MXenes as pioneers in immune modulation and tissue regeneration for spaceflight health

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MXenes, a novel family of 2D nanomaterials, are gaining attention for their biocompatibility, antimicrobial properties, and applications in cancer therapy, diagnostics, and tissue engineering [1-3]. However, their biological effects under microgravity conditions remain unexplored. Astronauts face compromised immune systems and impaired wound healing during spaceflight, largely due to the sensitivity of immune cells like peripheral blood mononuclear cells (PBMCs) to gravitational changes [4-6]. To address these challenges, we are investigating whether MXenes can modulate immune function and promote tissue repair under microgravity conditions. Based on the nanoimmunity-by-design approach [7], we assessed the impact of MXenes on PBMC populations in simulated microgravity using random positioning machine. Additionally, we explored MXenes' potential to enhance skin regeneration, addressing critical health concerns for astronauts on long-duration space missions. Preliminary results from our analysis in simulated microgravity show that this environment does not affect the viability of PBMCs treated with MXenes. Monocytes and dendritic cells demonstrate significantly higher uptake of MXenes under microgravity conditions, indicating a gravity-dependent impact on cellular interaction. Furthermore, Nb_4C_3 MXene is non-irritating and non-toxic to skin cells, promoting regeneration in a dose dependent manner up to 200 µg/mL. Further data from parabolic flight experiments are currently under analysis to validate these results. This research could lead to novel strategies for enhancing astronaut health and open new biomedical applications for MXenes in both space and terrestrial environments.

References

[1] VahidMohammadi A, Rosen J, Gogotsi Y. The world of two-dimensional carbides and nitrides (MXenes), Science, 2021.
[2] Fusco L, Gazzi A, Shuck CE, Orecchioni M, Alberti D, D'Almeida S, Rinchai D, Ahmed E, Elhanani O, Rauner M, Zavan B, Grivel J-C, Keren L, Pasqual G, Bedognetti D, Ley K, Gogotsi Y, Delogu LG*. Immune Profiling and Multiplexed Label-Free Detection of 2D MXenes by Mass Cytometry and High-Dimensional Imaging, Advanced Materials, 2022.
[3] Fusco L, Gazzi A, Shuck CE, Orecchioni M, Ahmed EI, Giro L, Zavan B, Yilmazer A, Ley K, Bedognetti D, Gogotsi Y, Delogu LG*. V4C3 MXene Immune Profiling and Modulation of T Cell-Dendritic Cell Function and Interaction. Small Methods, 2023
[4] ElGindi, M.; Sapudom, J.; Ibrahim, I. H.; Al-Sayegh, M.; Chen, W.; Garcia-Sabaté, A.; Teo, J. C. M. May the Force Be with You (Or Not): The Immune System under Microgravity. Cells 2021
[5] Spatz, J.M., Fulford, M.H., Tsai, A. et al. Human immune system adaptations to simulated microgravity revealed by single-cell mass cytometry. Sci Rep 11, 2021
[6] Akiyama, T., Horie, K., Hinoi, E. et al. How does spaceflight affect the acquired immune system?. npj Microgravity 6, 2020
[7] Gazzi, A.; Fusco, L.; Orecchioni, M.; Ferrari, S.; Franzoni, G.; Yan, J. S.; Rieckher, M.; Peng, G.; Lucherelli, M. A.; Vacchi, I. A.; Chau, N. D. Q.; Criado, A.; Istif, A.; Mancino, D.; Dominguez, A.; Eckert, H.; Vázquez, E.; Ros, T. D.; Nicolussi, P.; Palermo, V.; Schumacher, B.; Cuniberti, G.; Mai, Y.; Clementi, C.; Pasquali, M.; Feng, X.; Kostarelos, K.; Yilmazer, A.; Bedognetti, D.; Fadeel, B.; Prato, M.; Bianco, A.; Delogu, L. G. Graphene, Other Carbon Nanomaterials and the Immune System: Toward Nanoimmunity-by-Design. J. Phys. Mater. 2020