Microchimica Acta (2023) 190:42
https://doi.org/10.1007/s00604-022-05621-x

EDITORIAL

Dual-dimension Janus-based particles and micromotors in the frontier of (bio)sensing

Beatriz Jurado-Sánchez[1,2] · **Alberto Escarpa**[1,2]

Received: 21 December 2022 / Accepted: 23 December 2022 / Published online: 3 January 2023

Janus particles, named after the two-faced Roman god Janus, are microparticles with different surface structures, which combine one or more chemical properties — or nanomaterials — in a single unit. Using the surface anisotropy of Janus particles allows for spatially decoupling different analytical functions that would otherwise interfere with each other or impart them with novel features for targeted biosensing, and bioimaging, leading to revolutionary applications in (bio)analytical chemistry. Another dimension of these Janus particles is their use as self-propelled micromotors for biosensing *on the fly*. Indeed, the asymmetry of these particles can be strategically used to integrate onboard the propulsion and biosensing elements simultaneously. Yet, in vivo biosensing or drug delivery are also other key fields of high significance in the current scene where Janus particles and micromotors have invaluable potential.

Here, aware of the importance of bioanalytical applications in the current scene of analytical chemistry, we present this Topical Collection entitled *New directions in Janus particle-based bioanalytical methods*, with the main aim of covering cutting-edge advances in the use of Janus microparticles and Janus-based micromotors for biosensing and bioimaging.

Our main motivation and inspiration to edit this Topical Collection has been to search for high-quality manuscripts dealing with one this exciting and still frontier topic in bioanalysis. We humbly think about the high future potential of Janus's approach in both static (as particles) and dynamic (as micromotors) dimensions to explore relevant and modern bioanalytical schemes.

To our amazement, all the received manuscripts were directed at the exploration of Janus particles for biosensing of relevant biomarkers for diagnosis and target in vivo therapy, revealing and confirming the importance of healthcare in the current scientific scenario.

From a discursive point of view, the Topical Collection is composed of 2 review articles and 6 research articles. The two review articles are the starting point and nexus of the Topical Collection: biosensing and in-vivo biomedical applications of Janus particles and micromotors. In the first review article by Jurado-Sánchez et al., recent advances in electrochemical and optical biosensing, exploring their dual dimension of Janus as particles and micromotors, are critically presented and discussed. The review pointed out the unique features of Janus particles and micromotors for (bio)sensing: the asymmetric structure (for multifunctional capabilities) and the efficient propulsion, enhancing the fluid mixing for an improvement in overall analytical performance. The review also covers different synthetic routes to achieve the above-mentioned properties and electrochemical and optical biosensing approaches. In the second review, Liu et al. cover the use of biocompatible light-responsive Janus micro-/nanomotors for biosensing but most specifically for bioimaging, and theragnostic applications. Light as an external field source provides a non-invasive way to remotely control the Janus micro-/nanomotor motion, fully biocompatible, allowing for the in vivo applications of Janus micromotors.

Regarding the capabilities of Janus particles and micromotors for electrochemical biosensing, Ma et al. illustrated the use of antibody-modified Fe_3O_4@SiO_2/Pt Janus micromotors for immunoglobulin G (IgG) detection. The modified micromotors move autonomously within the sample, actively capturing the target analyte, which is subsequently labeled with core–shell Au@Ag nanocube–secondary antibodies.

✉ Beatriz Jurado-Sánchez
beatriz.jurado@uah.es

✉ Alberto Escarpa
alberto.escarpa@uah.es

[1] Department of Analytical Chemistry, Physical Chemistry and Chemical Engineering, Universidad de Alcalá, Alcala de Henares E-28802, Madrid, Spain

[2] Chemical Research Institute "Andrés M. del Río", Universidad de Alcalá, Alcala de Henares E-28802, Madrid, Spain

The magnetic properties of the micromotor allow for the capture and transfer into a screen-printed electrode (SPE) for detection via differential pulse voltammetry, exploiting the Ag tag in the secondary antibody. An excellent limit of detection of 3 pg/mL is achieved. In the same direction, Villalonga et al. employed Janus-like Au colloid nanoparticles modified with polyamidoamine dendrons and asymmetrically modified with horseradish peroxidase on the dendritic face and a specific aptamer for C-reactive protein (CRP) in the metallic surface. Then, a disposable SPE was modified with Au nanoparticles and the specific aptamer, followed by CRP capture, and labeling with the as-synthetized Janus particles for amperometric detection. An excellent detection limit of 3 pg/mL was achieved, with good reproducibility in human serum samples. These two excellent pieces of work demonstrate the potential of Janus nanomotors and microparticles for the development of simple and portable point-of-care testing (POCTs) for protein detection in clinical settings.

Also, in the context of portable detection, Guo et al. illustrated the combination of the autonomous movement of Janus nanomotors with lateral flow immunoassay (LFIA) for the analysis of pepsinogen I and pepsinogen II as biomarkers for cancer prediction and diagnosis. Au@mSiO_2@Pt Janus nanomotors were modified with a specific antibody and then used as active probes in connection with the LFIA. The autonomous movement of the nanomotors within the strip allows for the achievement limit of detection of 2 ng/mL for both analytes, with excellent operation in real samples, illustrating again the potential of Janus nanomotors as novel candidates for future POCTs.

Fluorescence detection can be also achieved by employing Janus micromotors and microparticles. Sha et al. reported on a new strategy for the microfluidic synthesis of quantum dot–encoded Janus magnetic microbeads for multiplexed immunoassays in the detection IgG, in microarrays and a sandwich-immunoassay format, achieving a limit of detection of 0.07 ng/mL. Pacheco et al. reported a strategy based on the use of MoS_2 or WS_2@polycaprolactone@Pt catalytic Janus micromotors for *Salmonella enterica* endotoxin detection. The Janus micromotors were modified with a Rhodamine-labelled specific affinity peptide for off–on fluorescence detection of the target endotoxin. Limits of detection of 1.2 μg/mL were achieved, with high selectivity even between different bacteria serotypes (*Salmonella enterica* serovar Typhimurium and *Salmonella enterica* serovar Enteritidis), revealing the analytical potential of the approach.

Finally, and in one extremely interesting direction, Janus micromotors were reported for in vivo biosensing and targeted delivery. Hang-Li et al. developed a magnetic mesoporous silica-Pt Janus nanomotor with integrated functions of cell capture, diagnosis, and photodynamic therapy. A model leukemia cell line was used to probe the feasibility of the nanomotors. The resulting Janus nanomotors integrate different features for the multifunctional capabilities: a magnetic core for directional movement, a Pt patch for oxygen generation and assisted oxidative damage, and a mesoporous silica part for drug loading. This strategy represents a new paradigm to design highly efficient drug carriers for improved and targeted photodynamic therapy in hypoxic cancer cells.

Overall, the eight articles compiled within this Topical Collection give an excellent and representative overview of the current and future potential of Janus particles and micromotors' novel approaches in biosensing and in vivo targeting for the next generation of biomedical tools. We hope that our readers will gain new ideas for their current and future research and will consider *Microchimica Acta* as a new forum for the publication of their works in this exciting field.

Beatriz Jurado
Assistant editor, *Microchimica Acta*
Alberto Escarpa
Editor-in-chief, *Microchimica Acta*

Acknowledgements We would like to acknowledge the work and support of the editorial team, Steffen Pauly (Springer Nature Publishing Director Chemistry), M. Prodomidis (editor-in-chief, *Microchimica Acta*), senior and associated editors, as well as Wolfgang Frenzel and Jolanta Oleksy-Frenzel (managing editors) for their invaluable support and to all the authors for their contributions and to the reviewers for helping us to maintain the high standards of the journal.

Declarations

Conflict of interest The authors declare no competing interests.