out without compromising key sperm quality metrics and fertilization potential. Furthermore, this work investigates the integration MSC conjugation and purification into assisted-reproduction workflows and supports further development toward automated in vitro and eventual in vivo applications.

1. Striggow F, Ribeiro C, Aziz A, Nauber R, Hebenstreit F, Schmidt OG, Medina-Sánchez M. Magnetotactic Sperm Cells for Assisted Reproduction. *Small*. 2024 Jun;20(23):e2310288. doi: 10.1002/smll.202310288.

2. Carla Ribeiro, Friedrich Striggow, Richard Nauber, Franziska Hebenstreit, Jennifer Schoen, Mariana Medina-Sánchez *bioRxiv* 2026.04.23.720095; doi: <https://doi.org/10.64898/2026.04.23.720095>

P15. Gorka Basso Alonso

Magnetic control of microcatheters using a 6 DOF robotic arm

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Minimally invasive endovascular and endoluminal procedures increasingly rely on magnetically actuated continuum devices to navigate tortuous pathways with reduced tissue trauma¹. Existing platforms fall into fixed electromagnetic coil systems, which offer precise fields in a limited, non-reconfigurable workspace at high power cost, and single-permanent-magnet manipulators, which are power-efficient but historically bound to custom

kinematic stages. This work presents a magnetic guidance platform using a large NdFeB permanent magnet (S-70-35-N) mounted on the end effector of a 6-DOF collaborative robotic arm (ROKAE) to steer a flexible microcatheter equipped with a hard-magnetic tip segment.

The contribution is twofold. First, we implement a torque-based steering scheme in which the arm reorients the external field to deflect the catheter tip. Axial advancement remains under manual operator control, and the magnet is not used to pull the catheter. Second, we introduce a CAD-derived open-loop trajectory pipeline, in which the 3D geometry of the target channel is exported from the phantom design model and converted into a sequence of end-effector poses that maintain an appropriate magnet-to-tip distance and orientation as the catheter advances. This provides a repeatable, deterministic reference without real-time tip sensing, and allows the same hardware to serve arbitrary phantom geometries via offline retargeting. Evaluation on curved and branched phantom channels achieved steering angles up to 60-80°, tip-following RMSE of 10mm across 20-50 trials, and single-step response times below 1-2s, at magnet-to-tip distances of 20-30mm. Relative to fixed-coil systems, the platform offers a reconfigurable, scalable workspace with negligible steady-state power draw. Ongoing work integrates visual and ultrasound feedback for closed-loop trajectory correction, extendable to tethered and untethered magnetic microrobots².

1. Z. Yang, H. Yang, Y. Cao, Y. Cui, and L. Zhang, "Magnetically actuated continuum medical robots: A review," *Adv. Intell. Syst.*, vol. 5, no. 6, p. 2200416, 2023, doi: 10.1002/aisy.202200416.

2. Z. Chen, B. Rivkin, D. Castellanos-Robles, I. Soldatov, L. Beyer, and M. Medina-Sánchez, "Rapid fabrication of selfpropelled and steerable magnetic microcatheters for precision medicine," *Adv. Mater.*, p. e06591, 2025, doi: 10.1002/adma.202506591.

P16. Hongyu Zhao

Real-Time Digital Twin-Assisted Tracking of Stent-Shaped Magnetic Microrobots

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A stent-inspired magnetically actuated microrobot for operation in confined biomedical environments, such as blood vessels and fallopian tubes, has been developed¹. The microrobot is fabricated using 3D printing and coating-based methods, and is composed of soft materials embedded with magnetic particles, such as NdFeB particles, enabling adaptive deformation and wireless actuation under external magnetic fields. Experiments show that, under a rotating magnetic field, the microrobot interacts with lumen-like walls and converts rotational motion into axial propulsion through asymmetric friction. To support the modeling and interpretation of microrobot motion, a real-time physics-based simulation framework is developed using Simulation Open Framework Architecture (SOFA). Using this framework, a preliminary digital twin model is built to represent the microrobot structure, deformation, and interaction with simplified confined environments under magnetic actuation. The model provides prior physical knowledge to assist in estimating microrobot motion performance that may be difficult to observe directly. Specifically, the digital twin is being integrated with ongoing work on microrobot segmentation and localization in optical or X-ray images, including blurred, low-contrast, and partially occluded images. Inspired by the general concept of world models^{2,3}, this system is being developed as an initial closed-loop framework that combines prediction, perception, and correction. By using real-time physical prediction to constrain visual analysis, the system aims to reduce ambiguity caused by limited image quality and improve the robustness of microrobot localization and tracking.

1. Zhao, H., Chen, Z., Striggow, F., Castellanos-Robles, D., & Medina-Sánchez, M. (2026, in press). A FEM framework for simulating magnetic soft continuum robots via consistent torque-to-nodal force mapping. International Conference on Manipulation Automation and Robotics at Small Scales.
2. World Labs Team. (2026, June 3). A functional taxonomy of world models: Renderers, simulators, planners, and the loop that connects them. World Labs. <https://www.worldlabs.ai/blog/taxonomy-of-world-models>
3. Wang, C., Kang, W., Sun, M., Zhang, H., Hong, C., Demir, S. O., ... & Sitti, M. (2026). Synthetic X-ray-driven tracking and control of miniature medical devices. Nature Machine Intelligence, 8(2), 276-291.

P17. Jiyuan Tian

Multimodal Magnetic Miniature Robot for Controllable Sampling of Gastrointestinal Cells

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Upper gastrointestinal (GI) cancer is a major global cause of cancer mortality. Its early detection is critical but limited by the invasiveness, cost, and poor scalability of endoscopy and biopsy¹. Non-endoscopic cellsampling devices, such as Cytosponge², are promising for esophageal disease; however, passive sampling and limited controllability are poorly suited to the large, deformable GI cavities. Capsule robots³ provide diagnostic functions, but existing systems rely on repeated sampling at isolated sites rather than continuous mucosal coverage. It calls for an active miniature robot for continuous sampling of GI epithelia.

Our previous work reported SpongeBot⁴, a magnetic sponge robot for targeted cell sampling. Here, we report a multimodal magnetic robot that enables both local and continuous sampling in the upper GI lumens. The robot has a magnetic core encapsulated in an open-cell sponge that acts as a soft sampling layer. Before use, it is packed in a gelatin capsule. Following expansion, the robot is actuated by magnetic torque and gradient force generated by an external permanent magnet, causing it to execute three magnetic-field-dependent operating modes. Above the critical threshold B₁, the robot undergoes localized pure rotation for targeted sampling. Between B₁ and B₂, it exhibits combined rolling and sliding. In the third mode, externally imposed helical-looping motion generates coordinated rotation and translation under magnetic gradient force, enabling continuous sampling over a large area of the GI surface. Fluorescent microscopy shows that the robot successfully retrieves abundant upper GI epithelial cells, sufficient for molecular diagnostic analysis.

In summary, the miniature robot enables targeted and continuous upper GI cell sampling, offering a minimally invasive, controllable strategy for cancer screening and early detection in the upper GI tract.

1. A. Vincze, Front. Surg. **10**, 1122454 (2023).
2. L. Paterson et al., Diagn. Cytopathol. **48**, 253 (2020).
3. Q. Cao et al., Nat. Commun. **15**, 4597 (2024).
4. J. Tian et al., in IEEE/RSJ IROS 2025, pp. 2034 (2025).

P18. John Böhm

Magnetically controllable Microrobotic Guidestars for Wavefront Shaping

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Imaging deep within scattering media, such as biological tissue, is fundamentally limited by multiple light scattering, which degrades spatial coherence and resolution. Wavefront shaping techniques, and especially digital optical phase conjugation (DOPC), address this challenge by enabling light to focus inside tissue, even in highly scattering environments¹⁻². A key component of these techniques is the guidestar, a localized optical reference point used to measure and correct distorted wavefronts. However, conventional guidestars often face limitations, such as requiring multiple optical access points, susceptibility to photobleaching, or reliance on incoherent fluorescence, which restrict their use in minimally invasive reflection-mode imaging. Recent advances in microrobotics, such as magnetically actuated sperm micromotors for assisted fertilization and drug delivery, demonstrate the potential of magnetic control for precise positioning and actuation in biological environments³.

We propose magnetically controllable Janus particles as a novel class of microrobotic guidestars designed to overcome these limitations. These micro-scale glass spheres feature two hemispheres, one coated with thin metallic layers (e.g. gold or magnetic alloys) and the other left uncoated. Both hemispheres are reflective, and their orientation-dependent reflectivity creates a unique optical asymmetry. By incorporating magnetic materials into the metallic layer, the Janus particles can be actuated and positioned remotely using external magnetic fields⁴. This magnetic control enables precise modulation of the guidestar's reflective state, allowing for dynamic adjustment of its position and orientation to optimize wavefront shaping in scattering environments. To investigate the potential of modulated guidestars, we constructed a digital optical phase conjugation (DOPC) system and performed initial proof-of-concept experiments on guidestar modulation. Biological tissues are highly dynamic, with continuous motion causing rapid changes in scattering pathways. This decorrelation disrupts the validity of wavefront corrections over time and is one of the principal challenges for in vivo wavefront shaping. Using well-defined optical guidestars, we studied how temporal modulation improves the separation of guidestar light from the scattered background and enhances playback focusing under dynamic scattering conditions. Modulated guidestars may provide a means to improve signal discrimination and robustness under such decorrelation, thereby establishing the basis for the development of magnetically controllable Janus guidestars.

Our ongoing work explores the fundamentals of guidestar modulation and its integration with DOPC systems for minimally invasive imaging. Magnetically steerable Janus particles, with their orientation-dependent reflectivity and remote controllability, represent a promising solution for advanced optical imaging in scattering media. Their compatibility with single-access reflection geometries positions them as a transformative tool for deep tissue imaging and future clinical applications in medical microrobotics.

1. Horstmeyer, R., Ruan, H. & Yang, C. Guidestar-assisted wavefront-shaping methods for focusing light into biological tissue. *Nature Photon* 9, 563–571 (2015). <https://doi.org/10.1038/nphoton.2015.140>

2. Nektarios Koukourakis, Felix Wagner, Stefan Rothe, Mike O. Karl, Jürgen W. Czarske, "Investigation of human organoid retina with digital holographic transmission matrix measurements" *Light: Advanced Manufacturing* 3, 23(2022). doi: 10.37188/lam.2022.023
3. Mariana Medina-Sánchez, Lukas Schwarz, Anne K. Meyer, Franziska Hebenstreit, and Oliver G. Schmidt, "Cellular Cargo Delivery: Toward Assisted Fertilization by Sperm-Carrying Micromotors", *Nano Letters* 2016 16 (1), 555-561, DOI: 10.1021/acs.nanolett.5b04221
4. C. Ribeiro, R. Nauber, A. Aziz, D. C. Robles, F. Hebenstreit and M. Medina-Sánchez, "Microrobot's Performance in Cell-Lining Surfaces and Ex-Vivo Tissue," 2024 International Conference on Manipulation, Automation and Robotics at Small Scales (MARSS), Delft, Netherlands, 2024, pp. 1-6, doi: 10.1109/MARSS61851.2024.10612747.

P19. Lucia Brunel

Magnetically-actuated living microrobots for the delivery of PROTAC drug to target breast cancer metastasis

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Each year, breast cancer accounts for the loss of lives of 650,000 women worldwide, with the majority of deaths resulting from therapy-resistant metastases rather than the primary tumor¹. Activation of the glucocorticoid receptor (GR) has been identified as a key mediator of triple-negative breast cancer metastatic progression and therapeutic resistance². While a proteolysis-targeting chimera (PROTAC) drug capable of selectively degrading GR has shown considerable therapeutic potential³, systemic GR degradation is undesirable due to the receptor's essential role in maintaining physiological homeostasis. For targeted drug delivery, we hypothesize that site-selective GR degradation can be achieved using magnetically actuated microrobots based on magnetotactic bacteria (MTB)⁴, which transport PROTAC-loaded nanoliposomes directly to metastatic targets.

Nanoliposomes with 10 mol% of PROTAC drug relative to lipids were fabricated using a herringbone micromixer and purified with centrifugation or a PD-10 desalting column. The size and concentration of the nanoliposomes were characterized by Dynamic Light Scattering and Nanoparticle Tracking Analysis. To determine the drug encapsulation efficiency and release kinetics, PROTAC concentrations were quantified with liquid chromatography-mass spectrometry. The MTB strain *Magnetospirillum magneticum* AMB-1 was cultured in suspension for 5-7 days and fluorescently-labeled using a CellTrace Far-Red cell proliferation kit. To attach the PROTAC-laden nanoliposomes to the MTB, the nanoliposomes were fabricated with pendant azides, while the MTB were functionalized with dibenzoazacyclooctynes, facilitating conjugation via Strain-Promoted Azide-Alkyne Cycloaddition⁵. To validate the retention of the intrinsic magnetism of the MTB, these living microrobots were subjected to rotating magnetic fields (20 mT, 2 Hz) by a magnetic field generator on a confocal microscope. The human triple-negative breast cancer cell line MDA-MB-231 was treated with free PROTAC drug, MTB alone, empty nanoliposomes (i.e., drug-free), or PROTAC-laden nanoliposomes for 24 h. GR degradation was quantified by Western Blot.

The incorporation of PROTAC into nanoliposomes did not significantly affect their hydrodynamic diameter and polydispersity index ($dH = 77 \pm 4$ nm, PDI: 21%) compared to empty nanoliposomes ($dH = 79 \pm 3$ nm, PDI: 20%). The drug encapsulation efficiency of the PROTAC in the nanoliposomes was 93 %. Burst release of the PROTAC from the nanoliposomes was fortunately not observed, with drug leakage of less than 10 % within 4 h. During that time, the PROTAC-laden nanoliposomes were successfully conjugated to the surface of the MTB, confirmed by the overlay of fluorescent signal from the bacteria and nanoliposomes. Upon treatment of the breast cancer cell line MDA-MB-231 with MTB alone or with empty nanoliposomes, no GR degradation was observed compared to untreated cells. When treated with nanoliposomes containing PROTAC, complete GR degradation was observed, achieving the full effect as a free PROTAC control. Next steps will investigate the PROTAC-carrying MTB to treat

cancer cell spheroids under magnetic actuation, followed by validation of the targeted drug delivery in pre-clinical models. Taken together, our results demonstrate a viable strategy for magnetotactic bacteria as drug delivery vehicles for PROTAC drugs that target breast cancer metastasis.

1. Ramos, P, and M Bentires-Alj. "Mechanism-based cancer therapy: resistance to therapy, therapy for resistance." *Oncogene* vol. 34,28 (2015).
2. Obradović, Milan M S et al. "Glucocorticoids promote breast cancer metastasis." *Nature* vol. 567,7749 (2019).
3. Gazorpak, Mahshid et al. "Harnessing PROTAC technology to combat stress hormone receptor activation." *Nature Communications* vol. 14,1 8177 (2023).
4. Gwisai, T et al. "Magnetic torque-driven living microrobots for increased tumor infiltration." *Science Robotics* vol. 7,71 (2022).
5. Gwisai, T et al. "Engineering living immunotherapeutic agents for improved cancer treatment." *Advanced Therapeutics* vol. 7,4 (2024).

P20. Lulu Song

Magnetically Guided Degradable Hydrogel Microcarriers for Localized Antibiotic Delivery

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Localized bacterial infections remain challenging to treat because systemic antibiotic administration often leads to insufficient drug accumulation at the infection site, while increasing the risk of systemic side effects. Magnetically guided microrobotic carriers provide a promising strategy for localized drug delivery by enabling remote navigation and on-demand therapeutic transport¹. Building upon our recently developed degradable magnetic hydrogel microcarrier platform, this work explores its application in navigation for localized antibiotic delivery².

Magnetic poly(ethylene glycol) diacrylate (PEGDA) hydrogel microcarriers were fabricated by droplet microfluidics and UV photopolymerization. The beta-lactam antibiotic cefotaxime (CTX) was subsequently incorporated into the microcarriers through post-fabrication loading. The CTX release profile was quantified over time, while the antibacterial activity of released CTX was evaluated against *Escherichia coli* using bright-field microscopy. Different CTX loading concentrations and different numbers of drug-loaded microcarriers were investigated to evaluate the tunability of antibacterial performance.

The magnetic hydrogel microcarriers exhibited clear magnetic responsiveness, allowing remote navigation under an external magnetic field while maintaining structural stability during antibiotic release. CTX release was characterized by a rapid initial diffusion, followed by a slower release phase, providing immediate antibacterial activity together with prolonged local drug availability. The released antibiotic retained its biological activity and effectively inhibited bacterial growth. An increase in CTX loading concentration resulted in progressively stronger antibacterial effects, whereas intermediate antibiotic concentrations induced characteristic bacterial filamentation, consistent with the mechanism of β -lactam antibiotics³. In addition, increasing the number of drug-loaded microcarriers while maintaining the same loading concentration further enhanced bacterial inhibition, demonstrating that antibacterial performance can be regulated through both drug loading and carrier dosage.

Overall, this study extends a previously established magnetic degradable microcarrier platform toward localized antimicrobial therapy. The combination of magnetic guidance, controlled antibiotic release, and tunable antibacterial efficacy provides a versatile strategy for targeted treatment of localized bacterial infections and represents a step toward magnetically guided microrobotic drug delivery platforms for biomedical applications.

1. Fabian C. Landers et al. "Clinically ready magnetic microrobots for targeted therapies." *Science* 390,710-715 (2025).DOI:10.1126/science.adx1708
2. X. Peng, L. Song, D. Mruga, et al. "Soft, Degradable, and Magnetic Microcarriers for Encapsulation and Guided Transport of Drugs and 3D Spheroids." *Advanced Materials* (2026): e73735. <https://doi.org/10.1002/adma.73735>
3. Spratt BG. "Distinct penicillin binding proteins involved in the division, elongation, and shape of *Escherichia coli* K12. " *Proc Natl Acad Sci U S A*. 1975 Aug;72(8):2999-3003. doi: 10.1073/pnas.72.8.2999. PMID: 1103132; PMCID: PMC432906.

P21. Mahmut Yorulmaz

Understanding the role of surface wettability on the locomotion of Janus microrollers

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At low Reynolds numbers, where viscous forces dominate over inertial forces, the locomotion of microparticles or microswimmers relies on symmetry-breaking mechanisms^{1,2}. For Janus microrollers, symmetry breaking occurs due to the presence of a nearby surface, creating an asymmetric distribution of hydrodynamic stress within the thin lubrication layer that separates the particle from the substrate. The substrate wettability can alter the boundary condition such as the thickness of lubrication film. To quantify the surface wettability, we use slip length, theoretically defined as the extrapolated distance below the surface where the velocity profile reaches zero. Previous studies have shown that the surface wetting properties can affect the translational velocity of catalytic self-propelled Janus particles and passive particles^{3,4}. However, it remains an open question how magnetically actuated Janus particles behave under varying wettability conditions of the planar surface.

Here, we investigate how the surface wetting properties of the substrate, specifically through altering the contact angle, affect the locomotion of magnetically actuated Janus particles of different sizes (i.e. different Reynolds numbers) under an alternating external magnetic field. Lastly, we aim to understand the underlying physical principles that couples the surface wettability condition to the rotation and translation of the microroller.

We conducted experiments on three different substrates with contact angles of 48°, 52.5°, and 112.1°, using three different particle sizes, a range of driving frequencies, and magnetic field amplitudes up to 14 mT. To understand the physical mechanisms, we performed corresponding theoretical analysis using a novel combined analytical-numerical technique based on bi-spherical eigenfunction expansion. In the theory, we examined the influence of slip length, lubrication distance, different magnetic field driving frequencies, particle diameters, and the effect of solid friction due to the intermittent contacts between the particle surface and the microscopic substrate asperities. , we compared the experimental and theoretical results and used the agreement between them to estimate the corresponding values such as the gap size, and velocity.

Our experimental results showed that the surface wetting properties have a substantial effect on the translational velocity of the particles. Depending on particle size, increasing contact angle either hinders the translational velocity for 10 µm particles or enhances it for 100 µm particles. For 50 µm particles, the effect of the wetting properties is balanced, resulting in no significant difference in translational velocity. In addition, for the first time, we provide a quantitative estimate of the relationship between the driving frequency and the lubrication distance.

The results demonstrate that substrate wetting properties significantly influence the locomotion of magnetic microrollers in a size-dependent manner, which starkly contrasts with the behavior of passive particles or catalytic Janus particles, where the speed increases with slip length^{3,4}. The observed behavior suggests a competition between wall-mediated propulsion and slip-induced drag reduction: for 10 μm particles, stronger near-wall hydrodynamic coupling dominates, leading to reduced translational velocity with increasing hydrophobicity; for 50 μm particles, these effects are approximately balanced; and for 100 μm particles, drag reduction becomes dominant, resulting in enhanced translational velocity. The combined experimental and theoretical approach provides insights into the role of lubrication distance and friction in governing particle motion and highlights surface wettability as an important parameter for controlling microroller transport.

1. Purcell, E. M. Life at low Reynolds number. *AIP Conf. Proc.* 28, 49–64 (1976).
2. Lauga, E. & Powers, T. R. The hydrodynamics of swimming microorganisms. *Rep. Prog. Phys.* 72, 096601 (2009).
3. Loussaief, H., Pasol, L. & Feuillebois, F. Motion of a spherical particle in a viscous fluid along a slip wall. *Q. J. Mech. Appl. Math.* 68, 115–144 (2015)
4. Ketsetzi, S., de Graaf, J., Doherty, R. P. & Kraft, D. J. Slip length dependent propulsion speed of catalytic colloidal swimmers near walls. *Phys. Rev. Lett.* 124, 048002 (2020).

P22. Myungjin Park

Magnetic Torque Trapping Enables Enhanced Retention and Translocation of Microrobots

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A primary challenge in deploying magnetic microrobots for cancer therapy is overcoming biological barriers. For enhancing penetration into biological barriers, existing approaches typically fabricate tailored nanoparticles and rely on enhanced permeability and retention (EPR) mechanisms¹. Others instead utilize magnetic fields as a manipulation method and actively enhance penetration, usually by leveraging non-uniform magnetic fields² or time-varying magnetic fields³. However, leveraging magnetic field gradients is challenging due to their poor scalability, as it generally requires magnetic field gradients exceeding ~ 10 T/m. In contrast, rotating magnetic fields provide substantial scalability and can drive torque-induced locomotion, enabling enhanced tumor infiltration and colonization. While these approaches are promising, an ideal solution would be the simultaneous achievement of retention and translocation.

In this work, we present a torque-trapping strategy that enables spatial localization of microrobots using a Lissajous function-based magnetic field actuation (LMF), and it allows leveraging the advantages of rotating motion induced convective flow and surface rolling induced trapping simultaneously. Particularly, microrobots experience spatial dependent torque, eventually being trapped at the target site under both static and flow conditions. Simultaneously, the distinct actuation generates focused convection flows that enhance the translocation of microrobots across biological barriers. We experimentally evaluated the retention and translocation performance of the proposed actuation scheme, demonstrating its potential to significantly improve microrobot targeting efficiency.

1. Nguyen, L. N., Ngo, W., Lin, Z. P., Sindhwani, S., MacMillan, P., Mladjenovic, S. M., & Chan, W. C. (2024). The mechanisms of nanoparticle delivery to solid tumours. *Nature Reviews Bioengineering*, 2(3), 201–213.
2. Jang, B., Amirshaghghi, A., Choi, J., Miller, J., Issadore, D. A., Busch, T. M., ... & Tsourkas, A. (2025). Enhanced accumulation and penetration of magnetic nanoclusters in tumors using an 8-magnet Halbach Array leads to improved cancer treatment. *ACS nano*, 19(1), 1794–1808.

3. Gwisai, T., Mirkhani, N., Christiansen, M. G., Nguyen, T. T., Ling, V., & Schuerle, S. J. S. R. (2022). Magnetic torque-driven living microrobots for increased tumor infiltration. *Science Robotics*, 7(71), eabo0665.

P23. Noah Franco

Small Scale Magnetic Robots for Targeted Gallstone Treatment

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Gallstone disease is a common hepatobiliary disorder causing cholesterol deposits which is most treated through a cholecystectomy, the surgical removal of the entire organ. Limited innovation has been done in addressing the treatment of the disease in a non-invasive and patient-centred manner. In addition, there are limited treatment options for high-risk patients who are not eligible for surgery. Medical microrobotics has yet to be applied to gallstone disease, a condition affecting an estimated 20 million people, with 300,000 surgeries annually in the United States alone¹. Our research aims to develop a novel, non-invasive treatment using magnetically controlled, millimetre-sized microrobots for the breakdown of gallstones, preventing surgical removal of the entire organ. We hypothesize that a magnetic small scale helical robot can provide a targeted treatment through mechanical disruption to facilitate localized breakdown of stones, with precise magnetic control via RMF (rotating magnetic fields) and real-time tracking via ultrasound imaging. Small scale screw-like robots were designed with dimensions of 6.0mm in length and 2.5mm in diameter, allowing them to be navigated from the small intestine through the duodenum, common bile duct, cystic duct, and into the gallbladder to the gallstone location. The robots are fabricated from biocompatible acrylate-based resin². The navigation mechanism uses an external magnetic field to generate magnetic force and magnetic torque on the microrobots which then drives forward translational movement of the helical microrobot. Human gallstone samples were obtained from the Waterloo Regional Health Network. An at-scale anatomical gallbladder-on-a-chip model was designed to test the robot navigation from the small intestine to the gallbladder and break down gallstones under flow rate V1. We demonstrate the robot's capability of real-time navigation and imaging through the biliary system, and mechanical disruption of gallstones via a targeted drilling mechanism.

Preliminary results demonstrated promising mechanical disruption results in addition to successful navigation of robot within the gallbladder-on-a-chip model. The development of this proposed treatment establishes a noninvasive and targeted microrobotic treatment of gallstones using RMF and ultrasound, without requiring the removal of the gallbladder. In the future, this novel work has the potential to create a treatment path for patients that cannot undergo surgery, improve patient outcomes, reduce post-cholecystectomy side-effects, and limit healthcare burdens.

1. Hassler, K. R., & Jones, M. W. (2023). Laparoscopic cholecystectomy. StatPearls [Internet]. National Center for Biotechnology Information. <https://www.ncbi.nlm.nih.gov/books/NBK448145/>

2. Franco, N., Aksu, N. Cho, C., Bouzari, N., Shahsavan, H., Magdanz, V. , CYTO-CLEAR: A Biocompatible Photopolymer Resin for High Resolution 3D-Printed Microfluidic Devices, Lab on a Chip 2026, under review.

P24. Qiufeng Yi

Auditing Sperm Target Records at the Vision-to-Microtool Handoff for Human-Supervised ICSI

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Vision-guided intracytoplasmic sperm injection (ICSI) micromanipulation¹⁻³ requires a reliable handoff from image-based sperm tracking to human-supervised microtool positioning. A candidate score or nominal coordinate is not action-ready unless it represents one contemporaneous spatial state in a traceable, geometrically verified source frame. Historically accumulated tracking rows can otherwise cause an aggregate to represent trajectory history and make local spatial measures difficult to interpret.

We investigated whether image-derived sperm detections could be converted into action-facing target records at this vision-to-microtool handoff. We defined a pre-action readiness gate requiring candidate and frame identity, one traceable current position, row-level provenance, source-frame linkage, verified image dimensions, local spatial measures, and an explicit retain-or-withhold outcome.

We retrospectively audited an existing coordinate export containing 383,765 rows across 124 numbered frame indices and 30 candidate IDs, together with ten sidecars selected by the recorded ranking. Rows were grouped by frame and candidate. We tested terminal-state duplication, exact carry-forward of earlier x-y histories into subsequent frames, and whether each sidecar contained the provenance and geometry needed to interpret its spatial fields before downstream microtool use. To quantify the change in spatial input at handoff, we calculated centroid-to-terminal handoff displacement as the Euclidean distance between each group's arithmetic-mean coordinate and its final coordinate after collapsing consecutive duplicate x-y rows.

All 3,571 frame-candidate groups ended with a duplicate of the preceding row. Across 3,541 observable within-candidate transitions, the complete prior x-y history was retained as an exact prefix in every case. For one representative candidate, group size increased from 7 rows at frame 0 to 376 rows at frame 123. Centroid-to-terminal handoff displacement had a median of 31.50 export coordinate units (IQR 19.59-55.45; 95th percentile 99.82) and was non-zero in 3,532/3,571 groups (98.9%). Thus, mean aggregation represented a history centroid rather than a demonstrably contemporaneous handoff coordinate. Although all ten sidecars contained spatial fields, none contained row-level provenance, source-frame linkage, or verified frame dimensions; all ten were withheld.

These findings identify a record-layer bottleneck at the perception-to-micromanipulation interface. Under the readiness gate, records whose spatial fields could not be traced to a verified source frame were withheld rather than treated as handoff-ready. The displacement measures an export-representation difference, not ground-truth localisation or robot-positioning error. This retrospective study evaluates pre-action record readiness rather than robot control, embryologist use, collision avoidance, or clinical outcomes, and defines an auditable prerequisite for future vision-guided, robot-assisted ICSI workflows.

1. Palermo, G., Joris, H., Devroey, P. & Van Steirteghem, A.C. Pregnancies after intracytoplasmic injection of single spermatozoon into an oocyte. *The Lancet* 340(8810), 17-18 (1992). doi:10.1016/0140-6736(92)92425-F.

2. You, J.B., McCallum, C., Wang, Y., Riordon, J., Nosrati, R. & Sinton, D. Machine learning for sperm selection. *Nature Reviews Urology* 18(7), 387-403 (2021). doi:10.1038/s41585-021-00465-1.

3. Zhang, Z. et al. Robotic immobilization of motile sperm for clinical intracytoplasmic sperm injection. *IEEE Transactions on Biomedical Engineering* 66(2), 444-452 (2019). doi:10.1109/TBME.2018.2848972.

P25. Stefan Merkens

A microfluidic platform for simultaneous chemotaxis and rheotaxis characterization of sperm-based microrobots

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Sperm-based microrobots have emerged as promising candidates for targeted drug delivery, assisted fertilization and other minimally invasive biomedical applications^{1,2}. Various fabrication and functionalization strategies have been proposed, including magnetic functionalization and biohybrid approaches, resulting in microrobots with diverse propulsion and navigation capabilities. Among the relevant navigation mechanisms expected to govern their behaviour, chemotaxis and rheotaxis are of particular interest^{3,4,5}. Chemotaxis describes the directed movement of a sample along a chemical concentration gradient (e.g., signalling molecules or tumor-derived factors), whereas rheotaxis refers to the directed movement in response to the flow of the media. Although significant progress has been made in the synthesis and functionalization of sperm-based microrobots, their combined rheotactic and chemotactic behaviour under physiologically relevant conditions remains poorly understood, limiting the rational design and control of these systems for biomedical applications. Here, we present a microfluidic platform for the simultaneous characterization of chemotaxis and rheotaxis in sperm-based microrobots.

The microfluidic devices, fabricated by high-resolution 3D printing, consist of i) a central observation chamber (OC) for microrobot characterization connected to inlet and outlet channels for sample loading and retrieval, ii) two lateral bypass channels (BP) that establish stable chemical concentration gradients, and iii) an array of bridge channels (BR) that connect OC and BPs balancing rheotactic and chemotactic stimuli. This architecture enables the independent characterization of chemotactic stimuli, generated by a horizontal concentration gradient, and controlled rheotactic stimuli, generated by a vertical flow velocity field, across an extended observation area (OA). Computational fluid dynamics simulations were employed to optimize device architecture achieving well-defined and independently tuneable flow and concentration gradients while minimizing undesired coupling between the two navigation mechanisms.

The proposed platform enables systematic and quantitative characterization of sperm-based microrobot navigation. Its optically transparent design permits semi-automated tracking by optical microscopy as fundament for reliable data analysis, while precise microfluidic control allows independent variation of key experimental parameters, including flow velocity, chemical species, flow velocities, concentration and pressure gradients. The platform therefore provides a versatile tool for investigating the interplay between chemotaxis and rheotaxis under controlled, physiologically relevant conditions, ultimately contributing to a deeper understanding of sperm-based microrobot navigation and accelerating the development of clinically relevant microrobotic systems. Beyond sperm-based microrobots, the platform is readily applicable to other (cell-based) systems and could serve as a screening tool for identifying and evaluating biologically relevant chemotactic cues, including tumor-targeting molecules.

1. V. Magdanz *et al.*, Development of a sperm-flagella driven micro-bio-robot, *Advanced Materials*, 25, 6581-6588, 2013.
2. F. Striggow *et al.*, Magnetotactic sperm cells for assisted reproduction, *Small*, 20, 2310288, 2023.
3. M. Eisenbach, Sperm navigation in humans: a concerted action of multiple means, *Communications Biology*, 8, 923, 2025.
4. K. Miki *et al.*, Rheotaxis guides mammalian sperm, *Current Biology*, 23, 443-452, 2013.
5. H. Xu *et al.*, Sperm micromors for cargo delivery through flowing blood, 24, 2982-2993, 2020.

P26. Xiaolei Chen

In Vivo Dynamic-Torque Driven DNA Manipulation via a Magnetic Micromotor

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Lv Cheng & Yu Cheng are the co-PIs of the work

The biological environment *in vivo* is complex, posing a great challenge for the deployment of DNA nanostructure-based precision nanomedicine. Despite the development of DNA nanostructures responsive to environmental cues, it remains difficult to manipulate DNA with spatiotemporal precision *in vivo*. While single-molecule mechanical techniques (e.g., conventional magnetic tweezers) achieve excellent spatiotemporal control over DNA conformations, their strictly limited millimeter-scale effective working distance precludes deep-tissue clinical applications. Addressing this spatial limitation, this study aims to develop a dynamic torque-driven strategy using anisotropic magnetic micromotors (MMs), whose magnetic anisotropy enables efficient coupling with rotating magnetic fields, extending the working distance of active DNA manipulation to the centimeter scale while maintaining minute-level precision *in vivo*.

Anisotropic rod-shaped MMs (1.8 μm in length, 0.6 μm in diameter) were synthesized via a solvothermal method and assembled with programmable DNA structures using click chemistry. Tension Gauge Tethers (TGTs) equipped with a Förster Resonance Energy Transfer (FRET) reporting mechanism were further constructed to quantitatively visualize DNA mechanical deformation with tunable force thresholds ranging from 12 to 54 pN. Confocal fluorescence imaging was utilized to systematically evaluate and compare the TGT conformational manipulation capabilities mediated by static magnetic field (SMF) gradient forces versus rotating magnetic field (RMF) dynamic torques. The system's performance across varying force thresholds, GC contents, and centimeter-scale distances was evaluated, followed by validation in cellular systems and an *in vivo* mouse model using live animal imaging.

The FRET mechanism accurately reported force-mediated DNA conformational transformations, revealing that RMF-driven dynamic torque enabled more efficient TGT unwinding than conventional SMF-induced gradient forces. Under a 5 Hz RMF, the MMs generated a robust torque of 76.6 $\mu\text{N}\cdot\text{nm}$, successfully driving the conformational change of 12 pN TGTs within just 1 minute. By precisely orchestrating the RMF frequency, we achieved tunable and accurate manipulation of DNA structures with distinct force thresholds (12–54 pN) and GC contents (22%–100%) over a centimeter-scale spatial range. Remarkably, the manipulation of 12 pN TGTs was accomplished on 94% of living cells within 5 minutes. Following the injection of MMs-TGTs into the mouse model, precise *in vivo* manipulation of DNA structures was efficiently realized within 5 minutes under magnetic stimulation.

Conclusion: By utilizing an RMF to drive anisotropic rod-shaped MMs, this study generates programmable dynamic torque to successfully extend the spatial range of *in vivo* DNA manipulation to the centimeter scale while maintaining high temporal precision. This strategy advances the regulation of DNA nanostructures from passive response to active programming *in vivo*, thereby paving the way for DNA nanostructure-based precision nanomedicine.

P27. Yasaman Khanbaba

MagRoD - Magnetically Controlled Robotic Drug Delivery System (Robotic System for Magnetically Controlled Hydrogel-Coated Microrobot Navigation and Targeted Drug Delivery)

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Fallopian tube obstruction is a major contributor to female infertility and remains difficult to treat because of the small diameter, complex geometry, and limited accessibility of the distal fallopian tube¹. Catheter- and guidewire-

based procedures can be limited by poor steerability in confined anatomical regions, while systemic drug delivery does not provide localised therapeutic action at the obstruction site^{1,2}. Magnetic microrobotics has shown promise for navigation, obstruction removal, and targeted delivery in confined environments¹⁻³. However, most existing approaches focus either on mechanical recanalisation using rigid magnetic microrobots or on hydrogel-based cargo transport.

A system that combines active navigation, obstruction interaction, and localised therapeutic delivery within one controllable robotic approach remains underdeveloped. Here, we examine whether soft magnetic hydrogel microrobots can be actuated and controlled within a fallopian-tube-mimicking environment while retaining the potential for localised therapeutic delivery. For this purpose, magnetic hydrogel samples were fabricated using sodium alginate as the hydrogel matrix, Fe_3O_4 magnetic particles as the responsive phase, and calcium chloride as the ionic crosslinking agent, following principles used in alginate-based magnetic hydrogel microrobot systems². The resulting calcium alginate structures combine the softness and cargo-carrying potential of hydrogels with magnetic responsiveness for external actuation². Preliminary experiments confirmed the successful formation of magnetically responsive hydrogel structures and demonstrated controllable displacement under magnetic fields generated by a permanent magnet. Ongoing material characterisation includes hydration analysis, dimensional stability assessment, and mechanical testing to relate material composition to actuation performance in confined tubular environments.

Building on this material work, MagRoD is being developed as a robotically reconfigurable magnetic actuation system inspired by magnetically driven microscrew approaches for oviduct recanalization and magnetic hydrogel capsule microrobots for targeted cargo delivery^{1,2}. The proposed system will use two collaborative robotic manipulators equipped with electromagnetic coil end-effectors. Rather than relying on a fixed-coil arrangement, this architecture is intended to reposition the magnetic field source around a transparent fallopian-tube phantom, allowing control over field direction, magnetic gradients, and actuation location. This approach aims to generate controllable magnetic forces and torques for translation, rotation, positioning, and interaction with obstruction models³. The coil system is being designed by considering coil geometry, winding configuration, electrical resistance, operating current, magnetic field generation, and thermal management. With machine-vision-based object detection and robotic path planning, the system is intended to support closed-loop magnetic manipulation and trajectory-guided navigation.

Overall, these preliminary results show that alginate/ Fe_3O_4 hydrogel structures can be fabricated and magnetically manipulated, providing an initial step towards a robotic electromagnetic system for minimally invasive fallopian tube recanalisation and targeted local drug delivery.

References:

1. Liu X, Liu Y, Huang J, Zhao X, Yu J, Wang X, Xu H. Magnetically driven robotic microscrew for the oviduct recanalization. *Aip Advances*. 2024 Dec 1;14(12).
2. Xu Z, Wu Z, Yuan M, Chen Y, Ge W, Xu Q. Versatile magnetic hydrogel soft capsule microrobots for targeted delivery. *Iscience*. 2023 May 19;26(5).
3. Cheng Q, Qin Z, Tai Y, Lu X, Liu G, Yang R, Luo T. Magnetic Control Strategies of Microrobot Swarm for Biomedical Applications. *ACS Biomaterials Science & Engineering*. 2025 Aug 5;11(9):5264-84.

P28. Yingying Wang

A rotating fluctuating magnetic actuation device for cancer mechanotherapy

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Magnetic actuation technology demonstrates strong potential for precision medicine. However, its clinical translation has been limited by intrinsic bottlenecks in existing magnetic actuation devices. Conventional electromagnetic systems provide flexible multimodal control, yet they often require tens of kilowatts to generate magnetic fields of up to 50 mT over clinical-scale workspaces. In contrast, permanent magnet systems can produce higher field strengths within centimeter-scale working spaces at low power; however, their fatal limitation lies in the inability to be flexibly programmed like electromagnetic systems, restricting their actuation modes predominantly to simple rotation and dragging. These performance bottlenecks severely restrict magneto-mechanical force output, making current devices incapable of effectively actuating clinically relevant magnetic nanomedicines with relatively weak magnetic responsiveness, and thus limiting their therapeutic applications.

To address this challenge, we developed a three-dimensional rotating fluctuating magnetic actuation device (3DRFM) with a clinical-scale workspace of 30 cm in diameter. It can generate magnetic fields of up to 79 mT while maintaining versatile actuation modes at a power consumption of 1.23 kW. This device employed a hybrid configuration that synergistically integrated a custom-designed Halbach array with electromagnetic coils. This architecture fully capitalized on the complementary strengths of both systems by combining the high-intensity field output of permanent magnets with the agile dynamic modulation of electromagnetic coils. Through precise regulation, the device achieved the spatial superposition of a rotating magnetic field and an oscillating magnetic field, thereby generating a three-dimensional rotating fluctuating magnetic field (3D-MF). Consequently, this platform enabled magnetic robots to execute three distinct operational modalities: rotating, oscillating, and three-dimensional (3D) rotational-bouncing.

Moreover, this device enabled efficient mechanical activation of ferumoxytol (FMT), a US Food and Drug Administration (FDA)-approved superparamagnetic iron oxide nanoparticle. Dynamic analysis revealed that the 3D rotational-bouncing mode enhanced the propulsion efficiency of these weakly magnetic nanodrugs compared to rotational motion. Fluid dynamics simulations confirmed that this hybrid motion generated steeper velocity gradients and stronger fluidic interactions in high-viscosity environments compared to simple rotational modes.

At the subcellular level, 3D-MF stimulation triggered the targeted self-assembly of FMT into chain-like structures within lysosomes. The magneto-mechanical forces generated by the rotational-bouncing motion effectively ruptured the lysosomal membrane, significantly enhancing lysosomal membrane permeabilization (LMP). This subcellular damage was verified by the recruitment of Galectin-3 markers to the disrupted lysosomes. Moreover, we assessed the *in vivo* therapeutic performance of FMT integrated with the 3D-RFM device using the LLC syngeneic model in C57BL/6 mice. Tumor growth curves revealed that the rotationalbouncing motion of FMT induced stronger tumor inhibition compared to rotational motion. Kaplan-Meier survival curves further showed that 3D-MF stimulation provided the highest survival benefit, extending the median survival time to 28 days, which was 12 and 8 days longer than that in the FMT and RMF groups, respectively.

1. Landers, F. C., Hertle, L., Pustovalov, V., Sivakumaran, D., Oral, C. M., Brinkmann, O., Meiners, K., Theiler, P., Gantenbein, V., Veciana, A., et al., Mattmann, M., Riss, S., Gervasoni, S., Chautems, C., Ye, H., Sevim, S., Flouris, A.D., Puigmartí-Luis, J., Sotto Mayor, T., Alves, P., Lüthmann, T., Chen, X., Ochsenbein, N., Moehrlen, U., Schubert, T., Kulcsar, Z., Gruber, P., Weisskopf, M., Boehler, Q., Pané, S., and Nelson, B. J. (2025). Clinically ready magnetic microrobots for targeted therapies. *Science* 390, 710-715.
2. Kummer, M.P., Abbott, J.J., Kratochvil, B.E., Borer, R., Sengul, A., and Nelson, B.J. (2010). OctoMag: An electromagnetic system for 5-DOF wireless micromanipulation. *IEEE Trans. Robot.* 26, 1006-1017.
3. Gervasoni, S., Pedrini, N., Rifai, T., Fischer, C., Landers, F. C., Mattmann, M., Dreyfus, R., Viviani, S., Veciana, A., Masina, E., Aktas, B., Puigmartí-Luis, J., Chautems, C., Pané, S., Boehler, Q., Gruber, P., and Nelson, B. J. (2024). A human-scale clinically ready electromagnetic navigation system for magnetically responsive biomaterials and medical devices. *Adv. Mater.* 36, 2310701.

4. Jang, B., Amirshaghghi, A., Choi, J., Miller, J., Issadore, D.A., Busch, T.M., Cheng, Z., and Tsourkas, A. (2025). Enhanced accumulation and penetration of magnetic nanoclusters in tumors using an 8-Magnet Halbach array leads to improved cancer treatment. *ACS Nano* 19, 1794-1808.

P29. Zhi Chen

A Wave-Crawling Microcatheter for Focal Intratissue Delivery in the Upper Urinary Tract

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Upper tract urothelial carcinoma (UTUC) accounts for about 5 to 10% of all urothelial cancers, with an annual incidence of roughly 1 to 2 per 100,000 in Western populations. For low-grade disease, where kidney preservation is the goal, the standard non-surgical option is retrograde intracavitary chemoablation. In the pivotal phase 3 trial it reached a 59% complete response but caused ureteric stenosis in 44% of patients¹, two outcomes that follow from the same limitation. The drug acts only at the urothelial surface, so it cannot reach tumor within the wall, and prolonged surface contact drives the stenosis. Focal delivery into the tissue itself addresses both, sparing surrounding mucosa from sustained exposure. The narrow and tortuous upper-tract anatomy makes this demanding. The device must navigate a confined lumen yet stay mechanically stable to puncture the wall and infuse locally. We meet this need by extending our previously reported wave-crawling magnetic microcatheter² and redesigning its distal end for protected navigation, on-demand tip exposure, and localized infusion. A two-photon-polymerized puncture tip with embedded Y-shaped outlet channels sits at the catheter end. During transit, a crosslinked gelatin microcap shields the tip and is released in situ by intraluminal fluid pressure. In vitro, the device showed stable wave-crawling locomotion in 2-mm channels matching the targeted ureteral lumen. It released the cap in a confined space and punctured 1 wt% agarose (Young's modulus about 38 kPa) as a standard soft-tissue penetration model, then delivered a model drug (dye) locally. Together these results outline a transurethral microrobotic route from intracavitary chemoablation toward focal intratissue UTUC therapy. Next-stage validation will quantify ureteroscopy-coupled deployment, cap-release reliability, puncture depth and force in ex vivo porcine upper-tract tissue, and intrarenal pressure during operation, before in vivo translation.

1. Kleinmann, N. et al. Primary chemoablation of low-grade upper tract urothelial carcinoma using UGN-101, a mitomycin-containing reverse thermal gel (OLYMPUS): an open-label, single-arm, phase 3 trial. *Lancet Oncol.* **21**, 776– 785 (2020).

2. Chen, Z., Rivkin, B., Castellanos-Robles, D., Soldatov, I., Beyer, L. & Medina-Sánchez, M. Rapid fabrication of selfpropelled and steerable magnetic microcatheters for precision medicine. *Adv. Mater.* **37**, e06591 (2025).

P30. Alba Pejenaute

Engineering Conformational Biosensors for Personalized Medicine

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The future of personalized medicine relies on the use of biosensing technologies capable of performing continuous molecular measurements of many important biomarkers, drugs, hormones, and metabolites. These technologies will significantly improve our ability to monitor, diagnose and treat diseases, empowering patients to make informed

decisions on their own health¹. Motivated by this, our goal is to develop sensing technologies capable of performing real-time, continuous measurements, directly in vivo, of many different targets².

Conformational changes are central to the function of biomolecules, but also a useful property for biotechnologies. Inspired by some Nature's tools and strategies, our research focuses on understanding the biophysics that control different protein conformational equilibria, and their application for developing new receptors and signalling mechanisms³. By using computational tools, artificial intelligence, and experimental biophysics, we engineer proteins into conformational receptors, coupling ligand binding to conformational changes that we can use to trigger optical or electrochemical signal transduction. We have used this approach to design sensors for female hormones, immunosuppressant drugs, and immune evasion biomarkers.

Conformational sensing is thus a versatile approach, interesting not only for the development of new biotechnological tools, but also to explore new concepts in biomolecular function. The ability to rationally design conformational receptors, generalizable to many different targets, will enable the development of a new generation of biosensors, capable of performing continuous, real-time in vivo measurements. Such a technological breakthrough will support point-of-care, at-home, and wearable sensing devices, supporting the widespread implementation of personalized medicine.

1. Chamorro-García A, et al. International Encyclopedia of Public Health (Third Edition), **2025**, 6:490-510.

2. Arroyo-Currás N, et al. ACS Pharmacol. Transl. Sci. **2018**, 1(2):110-118.

3. Pejenaute A, et al. Protein Engineering, Design and Selection, **2025**, 38:gza010.

P31. David Rivas

Biodegradable Microrobots for Active Navigation and Therapeutic Delivery on Ex Vivo Cardiac Models

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Magnetically driven microrobots are emerging as valuable tools for biomedical applications due to their high precision, remote controllability, and fuel-free operation. However, the development of simple, biocompatible, and biodegradable microrobots that can effectively navigate and function on physiologically relevant biological surfaces remains a significant challenge. In this study, we present biocompatible spherical microrobots driven by magnetic fields, capable of performing multiple tasks over the complex surface of chicken heart tissue. The microrobots are designed by synthesizing biocompatible spherical PLGA (Poly (lactic-co-glycolic acid)) microparticles and coating them with iron, a magnetic material, on one side via physical vapor deposition technique. Under a rotating magnetic field, the microrobots exhibit active rolling motion, with their movement precisely controlled through both manual open-loop and automated closed-loop settings. We then tested the efficiency of the microrobots on the complex and rough surface of ex vivo chicken heart tissue, where they showed consistent rolling motion and trajectory tracking across heterogeneous tissue surfaces. Additionally, the microrobots demonstrated the ability to transport cells to targeted locations on the tissue surface. Furthermore, biodegradability studies confirmed that the microrobots degrade over time, with no significant cytotoxicity observed at selected timepoints. This simple design, combined with biocompatibility, versatile locomotion, and biodegradability, positions these microrobots as promising candidates for active therapeutic delivery, in vivo diagnostics, and a wide range of biomedical applications.

1. F. C. Kirmizitas, S. Debata, B. Wu, et al. "Biodegradable Microrobots for Active Navigation and Delivery on Ex Vivo Cardiac Models." *Advanced Healthcare Materials* (2026): e04779. <https://doi.org/10.1002/adhm.202504779>

P32. Valentin Gantenbein

Metal-Organic Interlocks for Adaptive Magnetic Microrobotics: From Multimaterial Fabrication to On-Command Functionalization and Dynamic Reconfiguration

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The combination of rigid magnetic metals and soft polymers within micro-scale machines offers a powerful route toward adaptive microrobotic systems. However, realizing such systems requires fabrication approaches that not only integrate dissimilar materials but also enable the introduction of advanced functionalities. Here, we present the evolution of metal-organic interlocks, from a multi-material fabrication strategy to magnetic microrobotic systems capable of on-demand disassembly and programmable shape morphing for delivery in complex environments.

The fabrication of metal-organic interlocks is based on two-photon polymerization, mold casting, and electrodeposition to produce three-dimensional iron-gelatin interlocked microstructures with sub-100 μm feature sizes and complex shapes. This approach enables the realization of hybrid micromachines that simultaneously exploit the magnetic responsiveness of metals and the mechanical, chemical, and stimuli-responsive properties of soft polymers^{1,2}.

Building on this fabrication strategy, we introduced additional functionality by incorporating iron oxide nanoparticles into the gelatin struts connecting the magnetic microrobotic units. The nanoparticle-loaded soft part enables on-demand disassembly via magnetic hyperthermia, selectively dissolving the gelatin chassis by high-frequency alternating magnetic fields³. This functionality allows microrobotic assemblies to navigate large environments as coordinated superstructures before selectively releasing individual microrobots for operation in confined spaces, providing a new strategy for adaptive cargo delivery and deployment.

Finally, we demonstrate how the same metal-organic interlock can be engineered to achieve reversible, magnetically induced shape morphing. By tailoring the geometry and anisotropy of electroplated magnetic units interconnected through soft gelatin struts, the resulting networks undergo programmable and reversible deformation under externally applied magnetic fields. This active reconfiguration enables dynamic adaptation to constrained environments while maintaining wireless magnetic control, establishing a microscale 4D-printing approach for shape-morphing robotic systems.

Together, these advances establish metal-organic interlocks as a versatile platform for next-generation magnetic microrobots, providing a pathway from multi-material microscale manufacturing to on-demand functional reconfiguration through controlled disassembly and programmable shape morphing. The presented framework illustrates how combining magnetic building blocks with engineered soft interconnects enables increasingly

sophisticated adaptive behaviors for future minimally invasive biomedical applications.

1. C. C. J. Alcântara, S. Kim, S. Lee, B. Jang, P. Thakolkaran, J.-Y. Kim, H. Choi, B. J. Nelson, and S. Pané, "3D fabrication of fully iron magnetic microrobots," *Small*, vol. 15, no. 16, p. 1805006, 2019.

2. C. C. Alcântara, F. C. Landers, S. Kim, C. De Marco, D. Ahmed, B. J. Nelson, and S. Pané, "Mechanically interlocked 3D multi-material micromachines," *Nat. Commun.*, vol. 11, p. 5957, 2020.
3. V. Gantenbein, F. C. Landers, L. Hertle, A. Veciana, J. Llacer-Wintle, X.-Z. Chen, H. Ye, C. Franco, J. Puigmartí- Luis, M. Kim, B. J. Nelson, and S. Pané, "On-command disassembly of microrobotic superstructures for transport and delivery of magnetic micromachines," *Advanced Materials*, vol. 36, no. 18, p. 2310084, 2024

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Dissolvable Sugar-Based Untethered Magnetic Robots Enabling X-Ray-Guided Navigation in Three-Dimensional Vascular Environment

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The development of wireless, drug-loaded, dissolvable, untethered robots that can navigate arteries, deliver thrombolytic agents locally, and subsequently quickly degrade represents a significant departure from current systemic treatments. Achieving a quickly dissolving robot requires addressing key challenges, i.e., as the robot decreases in size during navigation from the point of insertion to the target site, it must retain sufficient propulsive thrust for controlled locomotion, while simultaneously providing adequate contrast for detection under X-ray fluoroscopy or other clinical imaging modalities. Using a thermally moulded sucrose–alginate composite embedded with superparamagnetic iron oxide nanoparticles, we fabricate robots with screw-shaped geometry, enabling magnetic actuation and X-ray visibility. These untethered robots are actuated against physiological flow of up to 32 mL/min while retaining X-ray contrast-to-noise ratio of 1.5 at a radiation dose of 0.17 $\mu\text{Gy m}^2$. The navigation capability of the robots is validated in a three-dimensional cerebral vascular phantom, where controlled motion is achieved along the common carotid–internal carotid–middle cerebral artery pathway.