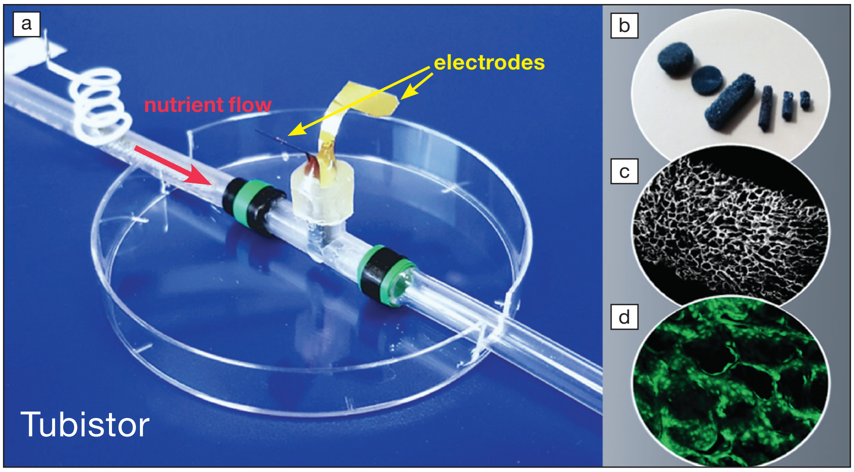
a 3D transistor that is connected to fluidic tubes to allow a linear flow of the liquid containing the cells, and to three electrodes. The device functions as a transistor and will amplify electrical signals recorded during the experiments. This geometry is particularly interesting, as it can mimic native blood vessels, soft tissues, and even organs.



(a) Three-dimensional T-shaped tubistor in an 8-cm-diameter petri dish, with (b) the electrically conductive porous scaffold placed inside, (c) its microstructure, and (d) with green fluorescent cells. Image courtesy of Róisín Owens.

The researchers tested the device using model mammalian cell lines that were fluorescently labeled. The conductive porous scaffolds were perfused by a continuous flow of cell medium, and the current in the transistor was recorded with time. At the same time, the morphology and number of the cells was monitored by fluorescence microscopy to determine the origin of the changes in electrical conductivity. The researchers observed that after cell seeding, their attachment and growth in the device led to a significant decrease in the conductivity. After two days, the electrical response stabilized, demonstrating that a steady state had been reached. "In the future, we hope to have a system that will monitor longer term effects, such as a week," says Charalampos Pitsalidis, the first author of the article.

The team plans to use the tubistor for continuous toxicology monitoring. Preliminary data using a drug that bound to calcium have already shown that cells were affected after only 15 minutes. In the future, Owens's team will perform electrical stimulation experiments with various cell types, including electroactive cells, and study the effect of various compounds on the fully formed tissues.

Lesley Chow, assistant professor in bioengineering at Lehigh University and who did not take part in the study, explains that "culturing cells in 3D is necessary to mimic the extracellular microenvironment found in native tissues. The authors demonstrate that advances in bioelectronics can be exploited to help us learn more about how cells respond to their microenvironment in real time. This is likely to have a major impact on tissue engineering, as such 3D devices will accelerate the optimization of biomaterials design."

Hortense Le Ferrand

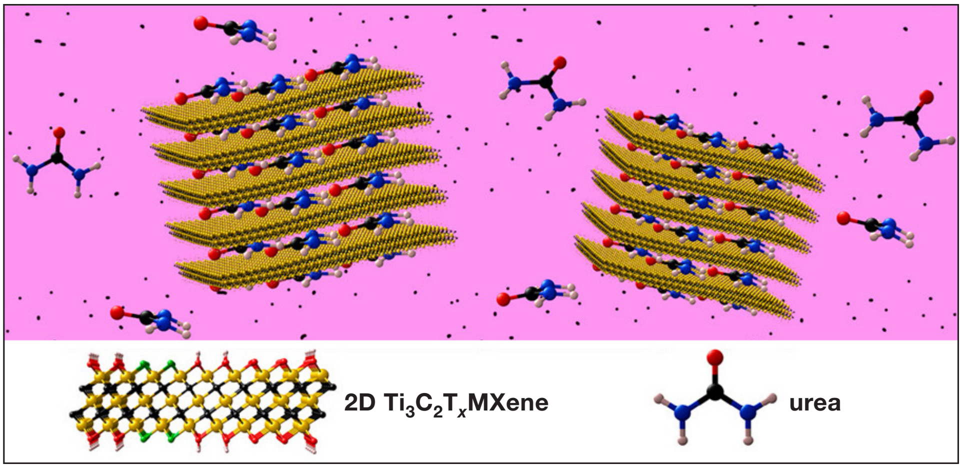
Nano Focus

MXenes poised to improve wearable artificial kidney options

Atomically thin two-dimensional (2D) materials are a burgeoning class of structures that now encompass numerous chemistries beyond graphene. They offer highly versatile properties and promising capabilities that transcend the limits of traditional materials. While certain obvious applications immediately jump to mind for these materials—electronics, memory chips, and energy storage—novel biomaterials also stand to benefit from 2D nanostructures. In particular, wearable artificial kidneys, which conduct round-the-clock dialysis for patients with end-stage renal failure, require new sorbents in order to become sufficiently lightweight, portable, and efficient to provide this lifesaving treatment.

In order for wearable kidneys to efficiently function, they must regularly remove urea molecules from the dialysate solution, which constantly collects these toxic molecules out of blood during dialysis. Traditional methods require catalytic decomposition and outgassing of carbon dioxide and adsorption of ammonia, another decomposition product. This solution is not acceptable and will not work for a proper wearable medical device. On the other hand, 2D materials can effectively trap urea molecules between their atomically thin sheets—but only if the surface chemistry, as well as the interatomic spacing of the laminates, is properly tailored for this process.

A relatively new class of 2D transition-metal carbides and nitrides, called MXenes, appears well-suited for this task. The atomically thin delaminated layers of MXenes are composed of metals (such as titanium) bonded to carbon and/or nitrogen, and terminated with oxygen, hydroxide, or fluoride surface groups. They resemble clays and can accommodate molecules such as water and urea. A team of materials researchers from Drexel University, alongside visiting scientists from Guangxi Medical University and Huazhong University of Science & Technology, and collaborators from Cedars-Sinai Medical Center and the University of Brighton, used this MXene material to remove almost all dissolved urea from dialysate solutions and to absorb 22 mg of this waste material per gram of sorbent. The researchers published their breakthrough in a recent edition of *ACS Nano* (doi:10.1021/acsnano.8b06494).



Atomically thin 2D MXenes exhibit optimal interlayer spacing and surface chemistry to efficiently remove urea from the bloodstream and operate as a sorbent in an artificial wearable kidney. Credit: *ACS Nano*.

Drexel professor Yury Gogotsi, the principal investigator behind the work and one of the original discoverers of MXene in 2011, emphasized the significance of this work: "MXenes perform well in many biomedical applications ranging from brain electrodes to cancer treatment (photothermal therapy and drug delivery) and urea adsorption. Now we need to find which of more than 30 available compositions works best and tune it for this specific sorption application in a wearable kidney."

The researchers found that MXenes based on a 3:2 titanium-to-carbon ratio and terminated with hydroxyl and oxygen surface groups adsorb urea at the highest rates and in the highest amounts. The material selectively removed 99% of the waste product from aqueous solutions of urea and 94% from dialysate (of chronic kidney disease patients). Once the researchers increased the temperature from ambient to the normal human body level of 37°C, the absorption capability of the MXene increased twofold. The sorbent did not break down any of the adsorbed urea into carbon dioxide or ammonia and, therefore, eliminated the complex need for the wearable kidney to process and remove these gas products. This material must exhibit no toxicity and must not adversely impact blood plasma during its operation as a biomedical sorbent, and the biocompatibility of MXenes was confirmed with live blood cells.

The MXene family of 2D materials is highly versatile, and its promising efficacy as a sorbent in artificial kidneys is likely to increase even further in follow-up research endeavors. Next, scientists will look to further optimize the materials structure, design a wearable device, and, eventually, complete clinical trials of successful prototypes. As the research community aims to find novel solutions for major healthcare problems, 2D materials are emerging as a powerful tool that is anticipated to gain prominence in artificial organ implants, wound treatment systems, drug delivery vehicles, and other essential components of this research field.

Boris Dyatkin