Selective photothermal effect of a pulsed laser in cultured cells with $Ti_3C_2T_x$ MXenes

Anton Roshchupkin; Yevheniia Husak
Biomedical Research Center
Medical Institute
Sumy State University
Sumy, Ukraine
rantad123@gmail.com
evgenia.husak@gmail.com

Illya Yanko; Ekpe Onyinyechi Peace
Biomedical Research Center
Medical Institute
Sumy State University
Sumy, Ukraine
yanko.ilya.brc@gmail.com
onyipeace99@yahoo.com

Oleksiy Gogotsi; Veronika Zahorodna
Materials Research Center,
Carbon-Ukraine (Y-Carbon ltd.)
Kyiv, Ukraine
alex@mrc.org.ua
veronika@mrc.org.ua

Daniil Burduli; Ivan Baginskyi;
Vitalii Balitskyi
Materials Research Center,
Kyiv, Ukraine
daniil@mrc.org.ua
ibaginskiy@mrc.org.ua
vitalik@mrc.org.ua

Oleksand Solodovnyk
Department of Surgery, Traumatology,
Orthopedics and Phthisiology,
Medical Institute
Sumy State University;
Medical Center LLC "VERBA MEDICAL"
Sumy, Ukraine
dr.solovi@gmail.com

Maksym Pogorielov; Sergiy Kyrylenko
Biomedical Research Center
Medical Institute
Sumy State University
Sumy, Ukraine
m.pogorielov@gmail.com
kyrylenk@gmail.com

MXenes is a large family of 2D transition metal carbides and/or nitrides derived primarily through the selective etching of the A-group element layers in layered ternary transition metal carbides and/or nitrides (MAX phases) [1]. MXenes strongly absorb light in the near-infrared (NIR) spectrum, including in physiological NIR window (650 to 1350 nm); and possess a high photothermal conversion efficiency [2]. Because of that, they show a high potential for development of minimally invasive anti-cancer treatment via a photothermal therapy approach (PTT) [3].

The PTT effect depends on an interplay of many factors. Analysis of literature revealed that in the previously described experiments predominantly the continuous power lasers were used at 1-1.5 W/cm2 [4,5]. We hypothesized that a pulsed laser with higher power and shorter exposures could be more beneficial in PTT as such regiments could quicker destroy cancer cells while giving a chance to spare the surrounding tissues.

Therefore, we set out to investigate if irradiation with a pulsed laser could selectively kill cultured cells with MXenes while leaving the control cells unaffected. The EvoLINE-1 equipment was used as a source of laser pulses. The Chinese hamster ovary (CHO) cells were grown in 96 well plates at various densities and incubated for 24 hr with MXenes at various non-toxic concentrations. Then, the cells were irradiated with various power densities, frequencies and duration of pulses, and exposure times. The viability of the cells was then assessed with resazurin reduction assay.

We found that irradiation with a pulses laser with a power density, which was set higher than the reported power density for the continuous laser, efficiently killed cultured cells with MXenes while sparing the control cells without MXenes. The selective photothermal effect strongly depended on the concentration of MXenes and also on the cell density. Interestingly, the moderately affected cells maintained their metabolic activity immediately after irradiation, while losing it after overnight incubation. We postulated that such treatment induced apoptosis, which was executed during hours after treatment. We also noticed that excessive laser treatment instantly "fixed" the cells, rendering them looking like if they were still normal under microscopic investigation while they were not metabolically active (dead). Altogether, we concluded that the intermittent irradiation with the pulsed laser can be promising for development of PTT protocols.

ACKNOWLEDGEMENTS

This work was supported by the Ministry of Education and Science of Ukraine (grant 0120U101972); National Research Fund of Ukraine (2020.02/0223); H2020 Marie Skłodowska-Curie Actions (NanoSurf 777926, CanBioSe 778157, NANO2DAY 77810, SALSETH 872370); Jean Monnet 599989-EPP-1-2018-1-UA-EPPJMO-MODULE.

REFERENCES

[1] B. Anasori and Y. Gogotsi, "Introduction to 2D transition metal carbides and nitrides (MXenes)," in 2D Metal Carbides and Nitrides (MXenes): Structure, Properties and Applications, Springer International Publishing, 2019, pp. 3–12.

[2] D. Xu, Z. Li, L. Li, and J. Wang, "Insights into the Photothermal Conversion of 2D MXene Nanomaterials: Synthesis, Mechanism, and Applications," Advanced Functional Materials, vol. 30, no. 47. Wiley-VCH Verlag, p. 2000712, Nov. 01, 2020, doi: 10.1002/adfm.202000712.

[3] H. Lin, S. Gao, C. Dai, Y. Chen, and J. Shi, "A Two-Dimensional Biodegradable Niobium Carbide (MXene) for Photothermal Tumor Eradication in NIR-I and NIR-II Biowindows," J. Am. Chem. Soc., vol. 139, no. 45, pp. 16235–16247, Nov. 2017, doi: 10.1021/jacs.7b07818.

[4] C. Xing et al., "Two-Dimensional MXene (Ti3C2)-Integrated Cellulose Hydrogels: Toward Smart Three-Dimensional Network Nanoplatforms Exhibiting Light-Induced Swelling and Bimodal Photothermal/Chemotherapy Anticancer Activity," ACS Appl. Mater. Interfaces, vol. 10, no. 33, pp. 27631–27643, Aug. 2018, doi: 10.1021/acsami.8b08314.

[5] J. Yin et al., "MXene-Based Hydrogels Endow Polyetheretherketone with Effective Osteogenicity and Combined Treatment of Osteosarcoma and Bacterial Infection," ACS Appl. Mater. Interfaces, vol. 12, no. 41, 2020, doi: 10.1021/acsami.0c14752.